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The dynamic role of universities in developing an emerging sector: a case study of the biotechnology sector

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ABSTRACT

Literature maintains that the role of universities has shifted from pure knowledge dissemination organisations into the key intermediaries of technology commercialisation, especially in the case of the developing emerging high-tech sector (Etzkowitz, Webster, Gebhardt, & Terra, 2000; Vallas & Kleinman, 2008). To further explore the dynamic role of the universities interacting with the other actors in the innovation system, this paper examines the changing roles of the universities that have actively interacted with the biotechnology industry in Taiwan from 2000 to 2012. Combining social network analysis and interview data on a longitudinal dataset gathered from 125 IPO biotechnology firms, this paper aims to explore the R&D collaboration networks between the universities and the other actors in the biotechnology sectoral innovation system to understand how universities make use of knowledge exchanged with other parties to shape society while developing emerging industries. The involvement rate of academia in the knowledge transfer networks appears to have increased since 2000 but more can be done to spur scalable action after 2008, and therefore association with other similar evolving areas. Moreover, the participation of foreign collaboration is one which needs some attention. The finding of this paper sheds light on the changing role of academia in developing emerging technologies in technology followers, while the innovation ecosystem is ready for academia-industry collaboration, universities not only take charge of disseminating knowledge but also serve as the major intermediaries in the process of commercialising science and technologies developed through the universities. Future policies may need to boost more partaking between the universities and industries by motivating the transmission of knowledge capital through encouraging technology commercialisation in academia.

1. Introduction

Innovation is an interactive process in which the creation and flow of knowledge between firms, and access to externally-generated knowledge from non-firm sources, are particularly important. In the recent literature on innovation, the positive association between firms' networking activities and their long-term innovation performance has been recognised (Breschi & Malerba, 2005; Edquist, 2011; Malerba & Vonortas, 2009), especially in science-based industries (Edquist, 2011). The central role of knowledge transfer in the inter-organisational innovation process, particularly in emerging technologies such as biotechnology, has also been well established in the literature (W. W. Powell & Grodal, 2005).

Biotechnology has been widely expected in the existing literature to stimulate a shift in the industrial structure of the pharmaceutical industry from large drug companies to networks of biotech firms agglomerated in innovation systems (Hopkins, Martin, Nightingale, Kraft, & Mahdi, 2007; Nightingale & Martin, 2004; Rafols et al., 2014). The innovation network literature has reinforced that innovation is embedded in the networks instead of any single actor (such as a firm), especially in the biotech sector. Literature also maintains that the biotechnology industry has been characterised by a set of production techniques with application across a broad range of industrial sectors (Bartholomew, 1997). As Malerba (2002) defined,

> A sectoral system is a set of products and the set of agents carrying out market and non-market interactions for the creation.

In fact, the biotechnology industry has been widely considered as a high-tech sector which can be traded in various stages of the R&D process. Moreover, during the innovation process, the young start-up biotech firms rely heavily on the interdependence with the universities and large multinational firms. As W. Powell et al. (2005) indicated,

> In the early years of the industry, from 1975-87, most dedicated biotech firms (DBFs) in the US were very small start-ups, and deeply

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reliant on external support out of necessity. Thus, they became involved in an elaborate lattice-like structure of relationships with universities and large multinational firms.

DBF is defined as "a biotech active firm whose predominant activity involves the application of biotech techniques to produce goods or services and/or the performance of biotech R&D" (OECD, 2005). According to the observation by Powell et al., the interdependence between firms and the non-firm actors is not only because of the associations of their technologies and development experiences, but also because of the accumulations of interpersonal connections (Chen et al., 2015) . Hence, how interaction occurs in local networks to develop linkages between diverse actors has become an interesting question to be further explored. In particular, how universities make use of knowledge exchange with other parties to shape the process of developing emerging industries would be another interesting question to study. Therefore, the main research question this paper attempts to answer is: how do interactions occur in the biotechnology networks to develop linkages between actors and what role do universities play in the emergence of emerging networks? Analytically, this paper firstly analyses the R&D collaboration networks of the biotechnology sector in Taiwan in 2000, 2006 and 2012 as an example to explore the R&D collaboration networks changing over time. A dynamic perspective is employed using data from the above-mentioned three periods. This permits the analysis of the structural and functional evolution of the entire innovation system, particularly in relation to the knowledge transfer network between academia and industry. Consequently, this paper analyses in greater detail about the roles that universities play.

This paper is anticipated to contribute to the literature in several ways. Firstly, it will provide a deep empirical study of how universities network with other actors while developing an emerging high-tech sector. Secondly, this study attempts to conduct in-depth analysis regarding the dynamic roles that universities play while developing an emerging sector. Finally, this study contributes an innovative approach of empirical longitudinal data collection and analysis to map the knowledge transfer and innovation networks in a complete sectoral innovation system (Malerba, 2002).

2. The triple helix model and the changing role of the universities in the innovation networks

This section reviews the literature concerning systems of innovation, knowledge production network, the dynamic role of the universities in the network, and knowledge transfer in a triple helix model with the aim of constructing a conceptual framework. This framework will later be applied to analyse the role that actors play in shaping the structure of relationships in the knowledge transfer networks in an emerging high-tech sector, biotechnology sector, in Taiwan – which has the prospect of transforming the industrial structure into a knowledge economy through building up the biotechnology sector.

2.1. Systems of innovation and knowledge production networks

Since the modern concept of innovation systems was proposed in the past three decades, there have been several levels of analyses at which the concept has been applied. These include the national innovation system (NIS) (C. Freeman, 1995; Lundvall, 2010; Nelson, 1993), which was developed from the theory of production development (Lundvall, Johnson, Andersen, & Dalum, 2002), sectoral innovation systems (SIS) (Malerba, 2002), and technological innovation systems (TIS) (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008) which were developed from evolutionary economic theory (Witt, 2008), as well as the regional innovation system (RIS) (Cooke, 1992, 2001, 2002, 2004), which came from economic geography.

Each of the innovation system approaches has drawn attention to various components, structures, and theoretical issues, and therefore contributing to differentiated analytical approaches. The most straightforward way to distinguish these approaches would be to explore the boundary of the framework (Edquist, 1997, 2005, 2011; Lundvall, 2007; Niosi, 2011; Smith, 2000).

Whilst significant interplay exists between the systems, in particular between the NIS and SIS, these systems have different components (Chaturvedi, 2007; Malerba & Nelson, 2011). For instance, the SIS consists of the knowledge base, institutions and networks, whereas the NIS focuses on the structure of production, regulation, financial system, education policy, innovation policy, and the institutional set-up (Lundvall, 2010). According to Malerba (2009), the SIS is defined as comprising a knowledge base, technologies, networks of actors, and institutions. It therefore offers a framework to examine the systemic processes relating to a particular set of technologies from the global perspective. In the SIS approach, institutions are defined to include norms, routines, common habits, and established practices which shape the behaviour (interactions, communications, exchanges, cooperation, and competition) of agents in the innovation system. These affect the generation and adoption of new technologies or innovation at the sectoral level.

Sectoral systems have a knowledge base, technologies, inputs and a (potential or existing) demand. The agents are individuals and organisations at various levels of aggregation, with specific learning processes, competences, organisational structure, beliefs, objectives and behaviours. They interact through processes of communication, exchange, cooperation, competition and command, and their interactions are shaped by institutions (Malerba, 2002, 2005, 2009). For analysing inter-organisational agent activities in a specific sector, an SIS would be appropriate. The interactions between firms and non-firm actors are one of the key elements of the SIS approach, but the empirical analysis of such interactions in complete sectoral systems is still rare. Although Malerba and Vonortas (2009) take industries and sectors into consideration, the network topologies mainly stayed at the industry level. The topology of networks between firms and non-firm actors in the system has still been rarely touched.

Knowledge production has played a crucial role in the modern economy (Leydesdorff & Zawdie, 2010) for a relatively long period. In the 1990s, the literature moved from the linear model into the interactive model. This shift was marked by analyses of the society's role in shaping the knowledge base and knowledge production in academia (Pavitt, 1998) and the emergence of the innovation systems' literature. OECD (1996) suggested, given the importance of knowledge networks, that "the firm-level innovation study needs to be developed to better characterise innovation processes and interactions among firms and a range of institutional actors in the economy". Vallas and Kleinman (2008) suggested, based on their study of the confluence of academia and commercial biotechnology innovation in the US, that a knowledge regime has begun to emerge across previously distinct institutional domains.

2.2. The triple helix model and the dynamic role of the universities in the network

Etzkowitz and Leydesdorff (2000) referred to the triple helix as the reciprocal relationships among academia, industry and government at different stages for the purpose of knowledge development, diffusion and economic growth. This relationship is also associated with certain shifts, discussed below, due to the cultural differences between the agents involved. This interconnection is based on the need for universities and firms to collaborate in order to enable knowledge transfer that has economic value (Etzkowitz et al., 2000). Mueller (2006) revealed academia's contribution towards penetration of the knowledge filters (especially in aiding entrepreneurs) through increasing absorptive capacity and co-location advantages of knowledge diffusion often spanning informal means. Knowledge filter in this context denotes the mechanism through which knowledge transitions can be substantiated into commercial activities (Acs, Audretsch, Braunerhjelm, & Carlsson,

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2004); this means the line between formant knowledge and knowledge which is channelled into commercial value.

Universities have done these by providing research and development facilities for industries, enhancing understanding of practical issues, improving knowledge content to take into consideration compatibility in industrial practices and provide services which ensure assimilation and stability of new technology. For example, (Franzak, Arechavala-Vargas, & Wood, 2010) show the role of academia, facilitating technology commercialisation using the case of Virginia Commonwealth University and British Columbia University, thereby performing a third mission function (subsequently defined) through the provision of physical location and consulting; expertise advisory centres and employees provide input and resources during the course of the knowledge transfer process.

The firms which were successful benefited from academic resources and technology based on owned licenses of the incubator-sponsoring university. Furthermore, Meyer-Krahmer and Schmoch (1998) identified that the university–industry relationship is a two-way process providing research bases for firms, recruitment of qualified personnel and familiarisation with the newest insights from industrial research into the academia curriculum. This portrays the "third mission" concept which Sánchez-Barrioluengo (2014) defines as the broadening of the remit of academia, denoted by the addition of other market-oriented innovation and knowledge transfer. Furthermore, Etzkowitz (2003) regards the third mission the transition in education from educating individuals to shaping organisations. Universities are now being included as engines of economic growth through the strategic role of science (Hussler, Muller, & Rondé, 2010). This places universities in a position of being recognised and engaged in societal and economic growth activities, through knowledge transfer and engagement with industry society at large. This takes place through different channels with each agent playing a different part and receiving motivation through diverse incentives. Table 1 below summarises the third mission explanations (Etzkowitz, 2003), Table 2 illustrates some of the motives succinctly (Siegel, Waldman, & Link, 2003), and Table 3 indicates the functions of university, industry and government in the triple helix structure.

The implication of this is that it helped retain academics involved in the venture, reduced operating costs of acquiring an office off-campus and also variable rental and personal costs. Moreover, Herliana (2015) establishes an argument saying that universities encourage a creative foundation for growth and preparation towards work practices; providing research which has applicability potential in impacting industries, policies, encouraging competitive national structure and allowing for resource efficiency utilisation.

Technology firms and certain departments within the life sciences have demonstrated reliance and effectiveness on strategic partnerships in promoting competitiveness, generating productivity and efficiencies. Powell and Owen-Smith (1998) observed the evolution of the biotechnology sector within the university, involving multiple relations among university scientists and firms. Therefore, the role of universities in developing emerging technologies not only remains efficient in applying technologies but also in generating and commercialising knowledge (Chen, 2014). As a consequence, academia is witnessing a functional shift from basic to applied research. A simplified distinction of this concept is taken from Powell and Owen-Smith (1998) which identifies basic research as one which aims to provide a broader understanding of the subject being studied, whereas applied research has a more practical application.

Table 1
Expansion of university mission (Etzkowitz, 2003).

Teaching	Research	Entrepreneurial
Preservation and dissemination of knowledge	First academic revolution	Second academic revolution
New missions generate conflict of interest controversies	Two missions: teaching and research	Third mission: economic and social development; old mission continued

Basic research is driven by interest in a research question with the intention to promote knowledge and understanding without a preconceived motive of invention or financial gain from the outcomes. With respect to the issue of organisations relying on research to gain a competitive edge, we use the applied research argument to foster understanding on this aspect. We caution against implying that the motivational entirety of basic research is purely non-commercial as depicted above because, if we look closely, (some) basic research could also sometimes precede applied research. However, the essence of reference lies with applied research which has some practical application to real world issues beyond merely acquiring knowledge for the sake of knowledge, among other considerations. It is this element of contributing towards economic development in addition to (1) research and (2) teaching that Etzkowitz and Leydesdorff (2000) referred to as the "third mission" of academia.

Landry, Amara, and Rherrad (2006) provide some examples of the role universities play in fulfilling the third mission. Some of these include: consulting, research contracts with firms, patenting and spin off. In other words, these universities are becoming increasingly capitalised in nature and having to confront challenges which could make or break the initiatives; in others, to forge ahead in relation, adaptability and harmony is expected. This evolving practice brings with it conflicts of interest, conflict of commitment and conflict over ownership of intellectual property (Franzak et al., 2010). Goldstein and Drucker (2006), in a study testing the importance of universities in determining regional economic development in the USA since the mid-1980s, discovered that university activities (research, teaching and technological development) are the main contributing factors towards increase in regional average earning.

Back to the function of individual elements, Lengyel and Leydesdorff (2011) study of the role of the triple helix in Budapest's development uses the following table to indicate the task of each sphere, as a top-down approach showcasing the interconnected supportive knowledge creation process.

We can learn from the above that each body is engaged in a dedicated role in addition to supporting the knowledge creation process borne out of the triple helix edifice. In particular, identifying market needs, conducting R&D through projects, patenting, tech transfer, education and publications are the main function that universities play in the triple helix context. The benefits from such interaction are beneficial to the government, industry and universities. For example, BagheriMoghadam, Hosseini, and SahafZadeh (2012) showed that universities are able to generate more funding for research, able to expose students and also faculties to practical research issues, and provide employment opportunities and accessibility to applied technological areas. On the other hand firms reap such benefits as gaining access to highly-trained graduates, faculties and facilities. The firm's image is also enhanced when there is collaboration with prestigious and renowned academic institutions with added advantages of being able to obtain state of the art knowledge and technology. This concept emphasises more interaction among institutional actors and also means that one or more of these actors assumes additional roles different from their traditional identity. A case in point, the universities will be involved in capitalised activities of knowledge marketing in order to seek alternative funding channels while companies will have to assume some academic responsibilities.

2.3. The analytic framework

In a knowledge-intensive sector, such as biotechnology, innovation is usually jointly developed among actors, networks and institutions. Studies have addressed knowledge transfer in the biotechnology sector with a focus on the academia-industry level and the impacts that academic industrialisation has had on the industry's development. The literature has also addressed the global level of the R&D knowledge acquisitions.

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Table 2
Key stakeholders in technology transfer from universities to private sector (Siegel et al., 2003).

Stakeholder	Actions	Motives	Perspective
University scientist	Discovery of new knowledge	• Recognition within the scientific community – publication grants (especially if untenured) • Financial gain and a desire to secure additional research funding (mainly for graduate students and lab equipment)	Scientific
Technology transfer office	Works with faculty members and firms/ entrepreneurs to structure deals	• Protect and market the university's intellectual property • Facilitate technological diffusion and secure additional research funding	Bureaucratic
Firm/Entrepreneur	Commercialises new technology	• Financial gain • Maintain control of proprietary technologies	Organic/entrepreneurial

This section analysed the functions of agents in bringing into being the knowledge transfer networks, adopting sectoral innovation systems as the main framework, and using the triple helix model to illustrate the sprouting role of universities as an epicentre of focus. We comprehend from this section that as a matter of modern-day progression, universities are altering into more cohesive and often attached roles with industries. Some are closely tied to providing inputs necessary to complete research and development activities in firms, and others include pushing the boundaries of dynamic innovation by taking prominent roles in directing the technologies introduction often due to technology transfer. As a pilot assessment, the performance of universities in fulfilling these extra responsibilities of contributing to economic value has certain results for industries.

In the following section, we empirically analysed the dynamic roles of universities in the process of developing emerging technology, using the case of the biotechnology sector in Taiwan to demonstrate the changing role of academia after the 2000s, the era when the biotechnology industry started rapid development in Taiwan. Using networking analysis methodology, we analysed R&D collaboration data to evaluate the changing roles of the universities in relation to this technological development in an emerging economy.

3. Data and methods

In order to map out the main institutional factors influencing the extent to which Taiwanese biotechnology firms can get access to and commercialise new knowledge in the R&D networks, this paper applies multiple methods to a dataset gathered from multiple resources to study the innovation networks in the Taiwanese biotechnology sector. To analyse the dynamic role of the key actors in the innovation system in order to understand the interactions between actors in various dimensions in three time periods (2000, 2006 and 2010), social network analysis was employed to show how nodes (actors) within a network interact, the structure of the network, and how these networks develop over time (Borgatti & Everett, 2006; Prell, 2011; Wasserman & Faust, 1994).

This paper has collected data from multiple resources, including online electronic databases, official publications, interviews, and financial reports of firms, the webpages of firms, research institutes, intermediaries and governmental organisations. Triangulating the information from multiple resources will help to avoid information bias (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). The mixed-methods approach will be useful to ensure the validity of the research, and could provide insightful information to explore the relationships between the variables (Bryman, 2008).

3.1. Data collection

3.1.1. Financial report

By the end of 2013, 125 biotech firms included in this study had been successful in IPO; therefore, the detailed financial report and the important collaboration activities of these firms are well-documented and publicly available at the Market Observation Post System of the Taiwan Stock Exchange (http://emops.twse.com.tw/emops_all.htm). Many of the major stock information bulletins, such as Yahoo stock website (https://tw.stock.yahoo.com/), Statementdog (statementdog.com) and cnYES.com (www.cnyes.com), categorised IPO firms according to their specialised industries, including the biotechnology industry. Therefore, we cross-referenced these major stock information bulletins to produce a list which includes 125 IPO biotechnology firms. This research collected manually the following information from the financial reports of the firms from 1998 to 2013 in order to establish an attribute dataset to describe the structure of the industry. These attribute data include the following information of the firms: the age of the firm, the year of IPO, the main collaborators, the top 10 shareholders of each firm, the numbers of staff, the revenue, the R&D expenditure, and the capital size of each firm. Moreover, the relational data of the R&D networks about these 125 IPO biotech firms are collected from the annual financial reports of these 125 IPO firms. The firms were named by their stock code given (e.g. F1784, F4728) in the dataset. The Google news archive and the webpage of the firms were visited to collect the additional information relating to partnership and alliances which were involved in the biotechnology sector in Taiwan.

3.1.2. Interviews

In order to understand the insightful driver of academia-industry collaborations, this paper also conducted 7 interviews with the technology transfer officers in the academia. The majority of interview data was from elite informants involved in technology transfer in this sector. Interviews were semi-structured and ranged between 45 and 120 min in length and were digitally-recorded. The interview questions were

Table 3
Functions within the Triple Helix (Lengyel & Leydesdorff, 2011).

	University	Government	Industry
Socialisation Permanent relation	Identifying market needs	Identifying scientific and economic trends	Identifying break-out points
Externalisation Regular relation	R&D projects	Policy making Call for proposals Central agreement	Strategy making R&D projects
Combination Systemic relation	Patenting Uni. Tech Transfer	Promoting ICT, Media Region Marketing	Financial Support Patenting
Internalisation Casual relation	Education Publications	Evaluation Political messages	“Learning by doing” Products, services

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Table 4
The abbreviation of the nodes.

Actors	Coding	Examples
Domestic IPO firms	"F_" + stock code + short name	F_8406Ginko
Domestic non-IPO firms	"FD_" + short name	FD_ Lumosa
Foreign firms	"FF_" + short name	FF_Biokey
Universities and PRIs	"U_/UF_" + short name	UF_Rockefeller
Research organisations	"O_" + short name	O_ITRI
Government agencies	"G_" + short name (+ .city name)	G_MOST
Hospitals and clinics	"H_" + short name (+ .city name)	H_NTU
Individuals	"I_" + name	I_ RobertJ

initially designed to ask about the collaboration and knowledge transfer experiences of the actors.

3.2. Data analysis

The data collected from multiple resources have been analysed by the approaches of simple quantitative analysis, qualitative thematic analysis (Braun & Clarke, 2006), and network analysis (Borgatti & Everett, 2006). Qualitative methods will be mainly used in order to provide detailed analysis, and these will be supplemented by simple quantitative analyses to show the industry structure of the biotechnology industry as well as the R&D collaborations between the actors.

The following Table 4 shows the major coding rule for different types of actors; for example, the codenames of the IPO firms start with an "F_", and are combined with their stock code and companies' short name (e.g. F_8406Ginko).

Table 5
Network measurements (2000, 2006, and 2012).

Year	2000	2006	2012
Total nodes (actors)	44	96	183
Total edges (relationship)	32	106	213
Total lines (links)	31	83	177
Network density	0.0338	0.0232	0.0132
Average degree	0.0327	0.0183	0.0111
Universities/RIs			
Number of universities/RIs-	2	10	20
Growing rate	–	500%	200%
Average degree centrality[a]	0.023	0.013	0.011
Maximum degree centrality	0.023	0.021	0.039
Average betweenness centrality[b]	0	0.323	1.803
Maximum betweenness centrality	0	3.180	7.525
Organisations			
Number of organisations'	2	5	9
Growing rate	–	250%	180%
Average degree centrality	0.035	0.023	0.013
Maximum degree centrality	0.047	0.053	0.034
Average betweenness centrality	0.332	1.043	2.522
Maximum betweenness centrality	0.664	2.844	9.323
Government			
Number of actors	3	4	5
Growing rate	–	133.33%	125%
Average degree centrality	0.047	0.019	0.009
Maximum degree centrality	0.070	0.032	0.017
Average betweenness centrality	0.775	1.008	0.726
Maximum betweenness centrality	1.661	3.942	2.540

[a] Degree centrality of an actor is the number of edges that directly connect to the node. The implication of degree centrality is the opportunity to influence other nodes or be influenced directly by others (Freeman, Roeder, & Mulholland, 1979). Since the numbers of total actors (n) are different, researchers can normalise the degree centrality by dividing it by n − 1.

[b] Betweenness centrality of an actor k is to calculate how many shortest paths between other actors, I and j that pass through k, and dividing the number by the total number of the shortest paths (since there could be more than one shortest path between I and j). Betweenness centrality implies the potential of gatekeeping, brokering, and controlling the flow of an actor in the network.

Table 6
Licensing and transfers in the biotech sector.

	2000	2006	2012
Foreign firms	6	17 (↑ 283.33%)	27 (↑158.82%)
Universities/RIs	1	2 (↑ 200.00%)	16 (↑800.00%)
Domestic firms	1	10 (↑1000.00%)	13 (↑130.00%)
Organisations	1	7 (↑ 700.00%)	9 (↑128.57%)
Government agencies	0	1	3 (↑300.00%)
Individuals	0	2	2 (− 100.00%)
Hospitals	0	0	1
Total	9	39 (↑ 433.33%)	71 (↑182.05%)

The software UCIENT, bundled with NetDraw, was chosen to be the network analysis software tool in this paper. The network relational data (Wasserman & Faust, 1994) were primarily collected from the webpage of the firms, financial reports, and the new archives. A variable for the existence of a connection between any two actors (nodes) was created. The variable takes on the value of 1 where there is a connection and 0 otherwise. Based on the relational dataset resulting from this variable, an adjacency matrix was constructed. The data was entered manually to create the edgelist in the text files, and then the software, UCINET (Borgatti et al., 2002) was used to read the edgelist and transform the data into the adjacency matrix. These visualisations are essentially a graphic representation of networks including nodes and relations, as shown in Fig. 1.

4. The changing role of the universities in the networks

This section investigates the relationship and the R&D network of the biotechnology sector. The major focus is: how do interactions occur in the biotechnology networks to develop linkage between actors and what role do universities play in the emergence of emerging networks? Firstly, the overall R&D networks that include the actors show the development of the biotechnology sector. Secondly, this study analysed the role of universities/RIs in the networks and took deep insights through elite interviews. This study also analysed the incentives which facilitate the academia-industry collaboration.

4.1. The development of networks in the innovation system

In order to understand the innovation networks of the biotechnology sector in Taiwan, this section maps out the networks based on the R&D collaborations in the biotechnology sector. Fig. 1 shows the firms' ego network of R&D collaboration activities in 2000, 2006 and 2010. Each node represents one organisation. The lines between two nodes represent at least one collaboration activity (e.g. collaborative R&D, licensing, contract R&D) was in progress in the particular year. In other words, these non-direction lines present collaboration relationships between two actors. The lines are thicker if the times of R&D collaboration are more. Furthermore, the different shapes of nodes on the map show different types of

Table 7
Biotechnology patents owned by major universities/RIs in the biotechnology sector.

	2000		2006		2012	
	Total	Invention	Total	Invention	Total	Invention
Academic Sinica	0	0	45	45	143	143
National Taiwan University	352	322	1210	1179	2426	2375
Taipei Medical University	1	1	8	7	90	81
Kaohsiung Medical University	0	0	3	3	32	31
National Defence Medical University	0	0	2	2	12	11
National Yang Ming University	0	0	0	0	15	15

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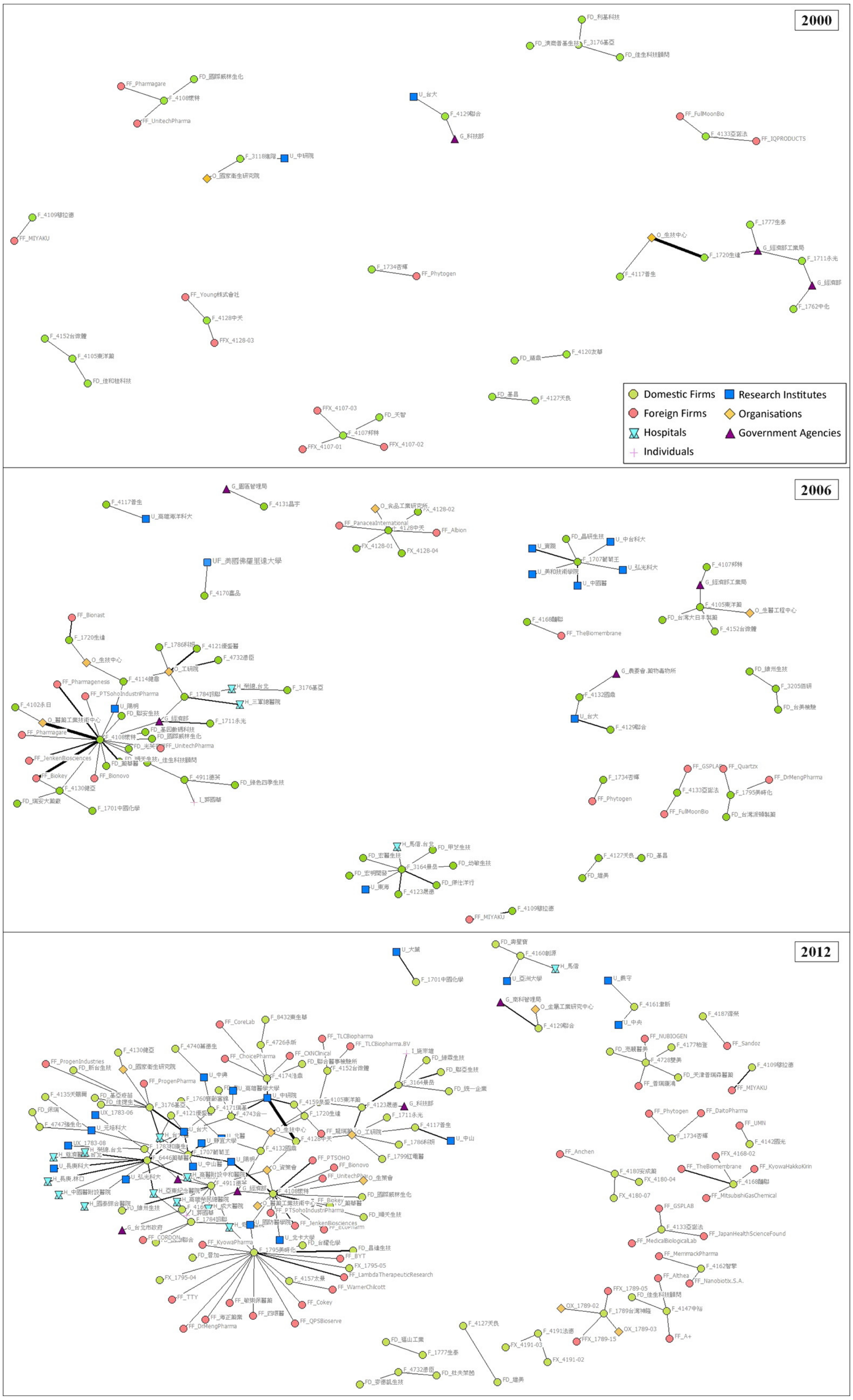

Fig. 1. R&D collaboration networks in 2000, 2006, and 2012.

actors. The red circles are foreign firms, and the green circles are domestic firms. The blue squares represent universities and public research institutes (RIs). The yellow diamonds are non-governmental organisations. The purple triangles show the government agencies and finally the nodes in the purple hourglass shape present the hospitals involved in the biotechnology R&D innovation.

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There were few R&D collaborations between the actors in 2000 with a slight increase in 2006 and further development by 2012. The network changing over 2000, 2006, and 2012 shows that in the case of the biotechnology sector, the innovation networks developed from purely inter-firm networks into the networks that mixed with the non-firm actors. In particular, the non-firm actors, such as universities, hospitals, and research organisations, have played more and more central roles in the networks. In 2000, the R&D collaborations were mainly occurring between the firms (red and green nodes). However, collaborations were less scanty in 2006 and 2012 with a large connected component and some other smaller ones. The firms started to collaborate with the domestic universities, RIs and organisations. The changing collaboration reshuffled the network structure of the biotechnology innovation system in Taiwan. By 2012, many more domestic universities, RIs and organisations were involved in the network. Domestic universities/RIs have become the key actors in the networks as shown in Fig 1.

The following Table 5 presents the measures of the whole networks in 2000, 2006 and 2012, including network density, normalised degree, number of nodes (actors), edges (times of R&D collaboration between actors), and lines (links between nodes). As the map shows in Fig. 1, the numbers of nodes, edges and lines all had large increases. Table 5 also illustrates the features of the specific types of actors. Universities/RIs had the highest growing rate, 500% from 2000 to 2006 and 200% from 2006 to 2012, which are the highest growth rates of the non-firm actors. The increasing connections of the RIs mean the developing role of the RIs in the networks. Moreover, the maximum degree centrality of universities/RIs in 2012 is higher than in 2000 and in 2006. This means some actors had large numbers of direct connections which were not diluted by increasing the number of actors. The increasing betweenness centrality of universities/RIs has indicated that universities/RIs played a more and more influential role in the main component in the network.

Figs. 2 and 3 summarized the accumulate numbers of R&D collaboration agreements in each year. Fig. 3 also reveals that academia-industry R&D collaboration increased the most. The number of academia-industry collaborations doubled from 2000 to 2006, and the firms that connect to universities/RIs became almost 25% of all firms in 2012 as shown in Fig. 1. Another interesting phenomenon is the collaboration between firms and hospitals rapidly increased since 2011. Most of the firm-hospital collaborations are clinical trials for new products or new treatment technologies. Some of the hospitals are connected with universities, such as the National Taiwan University Hospital, Taipei Medical University Hospital, and Chang Gung Hospital. This phenomenon also implies that the influence by universities/RIs and hospitals was getting higher in the biotechnology sector.

4.2. The role of universities in the networks

Fig. 4 marks the universities/PRIs as blue squares, and the firms that connect to universities/RIs as green circles. In 2000, the firm-universities/RIs collaboration only includes two sets of ties. One tie connects a firm and the National Taiwan University as a technology-provider in the process of joint product development. Another set of dyad has Academia Sinica as the technology provider. In 2006, excluding the firm “Grape King” that collaborated with five universities in the contract research projects for their Chinese herbal medicine and bio-food products, each of the other seven firms collaborated with one university/RI. The key roles of the RIs were mainly providing research and development knowledge and assistance in the technology transfer process. In 2012, 21 universities were involved in the network. Among these collaboration relationships, the major types of collaborations are contract research, technology transfer agreements, and licensing. In these sorts of collaborations, the firms received knowledge and technology from these universities. Consequently, the major roles of most universities in the emerging high-tech sectors are mostly technology-providers. The technology that developed by the universities has changed from pure research into applied science. The phenomenon that universities/RIs collaborated with more than one firm in 2006 and 2012 also implies that the firm-universities/RIs collaborations have the potential to become a common channel of knowledge transfer.

Figs. 5 and 6 illustrate the types of academia-industry R&D collaboration in each year. Based on the essential characteristics of the collaboration, the figures categorise the collaborations into seven major types. Similar to the trend shown in Fig. 2, the increasing ratio of collaborations from 2006 to 2007 is much higher. The main collaboration activities include contract research activities (mainly by Grape King), collaborative research, licensing, transfer, and collaborative development. This result reinforces that collaboration with universities/RIs can help firms to absorb knowledge from academia in the earlier stage of the R&D process. In addition, firms started to reach the licensing agreements with universities/RIs to get patents. Half of the licenses were authorized by Academic Sinica, a leading RI in Taiwan. Some firms also established further R&D collaboration from the same alters based on previous outcomes, such as contract research or industry-university collaboration projects. As the interviewee who is a manager in the technology transfer office indicated:

> Biomedical firms would look for further academia-industry collaboration with the faculty members who have good track records in the previous joint projects. The firms paid the original investors for advanced development of technologies. We are willing to see those collaborations, because the faculty members will get extra funding support for research through technology transfer.
>
> [(**Interview, T4**)]

Thus, the roles of universities/RIs can be seen as not only knowledge providers but also enhancers to move technologies forward in the R&D process.

Among the types of R&D collaboration activities, licensing bases on more practical or well-established technologies becomes a much more important solution to industry and academia. A reason to motivate

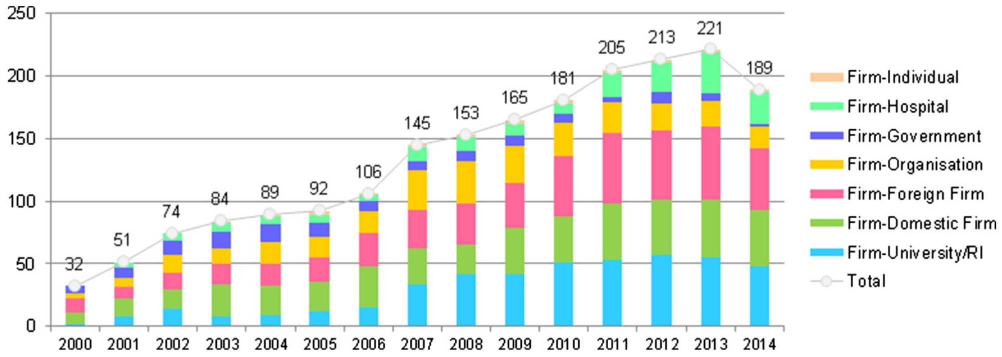

Fig. 2. The Types of the R&D collaboration contracts in the biotech sector (2000–2014).

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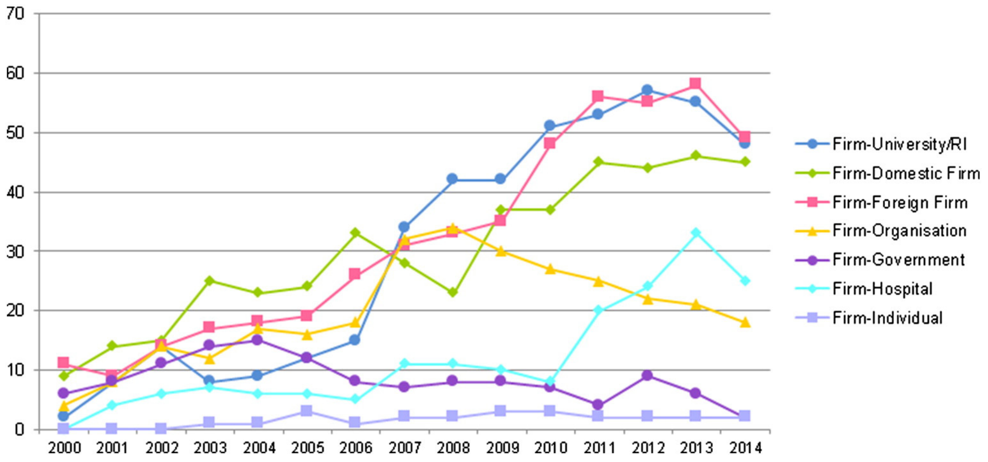

Fig. 3. Types of R&D collaborations in biotech sector (2000–2014).

academia-industry licensing is the high R&D expenditure. As an interviewee explained:

> The firms in Taiwan are a small size and rarely able to afford large R&D expenditures. Most firms expect commercialisation in 1-3 years after involving in the academia-industry collaboration RIs in Taiwan don't have enough ability to run clinical trials without the support of national funding supports.
>
> [(**Interview, T1**)]

Moreover, universities/RIs can also receive license fees from licensing new technology to firms (Caldera & Debande, 2010). Firms can utilise or commercialise from patent-protected technologies with lower license fees in the early stages. Another interviewee indicated the profit and the incentive of technology transfers in the biomedical subsector:

> Since the higher risk, the first milestone of the license fee should be lower. Universities will charge more fees in the later stage. The milestone is based on the progress.
>
> [(**Interview, T4**)]

Thus, universities/RIs may play a role to facilitate technology transfer with appropriate incentives, such as funding support and lower license fees. Firms are expected to lower their costs by obtaining new technologies or products from academia. Licensing and technology transfer from academia are the main approach to receive potential technologies or products for a firm. Fig. 7 highlights the actors which are involved in licensing and transfer activities. The red lines represent the relationships which consist of licensing and technology transfer between the two actors. Each arrow head from one node to another represents the direction of technology and knowledge flow. The map marks other actors not involved in licensing and transfer as white nodes, and the non-licensing and non-transfer relations as grey lines. Over the time, the changing structures show that more and more actors involved in the major component in the network. As the descriptive statistics in Table 6 and Fig. 8, among the different types of actors, universities/RIs involved in licensing and transfers had the highest increasing ratio 1600% from 2000 to 2012. Although the most licensing and transfer activities are with foreign firms, more than half of the foreign firms are transferees or licensees. In contrast, universities/RIs played their roles as technology providers, especially in the major components of the network in 2012. This situation implies that universities/RIs have become important resources of technology for developing industry.

To further understand the technology licensing activities from universities/RIs, Fig. 9 focuses on the ego network of academia-industry licensing in 2012 as an example. The arrowheads point from a licensor to a licensee, with the thickness that corresponds with the times of licensing activities. The blue squares represent universities/RIs, and green circles represent domestic firms. In this map, NTU and Academic Sinica ae licensed to more than one company. Some firms also take licences from more than one university/RI. The relations imply that industry has motivation to acquire knowledge from academia. However, to compare with the biotechnology patents owned by major universities/RIs in the biotechnology sector (see Table 7), the ratio of licensing and patents are relative low. Indeed, many cases of the technology licences in the network are in relation to medical and biopharmaceutical technologies and products, while the patents owned by universities/RIs are in similar categories, such as medicines, biopharmaceutics, bio-foods, and treatment technologies. It is interesting why the outcomes of the researchers' works may not fit the demand of the industry. As the interviewees explained:

> Even if there are funding supports for applying patents, some faculty members didn't care about the quality of the patents or the commercialisation. Some patents are useless after a few years.
>
> [(**Interview, T3**)]

> If a researcher set commercialisation as the final goal, you probably won't invent something really important.
>
> [(**Interview, T2**)]

On the other hand, the opposite perspective is that patents with the potential of commercialisation should be commercial-oriented in the early stage. Commercialisation also needs systematic supports by experienced firms. As the interviewees indicated:

> If a patent is identified by its business value, it needs systematic supports to accelerate. The next stage, it needs an experienced firm to take over and manage. It is easier to become a real product.
>
> [(**Interview, T2**)]

> If a patent had been considered by its business value and even the firms which can commercialise, it would be easy and early to be applied. However, if a patent is not product-oriented, it would need to be largely modified during the process of commercialisation.
>
> [(**Interview, T1**)]

The responses address that commercial-oriented and product-oriented innovation is important for academia-industry commercialisation. Interviewee (**T5**) also mentioned:

> Firms will invest the patents in consideration of the potential of new technologies.
>
> [(**Interview, T5**)]

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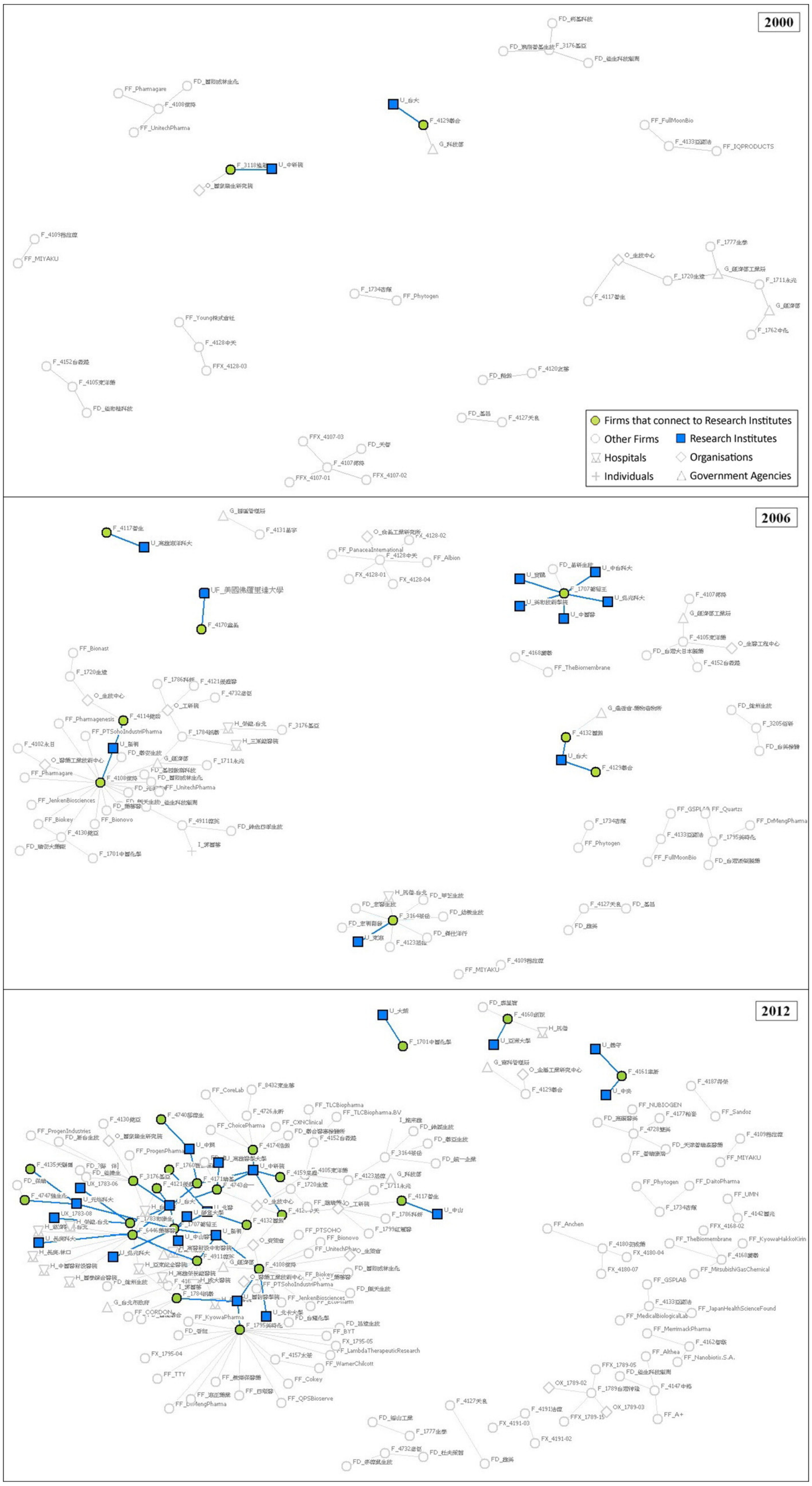

Fig. 4. Academia-industry R&D collaboration in the whole network.

This perspective shows that the role of universities/RIs are not only the knowledge-providers but also the developers which incubate potential technologies and products. As the reason explained above, technologies developed in the universities/RIs would reduce R&D expenditure of firms. Nevertheless, to identify technologies or products with business value is not

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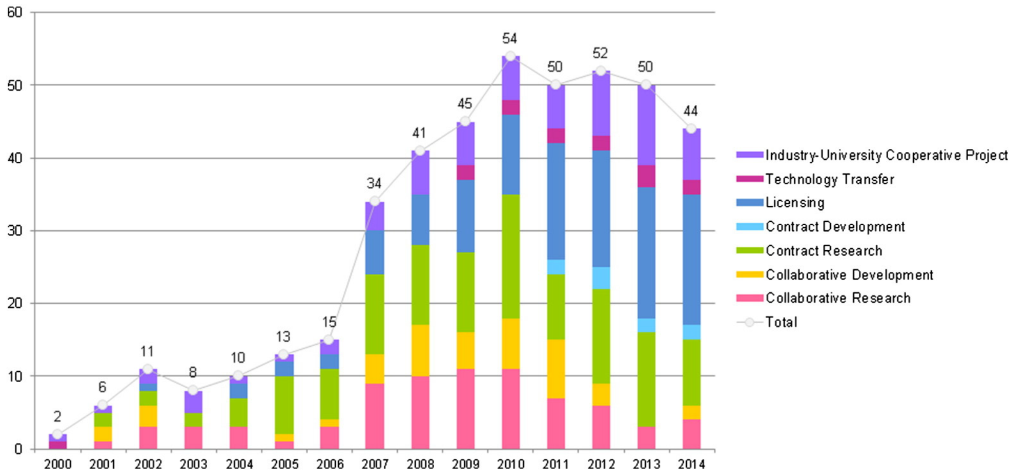

Fig. 5. The development of academia-industry R&D collaboration in biotech sector.

a clear path for both academia and industry. As the interviewee commented:

> Sometimes firms didn't know what they needed. They asked for a new technology or product, but they didn't have any idea of their demand. Secondly, sometimes firms had very practical demands, but there were no faculty members who conduct relevant research in academia. Even there were few faculty members doing certain research, their works were still in a very early stage.
>
> [(**Interview, T4**)]

To seek for potential outcomes for commercialisation requires both efforts of universities/RIs and firms. Firms have to identify the demands and provide systematic support to universities/RIs. Universities/RIs play their roles of basic research and applied research of commercial-oriented R&D if the potential of commercialisation is identified. As the interviewee (**T1**) indicated:

> If the inventors have a deep understanding of commercialisation process, their work will be more easily to be commercialised.
>
> [(**Interview, T1**)]

This means that the commercialisation experiences of the inventors can facilitate technology commercialisation from academia to industry.

4.3. The incentives and the development of institutions

The role of universities/RIs in the innovation network had changed from knowledge generator to knowledge provider and developer. This research also investigated the incentives that facilitated the change and increased R&D collaborations.

Biotechnology research consists of basic academic research and applied research. According to the Science and Technology Yearbook (published during 1983–2012), more and more researchers were involved in the basic research of biotechnology from 2000 to 2004 (MOST, 2012). As shown in Fig. 10, Academic Sinica and the Ministry of Science and Technology (MOST) rose funding to support more basic research projects in biotechnology related subsectors. Since the different focus of research, Academic Sinica mainly supported the biomedical field, and MOST invested more in biotechnology and medical biochemistry. The basic research programmes have been integrated into life science since 2005. In general, Fig. 11 shows that both Academic Sinica and MOST kept investing more funding of life science research. Fig. 12 lists the funding from national genome and biopharmaceutical projects. In 2002, the government's principal investments were genomic research. Funding was raised for biopharmaceutical research in the following year. The funding of national projects decreased in 2007. In contrast, Fig. 13 shows the significant increasing amount of funding in applied research projects in 2007. In sum, the total funding for both basic academic research and applied research kept increasing. The funding supports provided universities/RIs with resources to develop a wide range of innovative ideas and encourage researchers in universities/RIs to apply for patents.

The high maintenance fees of the large number of patents will lower universities/RIs' intention to support applying new patents. Universities also started to control the applications to make sure

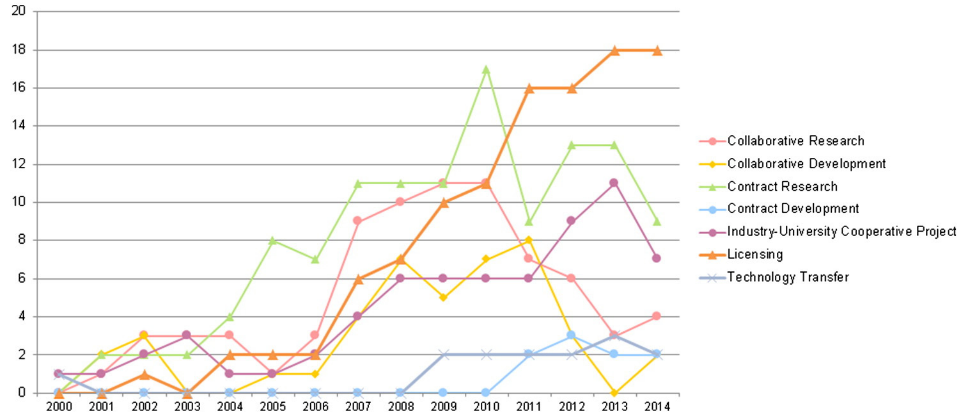

Fig. 6. Types of academia-industry R&D collaboration in the biotech sector.

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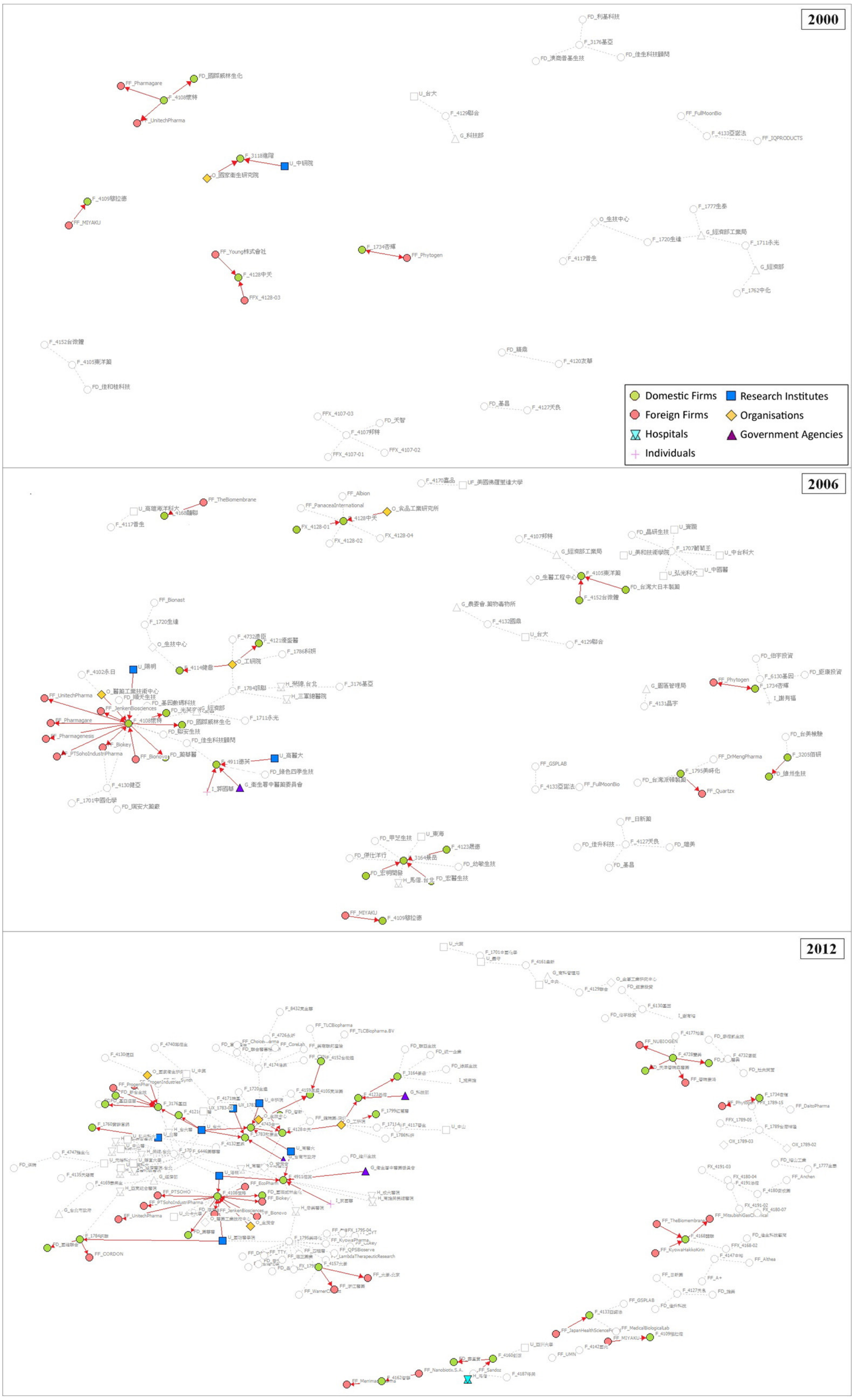

Fig. 7. Licensing and transfers (red lines) in the biotech sector R&D network. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the technologies had the potential to be commercialised. Under this circumstance, technology transfer offices (TTOs) are important mediators to match academia and industry in technology transfer progress (Caldera & Debande, 2010). Firms can seek technology transfers from non-firm sources by the help of TTOs (Kirkels & Duysters, 2010).

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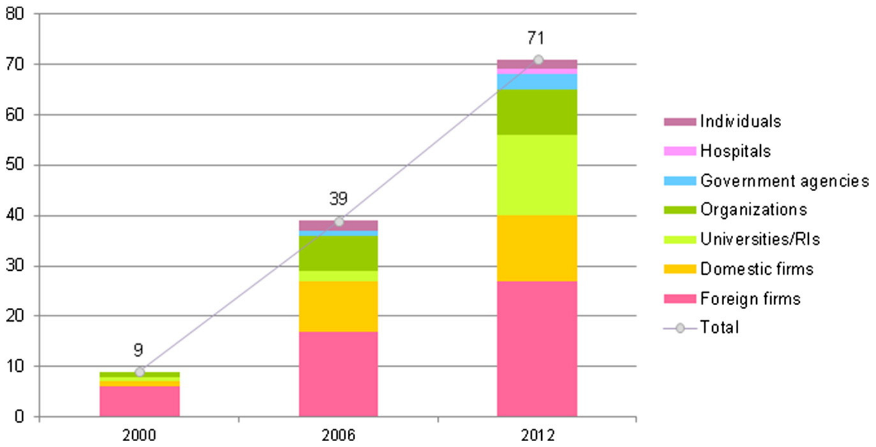

Fig. 8. Sources of licensing and technology transfer.

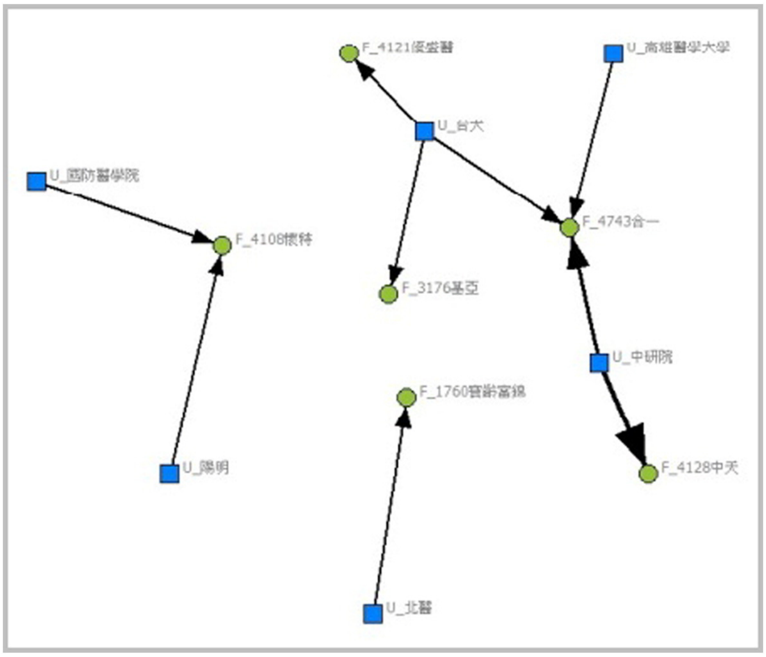

Fig. 9. Licensing from academia to industry (2012).

5. Discussion and conclusion

Knowledge and technology innovation are the key elements for developing the emerging biotechnology industry, a knowledge intensive high-tech sector. Section 4 discusses: (1) the development of networks in the innovation system in Taiwan's biotechnology sector; (2) the changing role of universities/RIs in the biotechnology innovation network; (3) incentives of academia-industry collaboration and the development of institutions. The results prove the importance of external knowledge sources from universities/RIs in the development of the biotechnology sector, an emerging sector. The changes of the innovation networks and roles of universities/RIs not only rapidly develop, but also

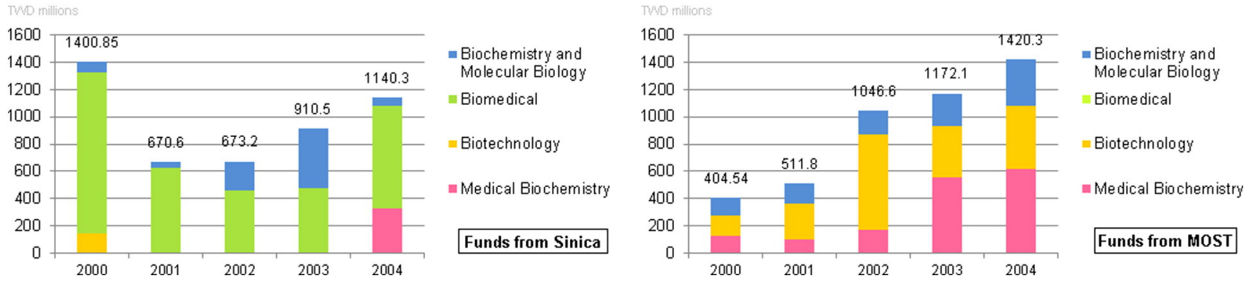

Fig. 10. Funding from Academic Sinica and MOST for basic research in biotechnology (2000–2004).

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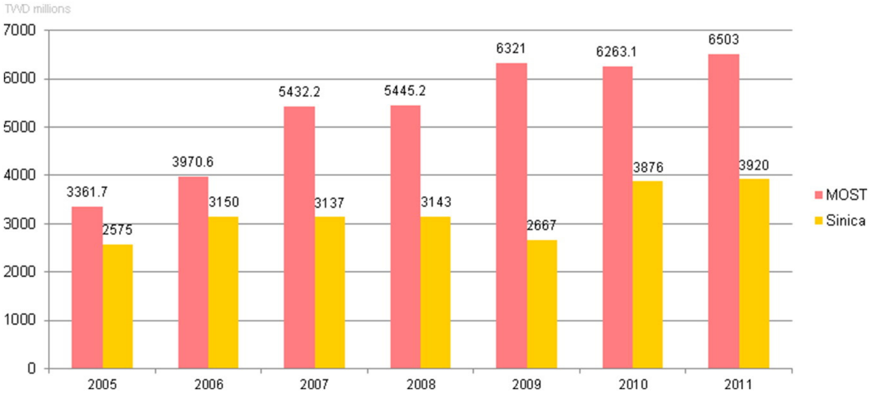

Fig. 11. Funding from Academic Sinica and MOST for basic research in life science (2005–2011).

Fig. 12. Funding from the national research project of genome and biopharmaceuticals (2002 — 2010).

shed light on the potential of knowledge flow in various academia-industry R&D collaboration activities.

Actors in the R&D network increased and connections with various types of actors also grew rapidly. The network developed from small partitions with scanty links, and changed into well-established structures which consist of major components and smaller dyads. In the development of the network, the importance of universities/RIs keeps increasing. Industries acquire knowledge and technologies from various external sources, in particular from universities/RIs. Many firms of a smaller size and with lower budgets for R&D relied on academia-industry R&D collaboration. Universities became knowledge providers for technological innovation. Firms also sought advanced development of their images via collaborating with prestigious scholars in the universities/RIs.

The links between actors in 2000, 2006 and 2012 represent the development of R&D collaboration: (1) Taiwanese firms established their foreign collaborations independently in 2000, but started to collaborate with the domestic research institutes and research organisations after 2006; (2) most inter-firm collaborations were established in the pharmaceutical and biopharmaceutical R&D. In contrast, the academia-industry collaborations were more well-established in the R&D activities in the research area of bio-food, medical devices, and the Chinese herbal medicine research for R&D collaborations. This shows that, in the knowledge intensive subsectors, such as the biotechnology sector, firms prefer to collaborate with the other firms who have mutual complementary technologies. While observing the academia-industry R&D collaborations in this study, we found that: (1) the number of universities involved in R&D collaboration significantly increased after 2006; (2) universities served as technology generators rather than knowledge disseminators; (3) government funding support stimulates technology transfer between public universities and firms. To enhance effectiveness of technology transfers from universities, future policy may provide incentives to motivate academic researchers in the universities to actively participate in academia-industry collaborations.

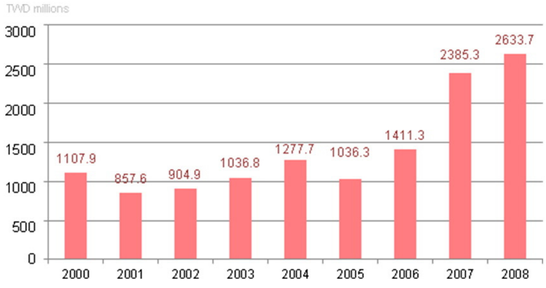

Fig. 13. Funding for biotechnology research projects (2000–2008).

The emergence of this set of network developments is theoretically supported as a path-dependent framework of evolutions starting with the support of a few institutes and slowly ramping over time as we have seen, increasing the spread to other institutes resulting in consolidation. One explanation for this is likely to be the lessons drawn for effective association, and mature supporting institutions. The result shows that bi-directional exchanges is a common denominator where interests align, starting from the process of initiating knowledge, involvement in the development and then taking part in the commercialisation of the technology through policy support. The drive spans the setting up of advisory services and the transfer of tacit knowledge to industry. This sheds light on how interactions occur in the emerging networks to develop linkage between actors, as an emerging field in the technology follower, such as Taiwan. The roles extend into the penetration of knowledge filters as shown in the case of supporting until the technology is commercialised, and thus allowing utilisation access to licensing possessed by the university and sharing awareness on the latest form of technologies in the field given the leading roles played by the universities.

The findings of this paper shed light on the changing role of academia in developing emerging technologies in technology followers. While the innovation ecosystem was ready for academia-industry collaboration, universities not only take charge of disseminating knowledge but also serve as the major intermediaries in the process of commercialising science and technologies developed through the universities. Future policies may need to boost more partaking between the universities and industries by motivating the transmission of knowledge capital through encouraging technology commercialisation in academia.

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