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Research and innovation in South African universities: from the triple helix's perspective

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Abstract This study explores the research and innovation in South African universities within the triple-helix framework. Patents and publications data have been used as output indicators to map the R&D activities of South African universities. The study observed that universities are the most prolific publishers and constitute about 91% of total South African publications. However, universities altogether produce only about 14% of total South African patents. Only a few universities are responsible for both patenting and publication portfolio of South Africa. The collaboration patterns from joint patents show that only about 19% patents are collaborative patents. South African public research institutes are more active in joint patents with universities followed by the foreign universities but local firms are less active in collaborative patents. The similar trends are observed in co-authored articles also. The study recommends that collaboration between universities and local firms need to be strengthened to develop technological capabilities in South Africa. South African universities need to collaborate more with the industries, particularly the local industries or institutes to achieve the 'entrepreneurial university' in terms of patents and technology transfer.

Keywords South African universities · Triple helix · Industry–academia linkages · Social network analysis · Patents · Scientometrics

Introduction

The world economy has witnessed many major changes with the present wave of globalization. The globalization has also impacted the structure and function of universities in the developed as well as developing countries. Universities are now increasingly being involved in the national as well as regional economic development (Meyborg 2013). Also,

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the role played by the universities in the national economics through University–Industry (U–I) linkages have been transformed drastically (Lundvall 1999; Mowery and Sampat 2005). The importance of knowledge in the national development and universities being the major actor in knowledge generation has given universities a prominent role in the institutional space (Etzkowitz and Leydesdorff 1998; Etzkowitz 2003; Cloete and Maassen 2015). Nelson (2005) argued that research and development (R&D) carried out in indigenous universities and public laboratories can play very important role in the 'catch-up' processes for the countries which are behind the technological and economic frontier. So, the role of universities is important in the globalized world for building an effective National System of Innovation (NSI).

As knowledge drives economic growth and development, universities are occupying the critical sources of education, research and innovation for firms in developed economies (Gibbons et al 1994; Nowotny et al. 2003). In the changing global landscape, the U–I relationship are considered as a burning issue in the scholarly literature as well as policy discourse (Leydesdorff 2010; Reddy 2011). Besides the traditional role of teaching and research, the role of universities is gradually being supplemented by the recent development of 'entrepreneurial university'. The entrepreneurial universities generate income by means of commercialization of technology produced in their R&D laboratories (Etzkowitz and Leydesdorff 2000; Leydesdorff and Meyer 2006; Leydesdorff and Zawdie 2010). According to Etzkowitz (2003) with a symbiotic relationship among University–Industry and Government (U–I–G), innovation then becomes an endogenous process of "taking the role of the other", encouraging hybridization among the institutional domains (Etzkowitz and Leydesdorff 1998; Etzkowitz 2003). This idea is based upon the "Triple Helix" (T-H) model of innovation where university, industry and government represent these three helices with the close and shared interactions in between (Etzkowitz and Leydesdorff 1998). The T-H model provides a neo-evolutionary model of innovation practice that can be measured (Leydesdorff and Meyer 2003). Many developed as well as developing countries are interested in U–I–G linkages to get the return on research investment and to catch up with the global knowledge economy (Kruss et al. 2012).

According to Etzkowitz and Dzisah (2007), in the knowledge-based societies, proper interactions among the three helixes of T-H can help in the creation of new start-ups or university spin-offs. If the U–I–G interactions already present, it can further enhance their growth. The study further observed that the T-H development model in African context is quite different from the original T-H models. In Africa U–I–G relationship is not well articulated and universities are quite isolated or have the limited interactions with other spheres (Etzkowitz and Dzisah 2007).

A survey of African universities by Ssebuwufu and Ludwick (2012) found that African universities face various types of challenges to initiate or support U–I linkages. However, there are lack of comprehensive data to map the strength and weakness U–I–G linkages in many African countries. However, South African case is different and according to World Bank ranking, South Africa being the upper middle-income economy, has many reputed universities and quite well-developed Science and Technology (S&T) infrastructure. South Africa is also at the top in terms of scientific publication and patenting from the African continent. So, there is ample data available from South African scholars as it is evident from the global citation database (like Web of Science and Scopus). With the increasing R&D activities, the linkages between the university and the industry in a developing country like South Africa are emerging (Kruss et al. 2012a, b). Hence, it is rational to map U–I linkages on the basis of co-publications and co-patenting.

In this context, this paper intends to study and analyze the research and innovation in South African universities in the light of T-H framework. The study will examine the South African universities' performance towards more entrepreneurial universities through co-publication and co-patenting. While analyzing the entrepreneurial university, the following questions are raised:

- Who are the major institutes, the universities are collaborating with in the commercialization of technology as indicated by the collaboration in joint patents?
- How are the universities collaborating in scientific publications?

This paper is organized into the following sections. After the brief review of the concept of entrepreneurial universities in Sects. 1, 2 deals with the literature of T-H in different countries' context followed by National System of Innovation (NSI) of South Africa with the particular focus on the South African universities. Section 3 illustrates the objectives of the study. Section 4 describes the methodology, data source and the limitations of the study. Section 5 deals with the results, Sect. 6 deals with the discussion and finally the concluding remarks.

Literature review

There are many scholarly literatures available from the developed countries' perspective on the role of universities in NIS and U–I linkages. For example, the Swedish innovation system within T-H framework showed that the innovation activities are restricted in a few regions due to the abundant supply of high skilled manpower, government and private research activities in those regions compared to other smaller regions (Danell and Persson 2003; Johnson 2008). Using Japanese co-authorship from scholarly publications as an output measure, Leydesdorff and Sun (2009) showed that the Japanese T-H system has been continuously decreased at the national level (Leydesdorff and Sun 2009). Similarly, in Korean case, scholarly publication data from the Web of Science (WoS), showed that national scientific productivity of Korea gained momentum during the 1990s with the globalization of R&D. However, after the initial growth it became stagnant during 2000s. Although, both U–I collaborations were increased at the international level but within Korea, the U–I collaboration had decreased during that period (Kwon et al. 2012).

From the developing countries' perspective, the study on T-H system in Brazil had observed the emergence of a "meta-innovation system". The system incorporated various sources of enterprise for example, top-down, bottom-up and lateral. This meta-innovation system explained the success of the same organizational mechanism in different contexts. Now, the business incubators in Brazil are more towards socially oriented objectives from its earlier more high-technology oriented focuses. Perhaps this development model may be applicable as an example for other developing countries (Etzkowitz et al. 2005).

To achieve the global competitiveness, many African countries have started investing in university education and research to fit into the 'Knowledge Society' (Giuliani and Rabellotti 2012; Cloete and Maassen 2015). The scholarly literature on the possible role of universities in the national and global economics has not been studied systematically both from developing and low income African countries. There are very limited research on the conditions of universities, firms and their potential interactions across the NSI in these countries (Muchie 2003). However, in the recent years, various empirical studies have observed that U–I interactions are quite prevalent in Sub-Saharan Africa. Many countries

in Africa have recognized that knowledge generated from the university research is crucial for the national development. Kruss et al. (2012a, b) found that the low and middle-income countries in Africa are simply adopting the developed countries' model in the local context. Many of these policies are formulated and/or implemented, without much understanding of the local context. Hence, there is an urgent need for the new models applicable for the developing and less developed African countries context (Kruss et al. 2012a, b).

Among the very few and limited scholarly works in African context, Giuliani and Rabellotti (2012) studied the U–I interaction in Chilean and South African wine industry. The study showed that U–I linkages in these countries are taking place through a few 'talented' and 'bridging researchers', the so called 'star scientists'. The study assumed that the strengthening and promoting those star scientists' skills in catching-up industries will increase U–I collaborations in developing countries (Giuliani and Rabellotti 2012).

U–I–G interactions in West African countries showed that at the regional level, the universities are the biggest knowledge producer in terms of scientific publications followed by the government and industry (Mêgnigbêto 2013). Universities are the prominent actors in information generation (mapped using the scholarly publication data) but the industries have very limited activities. The industrial publications are very few in both at the regional level and individual country level. Furthermore, there are evidences of very limited collaboration among these three actors (U–I–G), both at the regional and national levels. The government research institutes and universities are more active in research among West African countries. Hence, the collaboration between the university and government is more visible in these countries. Mêgnigbêto (2014) argued that the linkages among these three spheres are quite insignificant in-terms of knowledge exchange among various actors (Mêgnigbêto 2013, 2014). Beside these above-mentioned studies, in African context, U–I–G relationships were dealt with by Taylor (2004) for South Africa, Mêgnigbêto (2013, 2014) for West Africa, Etzkowitz and Dzisah (2007) for a general T-H overview of the whole Africa and Ssebuwufu and Ludwick (2012) conducted survey on university–industry linkages in Africa (taking a sample of 133 institutions across Africa).

Giuliani and Rabellotti (2012) studied the U–I linkages in wine industry of Chile and South Africa. The study used interview method and administered questioners to the university researchers. The thematic paper of Etzkowitz and Dzisah (2007) talked about the general T-H framework in Africa with policy recommendation. There are a few studies, tried to capture the dynamics of U–I relation in South African context from the survey (Kruss and Visser 2017; Kruss 2008), and also some conceptual framing of T-H in African context (Taylor 2004). Taylor (2004) recommended measures for human resource development to promote the T-H conceptual framing for better coordination of U–I–G linkage in South Africa. Mêgnigbêto (2013, 2014) mapped U–I–G relationships using publication data from Web of Science. These studies on Africa as well as South Africa described and analyzed relationships among university, industry and government. It is mentioned earlier that South Africa is at the top in terms of scholarly publication as indexed in the global indexing and abstracting databases (Scopus and WoS) and also in patenting (observed form different patent database). Research work on U–I–G relations using publication and patent data has not been done before. Hence it is an interesting case study in African context. This study will perhaps act as an example for other countries in African continent.

South African NSI

After the establishment of the democratic government in 1994, South Africa has made quite considerable economic progress (OECD Reviews of Innovation Policy: South Africa

2007). In the mid-1990s, the newly elected democratic government had recognized the role of Science and Technology (S&T) in the national development (Kaplan 2004, 2008). The government identified the key priority areas in science along with the promotion of selective technology areas to develop S&T in the country. The government's initiatives in the development of S&T had been reflected with the adoption of the 'White Paper on Science and Technology' in 1996 (Department of Science and Technology 1996). The White Paper outlined the foundation of S&T infrastructure in the country with an ultimate goal of employment generation, poverty reduction, sustainable development and economic growth. The plan was to build the nation and to be the leader in the overall African development (Manzini 2012).

The White Paper mostly stressed on the building of National System of Innovation (NSI). The policy blueprint of the 1996 White Paper laid the formation of National Research Foundation (NRF) in 1998. At the same time, the National Advisory Council on Innovation (NACI) was also established. The Department of Science and Technology (DST) was established as a separate department in 2004 to support science, technology and innovation in South Africa (OECD 2007). Now DST acts as a nodal agency for promoting and coordinating R&D in different research agencies including the Public Research Institutions (PRIs) for example, Council for Scientific and Industrial Research (CSIR), Agricultural Research Council (ARC) and so on. DST also looks after the funding agencies, for example, the National Research Foundation (NRF) and other source of funds.

Now, besides the 26 public institutions for Higher Education, R&D activities take place in the following major PRIs in South Africa (Table 1). Collectively, these institutions

Table 1 Major Public Research Institutes of South Africa

Name of the Institute and abbreviations	Objectives	Year of establishment
Agricultural Research Council (ARC)	R&D and technology transfer promote agriculture and industry, better quality of life; natural resource conservation and poverty alleviation	1999
Council for Geosciences (CGS)	Promotion of knowledge in the field of geoscience as well as the provision of specialized geoscientific services	1993
Human Sciences Research Council (HSRC)	Conduct interdisciplinary and problem-orientated research in various issues of national development priorities	1968
Medical Research Council (MRC)	Improvement of the health and the quality of life of South African population through research, development and technology transfer	1969
National Research Foundation (NRF)	Mainly the research funding agency human resource development and provides National Research Facilities in all fields of natural and social sciences, humanities and technology	1998
South African National Space Agency (SANSA)	Support human resource and industrial development in space technology	2010
Council for Scientific and Industrial Research (CSIR)	CSIR undertakes directed and multidisciplinary research, technological innovation as well as industrial and scientific development to improve the quality of life of the country's people	1945
Mintek	Technology organization related to mining and minerals products and services	1934

constitute the major portion of the formal institutional S&T component of the NSI in South Africa.

However, with all these initiatives, it was observed that, NSI in South Africa has strong footprint in some areas, and in other areas need further attention to be inclusive. An integrated and coherent framework for innovation and learning which includes tight links between firms and knowledge generating institutions are still lacking (Muchie 2003). In 2012 Minister of S&T appointed a 'Ministerial Review Committee' to make an assessment of South African science, technology and innovation landscape. The aim of this review was to form the committee to study and recommend the suitable NSI design to meet the present needs of the country as well as to design the future plans. The study observed that there are many voids in overall performance of NSI to move from'resource-based' to more 'knowledge intensive' economy. The Committee observed these weaknesses and came up with new policy recommendations (Final Report of the Ministerial Review Committee DST 2012).

Universities in NSI

South Africa has inherited the apartheid legacy in its NSI. The NSI in apartheid system was mainly characterized by racial discrimination in education and training. Higher education system in that period was to meet the persistent in-house needs of the globally isolated South African economy. Focus was mainly to produce high skilled manpower for the national requirement of long isolation. However, South African innovation system of that period was comparatively 'undeveloped' than the similar other systems under the colonial rules (Maharajh et al. 2011).

The first democratic government came into power in 1994 and took initiative to transform the higher education sector. A new legislation laid down in 1997; called the White Paper 3 (WP3) (*A Program for the*…Department of Education 1997). The aim of the WP3 was to make the education system inclusive to all section of the society. The Higher Education Act of 1997 gave legislative authority to the purposes of the WP3. In 2001, the National Working Group (NWG) was established to make suitable plans to restructure higher education system. NWG report recommended various issues related to regional cooperation, continuation of universities and technical institutes, distance education programs and more collaboration among universities. Beside these the NWG also recommended the consolidation and reorientation of higher education institutes by the establishment of new institutional and organizational forms. As per the recommendations, the numbers of universities or technical institutes were reduced to 21 through mergers and incorporations of many old institutions (Maharajh et al. 2011). With the establishment of 5 more universities in recent years, presently there are 26 universities in South Africa. The Table 2 shows the locations of universities, names and the earlier institutes merged with the present institutes.

In South African formal innovation system, R&D takes place in the above mentioned 26 public institutions for higher education as well as in PRIs. The Council of Scientific and Industrial Research (CSIR) is the largest performer of R&D. CSIR conducts multidisciplinary research and technological innovation in their chain of laboratories spread all over the country. CSIR receives about 40% of the government grant and the rest is generated through contract researches, royalties, licenses from their intellectual property (Reddy 2011).

Hence an emergent shift in knowledge production in universities and PRIs globally as well as locally (in case of CSIR) perhaps transform NSI to be more socially relevant

Table 2 South African universities and the merging Institutions. *Source* Inglesi and Pouris (2008) and Maharajh et al. (2011), Own compilation

Province	Name of the University	Merging Institutes
Eastern Cape	Nelson Mandela Metropolitan University	University of Port Elizabeth Port Elizabeth Technikon
	Rhodes University	
	University of Fort Hare	
	Walter Sisulu University	University of Transkei Border Technikon
Free State	Central University of Technology	Technikon Free State Vista University Welkom
	University of the Free State	
Gauteng	University of Pretoria	
	University of South Africa	University of South Africa Technikon South Africa
	Tshwane University of Technology	Technikon Northern Gauteng Technikon North West
	University of the Witwatersrand	
	Vaal University of Technology	
	University of Johannesburg	Rand Afrikaans University Technikon Witwatersrand
	Sefako Makgatho Health Sciences University	Medical University of Southern Africa (MEDUNSA)
Kwazulu-Natal	Durban Institute of Technology	M.L. Sultan Technikon Natal Technikon
	University of KwaZulu Natal	University of Durban Westville University of Natal
	Mangosuthu University of Technology	
	University of Zululand	
Limpopo	University of Limpopo	University of the North
	University of Venda	
North West	North West University	Potchefstroom University University of North West
Western Cape	University of Stellenbosch	
	University of Cape Town	
	University of the Western Cape	
	Cape Peninsula University of Technology	Peninsula Technikon Cape Technikon
Northern Cape	Sol Plaatje University	
Mpumalanga	University of Mpumalanga	

(Cloete and Maassen 2015). The U–I linkage in South Africa is clearly more direct, formal and knowledge intensive than the other countries in the continent (Kruss et al. 2012a, b; Kruss and Visser 2017). Kruss et al. (2012a, b) have observed the regional variations among the African countries. Waghid (2002) suggested that higher education

transformation in South Africa can become more socially relevant with the integration of "Mode 1" and "Mode 2" forms of knowledge production.

It is discussed earlier that universities all over the globe have been structurally transformed and moving more towards commercialization of their research through the increase in patenting activities (Leydesdorff and Meyer 2007). Hence the commercialization of basic research in terms of patenting and the publication data as indicator of basic research can be good to map the U–I linkage. In South African context, U–I linkage using publication and patent data is rare. So, it is an important research area which may be of interest to scholar, policy and decision makers in South Africa as well as for Africa and other developing countries.

Objectives

Using the Triple Helix framework this paper will map the productivity and collaboration of South African universities both in basic and applied research. The paper will trace the basic research (growth of scientific publications from the Scopus database) and the applied research (patent data from the WIPO patent database). The objectives of this paper is:

- To trace the scientific publication and patenting activities of South African universities
- To map the collaboration patterns in joint patents and co-authored publications among different actors, for example university, industry, public research institutes (PRIs)
- To map the important actors in collaborative activities using the social network analysis (SNA) tools

Methodology

This paper tries to map the entrepreneurial and collaborative activity of South African university research. It explores ways in which publications and patent-based metrics could be utilized in a T-H context (Leydesdorff and Meyer 2007). Globally many scholarly literatures on innovation studies use publication and patent for various mapping purpose (Meyer et al. 2003). Systematic publication and patent data for many African countries are not available or used in studies because of significantly low publication and patenting activities in many African countries (Kruss et al. 2012a, b). However, South Africa is the most productive country among the African continent in terms of both publications and patents. In terms of publication counts South Africa ranked 33rd in the world in 2010 (Pouris and Pouris 2011) and it still maintains its position. Hence the patent and publication data are a good indicator to map the U–I linkages among South African universities, industries and institutions.

Data source

The Patent cooperation treaty (PCT) is an international patent system in a single application allows an applicant for patent protection in more than one country. Patent application can be filed through national patent office of the inventors' resident country or through the World Intellectual Property Organization (WIPO). WIPO maintains the patent

application database of national, regional as well as patents applied through PCT system. PATENTSCOPE is an online patent database available freely on the Internet. The database maintains millions of bibliographic and full text patent documents from patent applications filed under the PCT globally and also from the collections of various regional and national patent offices of participating countries. The patent data for mapping patenting activities of South African universities were downloaded from the WIPO PATENTSCOPE database. The patent data extracted using 'field combination structured search' where the respective universities' name and its earlier names were put in the applicants' address search field using Boolean 'OR' operator.

To map the universities' productivity in basic research scholarly publications of South African universities were downloaded from Scopus® database of Elsevier B.V. With its worldwide coverage of journals, books and other scholarly media, this database gives a wider access to South African scholarly literature. Similar to patent search, literature data from Scopus were searched with the particular university's name in the address field or in the standard affiliation ID field. For example, "Nelson Mandela Metropolitan University", was searched where the affiliation was: AF-ID ("Nelson Mandela Metropolitan University" 60007279) AND (EXCLUDE (PUBYEAR, 2016)). In all cases (both patent and publication data) the search was limited to publication year 2015.

The collaboration in patenting between the universities was mapped using the networking software named Ucinet for Windows software (Borgatti et al. 2002). Ucinet and Net draw are open source networking software freely available for limited academic use.

Limitations of the study

Patents as measures for the commercially generated technological innovations are widely accepted in scholarly literature (Archibugi and Coco 2004, 2005, Smith 2006; Acs and Audretsch 1989; Belderbos 2001). Bibliographic data available from the front page of patent documents are useful to keep track of inventive capability of an entity, for example; firm, university or an even an individual (Callaert et al. 2006). Using this bibliographic information, various researches on innovation is possible (Nagaoka et al. 2011). However, use of patent and publication data has its own limitation. The pros and cons of statistics based on patents and scientific papers have been broadly discussed in many scholarly articles (Griliches 1990; Patel and Pavitt 1995). One of the major disadvantages is; patent data cannot provide the direct connection on how university patents are connected with government or industry through funding or utilization links. Patent information can record the productivity or link with certain institute but unable to find the potential gaps in translating basic research to applied technology and its commercialization. According to Meyer et al. (2003) the patent data had to be combined with inventor survey to relate academic patents with T-H environment (Meyer et al. 2003).

Results

Publication and patent profile of South African universities

To map the scientific productivity of South African universities, literature data from the Scopus database was downloaded for the year 1990–2015. From the Scopus database it was observed that university publications occupy almost 90% of total South African

Table 3 Patents and publication portfolio of South African universities (1990–2015)

Sl. no	Location	Name of the University	Abbreviations	Number of patents	Number of publications
1	Eastern Cape	Nelson Mandela Metropolitan University	NMMU	31	4644
1A		Port Elizabeth Technikon		7	–
2		Rhodes University	RU	7	7543
3		University of Fort Hare	UFH	2	2118
4		Walter Sisulu University	WSU	0	570
5	Free State	Central University of Technology	CUT	0	465
6		University of the Free State	UFS	26	9083
7	Gauteng	University of Pretoria	UP	134	27,440
8		University of South Africa	UNISA	1	4686
9		Tshwane University of Technology	TUT	36	3170
10		University of the Witwatersrand	Wits	210	34,100
11		Vaal University of Technology	VUT	8	626
12		University of Johannesburg	UJ	39	9927
12A		Rand Afrikaans University		14	–
12B		Technikon Witwatersrand		1	–
13		Sefako Makgatho Health Sciences University	SMU	0	1881
14	Kwazulu-Natal	Durban University of Technology	DUT	6	1223
15		University of KwaZulu-Natal	UKZN	36	30,886
16		Mangosuthu University of Technology	MUT	1	181
17		University of Zululand	UniZulu	1	1179
18	Limpopo	University of Limpopo	Turfloop	1	2078
19		University of Venda		0	978
20	North West	North West University	NWU	38	7767
20A		Potchefstroom University		21	–
21	Western Cape	Stellenbosch University	Stellies	199	24,019
22		University of Cape Town	UCT	252	44,210
23		University of the Western Cape	UWC	8	6008
24		Cape Peninsula University of Technology	CPUT	19	1863
24A		Cape Technikon		5	–
25	Northern Cape	Sol Plaatje University		0	21
26	Mpumalanga	University of Mpumalanga		0	3
		Total		1103	226,578

publications. So it can be assumed that South African universities occupy a major portion in comparison to other research agencies in generating knowledge. Table 3 shows the detail publications and patents data of South African universities. University of Cape Town

is the more productive university in terms of publication. *University of Cape Town* have 44,210 followed by *University of the Witwatersrand* 34,100; University of KwaZulu Natal 30, 886; University of Pretoria 27,400 and Stellenbosch University 24,019. The numbers of patents of the top four universities are as follows *University of Cape Town* (252); *University of the Witwatersrand* (210); *Stellenbosch University* (199) and *University of Pretoria* (134). The following six universities do not have any patents till 2015. Those universities are *Walter Sisulu University*, *Central University of Technology*, *University of Venda*, *Sefako Makgatho Health Sciences University*, *Sol Plaatje University* and *University of Mpumalanga*.

It is important here to note that universities which are active in publishing are also good at patenting. University of Pretoria, University of the Witwatersrand, Stellenbosch University and University of Cape Town are performing well both in publication and in patenting. University of KwaZulu-Natal is the university which is good at publishing but produce only about 3% of total university patents.

The Patent scope database search yields altogether 1103 patents from the year 1990 up to 2015. As discussed earlier, university publications constitute a major portion of total South African scholarly publication. However, university patents occupy only about 14% of total South African patent portfolio. It can be concluded that South African universities are more oriented towards basic research than experimental technology development and commercialization. So, to achieve the 'entrepreneurial university', patenting portfolio of South African universities is to be strengthened.

Collaboration patterns in university patents

Among the total 1103 university patents 207(19%) are collaborative patents (Table 4). However, only 12 universities have some joint patents. University of Cape Town (UCT) being the largest patentee has also the maximum number of joint patents. Among the total 252 patents in UCT, 91 patents (36%) are collaborative patents. University of Stellenbosch has 42 collaborative patents (21% of total). University of Pretoria has 29 collaborative patents and University of the Witwatersrand has 21 collaborative patents. Among the low performing universities, Vaal University of Technology has 3 collaborative patents among its total 8 patents.

Table 4 shows the joint patents with different entities. The collaborative actors are divided into seven different groups. The categories are *South African University*, *Foreign Multinational Company*, *Foreign University*, *South African Firms*, *South African Research Agency* (for example CSIR, Medical Research Council, and so on) *Foreign Research agencies* and NGOs (which cannot be categories into the above mentioned groups).

It is observed from the Table 4 that the universities mostly collaborated with the South African Public Research Institutes (PRIs). Among the total 207 joint patents; there are about 83 patents (40%) are with South African research agencies. *CSIR*, *Medical Research Council*, *Agricultural Research Council*, *Nuclear Energy Corporations*, *Sugar Research Associations* have quite good number of joint patents with different universities. Beside the South African research agencies, universities have good number of joint patents with other foreign universities namely; University of California, University of Guelph, and University of Bath and so on. The reason for more collaborative patents with foreign universities may be because of the South African universities' participation in many global R&D projects. However, there is a need for further investigation whether these types of collaborations are beneficial for the local economy or not.

Table 4 Collaboration pattern of South African University patents

Sl. no.	Name of the University	Total patents	Collaborative patents	Collaboration with						
				South African universities	South African firms	South African research agencies	NGOs	Foreign firms	Foreign research agencies	Foreign Universities
1	Nelson Mandela Metropolitan University	31	0							
1A	Port Elizabeth Technikon	7	0							
2	Rhodes University	7	0							
3	University of Fort Hare	2								
6	University of the Free State	26	1	1						
7	University of Pretoria	134	29	5	3	10		10		9
8	University of South Africa	1	0							
9	Tshwane University of Technology	36	0							
10	University of the Witwatersrand	210	21	2		12	1	3	1	4
11	Vaal University of Technology	8	3	3						
12	University of Johannesburg	39	2			2				
12A	Rand Afrikaans University	14	0							
12B	Technikon Witwatersrand	1	0							
14	Durban Institute of Technology	6	0							
15	University of KwaZulu Natal	36	7	2	3	1			1	

Table 4 continued

Sl. no.	Name of the University	Total patents	Collaborative patents	Collaboration with						
				South African universities	South African firms	South African research agencies	NGOs	Foreign firms	Foreign research agencies	Foreign Universities
16	Mangosuthu University of Technology	1	0							
17	University of Zululand	1	0							
18	University of Limpopo	1	0							
20	North West University	38	5	2		2		1		
20A	Potchefstroom University	21	2		1	1				1
21	University of Stellenbosch	199	42	1	4	14	3	16		7
22	University of Cape Town	252	91	7	4	41	2	5	5	36
23	University of the Western Cape	8	1		1					
24	Cape Peninsula University of Technology	19	3						3	
24A	Cape Technikon	5	0							
	Total	1103	207	23	16	83	6	35	10	57

Foreign firms are also actively collaborating with SA Universities. Among the total 207 collaborative patents 35 (17%) are with the foreign multinationals. South African university-university collaborative patents are about 23 (11%). Interestingly joint patents with South African firms are significantly lower. There are only about 16 patents with South African local firms. The following local firms are active in collaborative patents, Eskom Holdings Ltd., Pannar Seed (Pty) Ltd. Mondi Ltd. and so on. Beside these foreign research agencies have also joint patents with SA universities. The prominent among them are Department of Health and Human Services USA, Academy of Science of Czech Republic and so on.

Patent collaboration network

Social network analysis (SNA) is becoming increasingly popular research area in recent years. The concept was originated from the mathematical Graph theory and now applied in many disciplines (Otte and Rousseau 2002). A social network is a set of individuals or groups each of which has some types of connections to a few or all of the others (Abbasi et al. 2012; Newman 2003). In a scientific collaboration network, nodes are authors and ties (links) are co-authorship relations among them (Abbasi et al. 2012). This study maps collaboration activities through the joint patenting and co publications of scholarly articles. The link or tie exists between the two institutes if they have joint patents or joint authorship of articles. The nodes (actors and vertices) of the graph represent the institutes and the links (ties and edges) between the two institutes indicate some kind of collaborations (Abbasi et al. 2012). Relational ties link actors within a network and can be informal or formal (Hawe et al. 2004). If the line between two nodes is non-directional, then the network is called undirected; otherwise, the network is called directed (Li-chun et al. 2006). Here the network is undirected because it is assumed that two actors have equally participated in the patenting.

Centrality is one of the fundamental measures in any network to identify the prominent actors in a network. The indicator shows the ''importance'' of actors in a network (Freeman 1979; Borgatti and Everett 2006; Borgatti 2005). Four measures of centrality are used with high frequency in SNA. These measures are degree, closeness, betweenness and eigenvector (Otte and Rousseau 2002; Hanneman and Riddle 2005; Borgatti 2009).

The collaboration network of joint university patents has only 73 nodes and 158 edges. So, it apparently shows that the network is pretty small. The macro measurement (the whole network level measurement) of the network shows that the network has an average degree of 2.164. Generally, the higher the average degree the closure the network is. The small value of the average degree shows that network size is quite small. The macro level (the whole network) characteristics of this network are further evaluated with the following characteristics *Density*, *Diameter and Clustering Coefficient*:

Density of a (binary) network is the proportion of observed and possible edges. The density of this collaboration network is 0.03 means that only 3% of all the possible ties are present (Hanneman and Riddle 2005).

The *diameter* of a network is the largest geodesic distance in the (connected) network (Newman 2003). The diameter of a network gives an idea about the size of the network (Li-chun et al. 2006). The collaboration network in the patent collaboration network has the network diameter '7' and the average path length is 3.326. The average path length shows that only about 3.3 steps are required to reach from one node to other. It is a small-scale network and both the average geodesic distance and the network diameter indicate very less connection than expected (Fig. 1).

Social networks often form ‘cliques’ with very close groups. This often creates ‘‘clustering’’ or ‘‘transitivity’’ which is small but densely connected separate clusters (Hanneman and Riddle 2005). In these clusters inventors often cooperate and these clusters are very close to each other. In this collaboration network average *clustering coefficient* is 0.127 and connected component is 2. It means the collaborator of any one node has very less probability to work together with another.

The centrality of a node is its importance in a given network. The micro level characteristics of the individual actors in the network are evaluated by four centrality measures. These measures are *Degree*, *Betweenness*, *Closeness and Eigenvector* (Freeman 1979).

The most widely used centrality measure is the degree centrality. It shows an actor’s position is a given network. The higher degree shows the power of an actor in a network. In real situation, any actors with more links than other actors may be in advantaged position and have access to more of the resources of the network (Hanneman and Riddle 2005). In an undirected graph, the degree of a node is the number of edges incident to it (Robins 2013). This is an undirected network because all the collaborators are given the equal weightages; hence the degree of the node is the sum of all ties present of a given node. The Table 5 shows the degree of various actors in the second column and are arranged based on the degree of each actor in the decreasing order. The results show that only a few universities have high and others are with very low degree centrality. The noticeable top 20 entities with degree centrality are shown in the Table 5, column 2. University of Cape Town is the most prominent actor followed by Stellenbosch University and University of Pretoria. Among the PRIs, South African Medical Research Council and Council for Scientific and Industrial research have prominent position in collaboration.

Betweenness is a centrality measure of how frequently an actor is situated in the path between other actors. This measure shows the ‘brokerage role’ of actors while connecting others in the network. The nodes with high scores are expected as the significant actor because they control the flow of information in the network (Erfanmanesh et al. 2012). The between-ness value of the actors are in the following order, University of Cape town, South African Medical Research Council, University of Pretoria, Stellenbosch University, University of the Witwatersrand and CSIR (Table 5, column 4). University of Cape Town

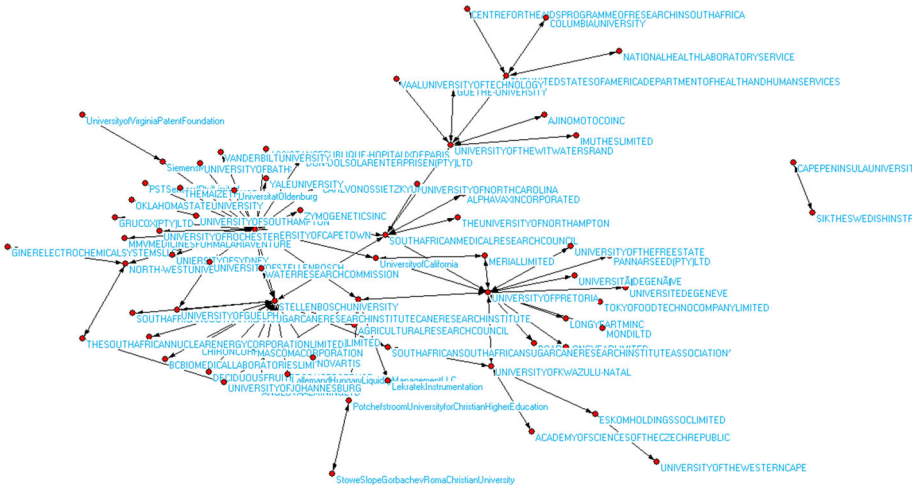

Fig. 1 Patent collaboration network

Table 5 Different centrality measures of important patentees

Name of the University	Degree	Name	Betweenness	Name of the University	Closeness	Name of the University	Eigenvector
University of Cape town	24	University of Cape town	1369.833	University of Western Cape	359	University of Cape town	0.604
Stellenbosch University	15	South African Medical Research Council	941.834	Center for the AIDS Program of South Africa	333	Stellenbosch University	0.339
University of Pretoria	14	University of Pretoria	807	Columbia University	333	South African Medical Research Council	0.247
South African Medical Research Council	7	Stellenbosch University	749.167	National Health Laboratory Service	333	University of Pretoria	0.191
University of The Witwatersrand	6	University of The Witwatersrand	518	Stowe Slope Gorbachev Roma Christian University	310	Council for Scientific and Industrial Research	0.186
Council for Scientific and Industrial Research	6	Council for Scientific and Industrial Research	404	Academy of Science Czech Republic	292	Water Research Commission	0.175
Department of Health and Human services, USA	4	University of Kwazulu-Natal	216.167	Eskom Holding Limited	290	University of California	0.16
University of Kwazulu-Natal	4	Department of Health and Human services, USA	204	University of Virginia	281	North-West University	0.122
North-West University	3	University of California	126.833	Ginner Electro Chemicals LLC	278	Siemens Medical Solutions USA Inc.	0.116
University of California	3	North-West University	116.5	Ajinomoto Inc.	270	Assistance Publique-Hopitaux De Paris	0.112
Eskom Holding Limited	2	Sugarcane Research Institute South Africa	72	Goethe-University	270	Carl Von Ossietzky Universitat Oldenburg	0.112
Nuclear energy Corporation South Africa	2	Eskom Holding Limited	69	Imuthes Ltd.	270	Dun –Dol Solar Enterprises (PTY) Ltd	0.112
Potchefstroom University for Christian Higher Education	2	Potchefstroom University for Christian Higher Education	69	Vaal University of Technology	270	Grucox (PTY) Ltd	0.112
University of Johannesburg	2	Siemens Medical Solutions USA Inc.	69	Department of Health and Human services, USA	264	Medicine for Malaria Venture	0.112

Table 5 continued

Name of the University	Degree	Name	Betweenness	Name of the University	Closeness	Name of the University	Eigenvector
Merial Limited	2	Agricultural Research Council	29.167	Nuclear energy Corporation South Africa	257	Oklahoma State University	0.112
Siemens Medical Solutions USA Inc.	2	University of Johannesburg	19.5	Boart Long Year Limited	243	PST Sensors (Pty)Limited	0.112
Sugarcane Research Institute South Africa	2	Nuclear energy Corporation South Africa	2	E I Dupont De Nemours & Co.	243	The Maize Trust	0.112
Agricultural Research Council	2	Merial Limited	0	Longyear TM Inc.	243	University of Sydney	0.112
Water Research Commission	2	Water Research Commission	0	Mondi Ltd	243	University of Bath	0.112
University of the Western Cape	1	University of the Western Cape	0	Pannar Seed (Pty) Ltd	243	University of Rochester	0.112

in terms of number of patents and collaboration is obviously a higher value (1369.833). The High value of Medical Research Council and CSIR shows the prominence of these institutes in joint patents along with the universities.

Closeness centrality approaches stress on the distance of an actor to all others actors in the network (Hanneman and Riddle 2005; Robins 2013). These measures indicate the influence of an actor because the actor with higher closeness value can easily acquire and disseminate information in a network (Erfanmanesh et al. 2012). Table 5 (column 6) shows the top scorers in terms of closeness centrality are: University of the Western Cape (359), Centre for the AIDS Program of Research in South Africa, Columbia University, National Health Laboratory Service (333).

In Eigenvector centrality measure, the greater eigenvalue scores means a node is "more central" to the main pattern of distances among all of the actors. Lower values indicate that actors are more peripheral (Hanneman and Riddle 2005). The Eigenvector values (Table 5, column 8) of the South African entities are as follows; University of Cape Town (0.604), Stellenbosch University (0.339), South African Medical Research Council (0.247), University of Pretoria (0.191), Council for Scientific and Industrial Research (0.186), Water Research Commission (0.175) (Table 5).

Co-authorship collaboration network

Co-authored articles involving different institutions in different locations or even in the same institute can be a possible indicator of research collaboration (OECD 2016). Authorship collaboration can be mapped using the authors' affiliations information from the scientific publications.

The research collaboration among firms and university research is complex. Particularly in high technology fields, firms heavily depend upon scientific research. High technology firms may conduct the research needed for their product development either in-house or outsource to the external research agencies through some types of agreements. If the institutes are universities or government research institute, their partnership can be formal collaborations and may be considered as 'public–private research collaboration' (Moya-Anegón et al. 2014).

All 26 South African universities' publication records are downloaded through the 'export refine' feature of Scopus search. About top 160 institutional affiliation addresses for each university's publication record has been downloaded. These affiliation data was used to map the collaboration pattern of universities. The two-mode network (universities in the column and the other entities in the rows) map (Borgatti and Everett 1997) was drawn from the social network software Ucinet–Netdraw (Fig. 2). The individual level centrality patterns are shown in the Table 6.

The network map had drawn using the co authorship linkages of 26 universities with about 1533 institutes which publish significantly along with the universities. From the study it is observed that universities collaborate with other universities significantly. The second most prominent collaborators are the government research institutes of South Africa. Council for Scientific and Industrial Research, South African Medical Research Council, Agricultural Research Council, Human Sciences Research Council of South Africa, South African National Biodiversity Institute, National Institute for Communicable Diseases; National Health Laboratory Services are the prominent actors in the collaboration with the universities.

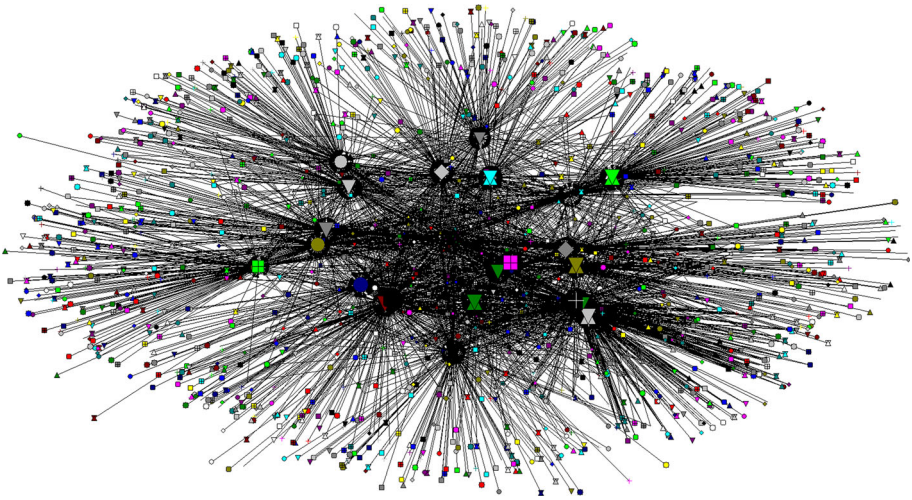

Fig. 2 Institutional collaboration network form the affiliation of coauthored articles

From the industries; *Sasol* group (Sasol is a diversified chemicals and energy firm), *Mintek* (an autonomous R&D organisation involved in mining related activities), *Eskom* (South African electricity producer and supplier firm) have limited collaborative articles with only a few universities. The numbers of collaborative articles with these firms are as follows. Sasol has the collaborative article with Nelson Mandela Metropolitan University (8 article), University of the Free State (32 articles), Tshwane University of Technology (4 articles), North-West University (67 articles), Stellenbosch University (35 articles) Cape Peninsula University of Technology (6 articles). Mintek collaborates with Rhodes University (21 articles), University of Pretoria (59 articles), University of South Africa (7 articles), Vaal University of Technology (9 articles), University of Zululand (3 articles), Cape Peninsula University of Technology (4 articles). Eskom's collaborative articles with universities are as follows; Nelson Mandela Metropolitan University (11 articles), Tshwane University of Technology (4 articles), Durban University of Technology (2 articles) Cape Peninsula University of Technology (2 articles). So, it is evident that only few universities have collaborative research articles with South African or foreign firms and that is also very limited. Beside the South African university—university collaborations other major collaborating entities are the foreign universities such as University College London (UCL), KU Leuven and so on and other research entities (Table 6).

Discussion

This study is an attempt to map the research and innovation capacity in South African universities and U–I linkages on the basis of co-publication and co-patenting using T-H framework. There are a few studies, tried to capture the dynamics of U–I relation in South African context from the survey and case study approach (Kruss and Visser 2017), and also some conceptual framing of T-H in African context (Taylor 2004; Kruss 2008). However, there is no such studies from South African context which has captured U–I–G linkages in the T-H framework using publication and patent data. As South Africa is the most

Table 6 Institutional level centrality measures of collaborating institutes through coauthored articles

Rank	Institute	Degree	Institute	Between-ness	Institute	Closeness	Institute	Eigenvector
1	The Council for Scientific and Industrial Research	23	The Council for Scientific and Industrial Research	32,245.66	University of Sheffield	6316	The Council for Scientific and Industrial Research	0.143
2	South African Medical Research Council	21	South African Medical Research Council	27,799.84	Imperial College London	6118	South African Medical Research Council	0.134
3	University of Oxford	18	University of Zimbabwe	19,217.66	The University of British Columbia	6078	University of Oxford	0.118
4	Agricultural Research Council, Pretoria	18	Agricultural Research Council, Pretoria	17,765.49	University of Cambridge	6070	Agricultural Research Council, Pretoria	0.11
5	University of Zimbabwe	16	University of Oxford	13,690.80	The University of Sydney	6050	UCL	0.103
6	UCL	15	Universiteit Gent	11,523.87	University of Melbourne	6048	University of Wisconsin Madison	0.1
7	University of Wisconsin Madison	15	University of Wisconsin Madison	11,246.71	University of Manchester	5996	University of Manchester	0.098
8	Universiteit Gent	15	Human Sciences Research Council of South Africa	10,081.03	University of Toronto	5974	Universiteit Gent	0.097
9	University of Manchester	14	UCL	9790.17	South African National Biodiversity Institute	5954	University of Zimbabwe	0.096
10	The University of British Columbia	13	University of Ibadan	9137.28	UCL	5734	The University of British Columbia	0.093
11	University of Cambridge	13	KU Leuven	8365.84	KU Leuven	5710	University of Cambridge	0.092
12	The University of Sydney	13	University of Toronto	6917.86	University of Wisconsin Madison	5672	The University of Sydney	0.092
13	University of Melbourne	13	University of Manchester	6501.48	University of Ibadan	5632	University of Melbourne	0.092
14	University of Toronto	13	The University of Sydney	6042.75	Human Sciences Research Council of South Africa	5592	University of Toronto	0.09
15	KU Leuven	13	University of Melbourne	5695.32	University of Oxford	5516	KU Leuven	0.085
16	Human Sciences Research Council of South Africa	13	University of Cambridge	5671	Universiteit Gent	5474	South African National Biodiversity Institute	0.084

Table 6 continued

Rank	Institute	Degree	Institute	Between-ness	Institute	Closeness	Institute	Eigenvector
17	University of Ibadan	13	The University of British Columbia	5244.99	Agricultural Research Council, Pretoria	5164	Human Sciences Research Council of South Africa	0.083
18	South African National Biodiversity Institute	12	South African National Biodiversity Institute	4968.89	University of Zimbabwe	5110	University of Ibadan	0.082
19	University of Sheffield	11	Imperial College London	3638.65	South African Medical Research Council	4822	University of Sheffield	0.079
20	Imperial College London	11	University of Sheffield	3177.10	The Council for Scientific and Industrial Research	4698	Imperial College London	0.079

productive country in African continent, it has quite substantial number of publication and patent data available for analysis. This study used scholarly publication data from the Scopus database of Elsevier and patent data from Patentscope of WIPO.

The initial findings suggest that South African universities are good at basic research as reflected from the scholarly publication trends from the articles indexed in Scopus database. However, in case of patenting, the universities are quite low in terms of total South African patents. University patents altogether constitute only about 14% of total South African patents. Boshoff and Mouton (2003) have observed the growth of South African patents filed or granted in the US Patent and Trademark Office (USPTO) during 1997-2001. As reported from that study, there was a definite growth of patents from South Africa during that period. However, many of those patents were not assigned to any university or institute rather they were assigned to individuals (Boshoff and Mouton 2003). Inventors of those patents may be affiliated with the universities but the patents are owned by the individual inventors. Kruss (2006) found many possible reasons for the low profile of university patents. Among the many reasons, the major reason may be the inventors from the universities find it difficult to file patent due to lack of financial, institutional, legal and administrative support. Moreover, there may be lack of awareness in terms of economic benefits of patents and the patenting procedure among the university inventors.

Kruss and Visser (2017) observed that South African universities are more 'hierarchical' and 'segmented'. These characteristics of universities limit knowledge flows and potential mobility. Further, the study observed that academicians are aware about the importance of research collaboration *but the scale of active and networked interaction was relatively low*, *particularly with firms* (Kruss and Visser 2017, p. 19). The study further found heterogeneity among the South African universities. This diversity leads to few distinct categories based on their research and teaching capabilities. The 'reputed universities' are less likely to interact with the industry because of its inherent inertia. The 'research universities' are more likely to collaborate with industry for commercialization and academic gain. 'Technology Universities' are generally prioritised entrepreneurial activities and generally engage in technology transfer in small scale (Kruss and Visser 2017). Contrary to that observation, this study found from the patenting and publications pattern that the universities which published more are also active in patenting. For example, the University of Cape Town, Stellenbosch University, University of the Witwatersrand and University of Pretoria are good both at publication and patenting. Only exception is the University of KwaZulu-Natal which is good at publication but the patenting is comparatively less.

Among the seven provinces of South Africa, the universities located in Gauteng and Western Cape provinces are the most productive because of the excellent universities and the PRIs are located in these provinces. However, there are a few universities located in these provinces are quite low performing, because there is heterogeneity in terms of the formation of universities. For example, some universities are newly formed and some of them are quite old. So, it is quite unlikely that these newly formed universities will perform at par with the old and well established universities.

South African universities are quite good in doing research in comparison to other actors of the innovation system (for example PRIs) as it is observed from the publication patterns. However, the university research is not being translated into the commercially viable product in the form of patents. Also, the patenting and publication activities are very limited and restricted only in a few universities. Therefore, U–I linkages need to be strengthened and the entrepreneurial university that makes systematic and predictable collaboration with measurable output is critical. This will increase local

technological capabilities and learning. The universities that are strong in basic research and the technical universities should link with industry to combine both research and industrial output through application of patents and technological learning, innovation and capability building.

The publications collaboration pattern shows that universities are mostly collaborated with the South African PRIs. Also, South African universities have good number of research collaborations with foreign universities. Interestingly joint patents with firms, particularly South African firms are significantly lower. In T-H framework, this is perhaps the most significant and weak point and need to be strengthened. The collaboration network through joint patents shows that the network size is quite small. Collaboration is only limited to a very few universities and those universities are the prominent actors in the collaboration network. So, there is the need for institutional linkages between South African universities and the local firms. Institutional linkages with the domestic firms will perhaps help in improving the technological solutions as the 'local solution' to the 'local problems'. More domestic U–I collaborations will increase the information flow among various actors in the innovation system and in the long run it will help in more balanced use of national resources.

South Africa is going to modify its earlier White Paper of 1996 on S&T and going to adopt a new White Paper soon. It is evident that a strong U–I linkage is very important to build strong S&T base. So, in South African context, particular emphasis should be given to university and local industry collaboration. This types of linkages are quite weak and needs to be strengthen. This assessment of strength and weakness of U–I–G relations using publication and patent data will be useful for the new NSI road maps.

Concluding remarks

The T-H model may provide a flexible framework for the transition of the South African universities. This framework can transform the universities from only teaching universities to more entrepreneurial universities. These new and transformed universities can generate their own revenue from the commercialization of technologies from their own laboratories. Further they can play active role in the national developmental issues by addressing the technological solution to the pressing local problems. Hence, for the universities, to play a dynamic role in national development, a new institutional arrangement is required. In the globalized world, innovation is no longer a linear process, rather it is increasingly becoming more complex and 'non-linear' process with many complexities. So, innovation policy cannot be only as a "top-down" initiative by the government rather it should be a 'bottom-up' approach. Citing the example of incubator movement in Brazil (Etzkowitz and Dzisah 2007) recommended for a 'bottom–up initiatives' that have proved successful. In South African case a similar approach starting from the universities will perhaps be useful.

South African public universities have grown in number in recent years with at least one university at every province. Time has come to increase their S&T and technology transfer capabilities to take a bigger role in overall South African socio-economic development. The formation of technology incubators, start-ups, technology parks and science-based firm closure to the universities to facilitate the commercialization of university research should be the major aims of these universities (Juma 2005; Etzkowitz and Dzisah 2007). In this way South African universities can commercialize their laboratory research to benefit the South African as well as the whole African populations and can play a lead role in the

African development process. Universities' role in NSI of developing country like South Africa may be a possible lesson for other developing countries in Africa as well as with countries with similar socio-economic conditions.

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