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Triple Helix of University–Industry-Government Relations in Biotechnology Cluster: the Case of Singapore

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바이오 클러스터에서의 트리플 힐릭스 관계 연구: 싱가포르 사례를 중심으로

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Abstract : This paper is a theoretically grounded empirical study aimed at shedding light on the Triple Helix of University-Industry-Government (U-I-G) relations in biotechnology cluster of Singapore. It questions the issue about the gap between theoretical consideration of the Triple Helix of U-I-G relations and the actual reality in biotechnology cluster, and the experience of Singapore was investigated. In terms of evolutionary perspective, biotechnology cluster in Singapore has gone through ongoing processes from a certain stage to other, and within the processes the Triple Helix nexus has been found.
Analysis of the empirical study reveals significant findings: first, the government policies play a critical role in the operation of U-I-G relations rather than universities; second, therefore, the binding force of U-I-G relationships is based on the government policies being comprehensive including researchers immigration, student scholarship for local students, and tax and non-tax incentives for firms, rather than focusing on a targeted policy; third, the role of government starts from an initial stage, and it's role is ongoing processes by supporting infrastructure, human sources and continuous nourishment enabling the triple helix of U-I-G relations.

Key Words : biotechnology cluster, biomedical sciences, The Triple Helix Model

요약 : 본 연구는 트리플 힐릭스 모형을 활용하여 싱가포르의 첨단생명과학단지에 대한 분석을 시도하였다. 트리플 힐릭스 모형의 이론적 논의와 현실에서의 산 · 학 · 관 관계의 차이점에 주목하고 연구문제를 제시하였다. 싱가포르 첨단생명과학단지는 대학, 정부 그리고 기업체간의 삼자간 상호작용이 존재하고 있었지만, 트리플 힐릭스 모형의 이론적 틀과는 다르게 작동하고 있었다. 우선, 대학보다는 정부가 삼자간의 관계를 결정할 정도의 주도적인 역할을 하고 있었다. 정부는 이민정책, 장학금, 세금감면 및 세금이외의 인센티브 정책 등 생명과학 및 의료산업에 대한 포괄적인 지원정책을 추진하였다. 또한 정부는 초기단계에서부터 삼자간 관계를 주도하였으며 이러한 역할은 클러스터가 어느 정도 진전된 이후에도 지속되고 있었다. 정부의 이러한 지원은 삼자간 상호작용을 가능하게 하는 추동력으로 작동하고 있었다.

주요어 : 트리플 힐릭스, 첨단의료산업단지, 바이오 메디컬산업, 싱가포르 의료산업

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1. Introduction

Modern biotechnology has been related to many attempts to change the institutional arrangements and how the stakeholders have enhanced innovative capacities by way of interactive relationships. In the development of biotechnology cluster, universities, firms and government may be viewed as important actors in a certain geographical area (Cooke, 2003: 758). Most research of biotechnology cluster focused on what has happened and is happening in relation to the relationships between universities, firms and government (Cooke, 2004: 917; Owen-Smith *et al*., 2005: 25; Wong, 2007).

With the emphasis of the knowledge-based economy and the knowledge intensive characteristics of biotechnology industry, the universities are increasingly expected to play a significant role in their proximate regions. In particular, the Triple Helix Model stresses the role of universities from the evolutionary perspective (Etzkowitz & Leydesdorff, 2000: 11).

However, it seems that there is the gap between the conceptual framework of the Triple Helix Model and the actual construction of biotechnology cluster. For instance, even though current liberal capitalism society, the role of the three institutions can not be seen as an equal level, this is because in some countries or regions any of institutions can be a dominant leader and it could organize the triple helix of University-Industry-Government(U-I-G) relationships predominantly.

This paper begins with the questions that which institution is the main actor in the triple helix of U-I-G relations, if there is a main actor, to what extent and in what ways the institution dominantly leads the U-I-G relations. In order to examine the question, it studies the Singapore's biotechnology cluster, this is because the country is considered one of the successful case in biotechnology cluster rarely in the Asian context (Wong, 2007: 368; Finegold *et al*., 2004).

2. Theoretical Background and Research Questions

1) The Triple Helix Model

The Triple Helix Model was initially derived from an analysis of the renewal of the Boston economy and the role of MIT (Massachusetts Institute of Technology), through the cooperative relationships between university – industry - government for firm-formation which were encouraged by academic research carried out since the 1930s (Etzkowitz, 2002; Cooke, 2004). This analysis points out that a region with a cluster of firms, rooted in a particular technological paradigm is in danger of decline once that paradigm runs out (Etzkowitz, 2002; Etzkowitz & Klofsten, 2005). In order to respond to the continuous need for renewal in the industrial and technological bases, it is necessary for this renewal to be undertaken by a variety of actors, typically including a triple helix of university-industry-government relations.

Etzkowitz and Leydesdorff (2000) in referring to the Triple Helix of U-I-G relations argue that "a triple helix in which each strand may relate to the other two can be expected to develop an emerging overlay of communications, networks, and organisations among the helices" (p. 112). U-I-G relationships can be considered as a triple helix of evolving networks of communication. The concept of the model highlights the fact that U-I-G relations are the key to improving the conditions for innovation in the knowledge-based economy.

At this point, with relation to the biological term 'triple helix', questions are raised; why not double or quadruple but triple, and why is the word 'helix' used? Industrial and economic policies have traditionally focused on a bilateral interaction between government and industry; however, in the knowledge-based economy, the university becomes a crucial institution in the innovation system because of its role as a knowledge stock and its capitalization. The Triple Helix Model considers the university and its changing role as a central institution and actor in innovation within increasingly knowledge-based societies, and this is a different viewpoint from the NIS (National Innovation System)/RIS (Regional Innovation System), which regards the firm as having the leading role in innovation (Etzkowitz & Leydesdorff, 2000; Lundvall, 1992; Cooke, 1998). In addition, it seems that the term 'helix' is used to explain the overlay of communications and expectations at the network level guiding the reshaping of institutional arrangements.

One of the outstanding points of this model is that it is by its nature unstable and transitive system (Etzkowitz & Leydesdorff, 1999; Lee *et al*., 2009). The triple helix hypothesis is that systems can be expected to remain in transition, which can be regarded as characteristics of the knowledge-based economy and trilateral interaction. That is to say, when a certain technology or knowledge is increasingly used as a resource for the current production system, creative destruction could be followed as a reconstruction course. Moreover, in opposition to a double helix, a triple helix is not expected to be stable. This is because the three strands continuously reflect each other, and there are ongoing transformations between helixes and within each of helixes (Leydesdorff & Fritsch, 2006; Lee & Lee, 2014). Each string relates to the other two in a triple helix, which makes it develop an overlay of communications, networks and organisations among the helixes. In this line of thinking, the model highlights the fact that the system of innovation can be expected to remain in transition, thus it does not become fixed in any specific system and its boundary. From these perspectives of unstable and transitive system, the triple helix model criticizes the 'national innovation system' and the 'regional innovation system' as 'a reified system', because a system may always be redefined (Nam, 2008).

With relation to the transitive system, what are the driving and binding forces that make the system or the three helixes continuously interact? Above all, the sharing of functions between university, industry and government is viewed as a rationale and encouragement of their interactive relationships including trilateral overlay. With the changing socio-economic environment, each institution wants to take on the role of the other, which creates interdependent relations between three spheres. Institutions and actors take on multiple roles compared to their previous behaviours as they find new ways of interacting with each other.

By interacting, complex and dynamic relationships emerge because the participants are based on the different system of reference, and they respond to a perception of each other's position (Leydesdorff & Etzkowitz, 2001; Lee *et al*., 2010). Through the consequent process of negotiations and interactions, the institutional actors will be reproduced and changed, which may be viewed as a reflexive process. Within these processes, trilateral network and hybrid organisations are created to solve social, technological and economic problems. Thus, Etzkowitz and Leydesdorff (2000, p. 115) regard a triple helix dynamic of university-government relations as being 'generated endogenously'. They also point out that the changing role in each helix and between helixes over time is the driving force of the interaction (ibid). These explanations provide a basis for the construction of a microanalytic framework for the investigations of the interactive relationships between the three helixes.

In sum, the Triple Helix Model comprises four basic elements. Firstly, it puts an emphasis on the more significant role of the university in innovation, in a knowledge-based economy on a par with industry and government. Secondly, it stresses the interactive and reflexive relationships between three major institutional spheres, and it considers that innovation policy is increasingly an outcome of interactions rather than a simple prescription by government. Thirdly, with the changing socio-economic environment, in addition to their traditional functions, each institution takes the role of the others, which encourages their interdependent relations. Fourthly, by its nature, this model is an unstable and transitive system.

2) Research Questions

The empirical research setting of this paper is located in Singapore, dealing with its biotechnology cluster aimed at building Asian biomedical hub. Theoretically, the concept of the Triple Helix Model are used as analytic framework. On the basis of the empirical and theoretical setting, the objective of the paper is to identify and understand the driving and binding forces which make the Triple Helix Nexus possible in the experience of Singapore. In the biotechnology industry a high degree of government's and universities' role in the Triple Helix Model is needed because of the science-driven and knowledge intensive nature (Cooke, 2003: 758; Wong, 2007: 369). However, the role of institutions also can be different depending on the regional or national situations.

With the above considerations, the key questions examined in this paper are: what are the driving and binding forces that make the Triple Helix Nexus or the three helixes interact? and in what ways, and to what extent, do the forces influence the developmental processes of biotechnology industry?

3. The Biotechnology Cluster in Singapore

1) Overview

The Singapore government, in particular the Economic Development Board (EDB) has articulated a vision of its country turning into Asian hub for biomedical sciences since 1998 alongside with the arising importance of a knowledge-based economy. In 1999, the life sciences sector was officially declared by the government as the "fourth pillar" of Singapore's manufacturing sector, after electronics, chemicals and engineering. The EDB is a government agency for planning and executing strategies to enhance Singapore's position as a global business centre and grow the Singapore economy. The EDB launched the Singapore Biomedical Sciences (BMS) initiative in 2000, which aimed to construct the Biomedical Sciences cluster. After the initial move by the EDB, the BMS of the country has been developed with three phases as following.

i) The First Period (2000-2005): Building the Foundation

The first phase of development (2000-2005) focused on establishing a firm foundation of basic biotechnology research in Singapore. Five research institutes of the Biomedical Research Council (BMRC's) developed core public research capabilities in the areas of bio-processing, chemical synthesis, genomics and proteomics, molecular and cell biology, bioengineering and nano-technology, and computational biology. All these support the BMS cluster, comprising the four key sectors: pharmaceuticals, biotechnology, medical technology and healthcare services.

ii) The Second Period (2006-2010): Strengthening Translational and Clinical Research Capabilities

This period focuses on enhancing capabilities in translational and clinical research, while continuing to build up basic research capabilities. the government considers the capabilities of Translational and Clinical Research (TCR) as an essential factor to translate basic discoveries in the lab into clinical applications to improve human healthcare. Therefore BMRC's Singapore Institute for Clinical Sciences (SICS) and Institute of Medical Biology (IMB) try to conduct translational and clinical research to bridge the gap between bench and bedside.

iii) The Third Period (2011-2015): Capturing Opportunities for Greater Economic and Health Impact

The government tries to accelerate the current biotechnology cluster in order to capture the growing opportunities arising from global trends in the BMS industry. Recently the Singapore Biomedical Sciences Industry Partnership Office (BMS IPO) has been set-up to serve as the one-stop coordinating office between the various research agencies and performers.

Since 2000, BMS manufacturing output has increased by nearly five-fold from $6 billion in 2000 to $29.4 billion in 2012. Employment in the BMS manufacturing industry grew 2.5 times, from5,880 to 15,718 in the same period. In 2012, the value-added of the BMS industry rose to $15.3 billion, contributing 25.5% of total manufacturing value-added. BMS is now the largest value-added(Electronics 25%, Chemicals, 7.9%, Precision Engineering, 14.6%, Transport Engineering 15.7%, General Manufacturing Industries, 11.3%) contributor to the manufacturing sector in Singapore.

2) Geographical Space and clustering

As shown in Figure 1, in Singapore, some infrastructures were constructed with interval by way of

Table 1. Performance of the BMS industry (2000–12)

	2000	2004	2006	2008	2010	2012
Manufacturing Output (SGD billion)	6.3	17.5	23	19	22.8	29.4
Value Added (SGD billion)	3.8	9.8	13.6	9.1	10.2	15.4
No. of Employment	5,880	9,393	10,571	12,292	13,926	15,718

Source: EDB Singapore Website; Ministry of Trade and Industry Singapore, Website; Lim & Wei, 2010: 4

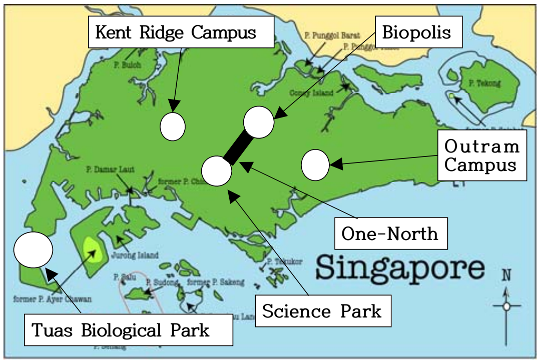

Figure 1. Map of Biotechnology Cluster in Singapore

government planning.

Firstly, in 1980, research agglomeration for general science was firstly builded up in Singapore. The Singapore Science Park (SSP) is one of the earliest parks founded in the Asia Pacific region. The government made a plan for the construction of the Science Park to provide an infrastructure for R&D, and recently the Science Park comprises working environment for an exclusive community of over 9,000 researchers, engineers and support staff. It is in close proximity to research and tertiary institutions such as the National University of Singapore (NUS), National University Hospital (NUH) and One-North. It was constructed not just for biotechnology sciences but high-technology industries such as Information Technology, Software Development, Telecommunications and Electronics.

Secondly, specified infrastructure for biotechnology was constructed, and called Biopolis. It is an research and development centre for biotechnology sciences located in One-North in Buona Vista. It provides space for research and development activities, and promotes peer review and collaboration among the private and public scientific community. It started in 2003 with seven buildings named Nanos, Genome, Helios, Chromos, Proteos, Matrix and Centros, Helios and Chromos were allocated for pharmaceutical and biotechnological companies, and the others were occupied by several government agencies, publicly funded research institutes. In 2013, there are 13 buildings with 3.5million square feet of space.

Thirdly, as a biotechnology manufacturing cluster, Tuas Biomedical Park (TBP) was constructed in the western end of Singapore. It supports not only physical infrastructures such as roads, power lines and telecommunications lines, not also 'plug-and-play' service that biomedical companies can set up manufacturing operations with minimal lead time. Currently, in TBP there are many well-known international firms including Merck, Novartis, Pfizer, Wyeth, Genentech and GlaxoSmithKline

Fourthly, Fusionopolis is opened in 2008, and it is a research and development complex located at the One-North business park. It houses various research organizations, high-tech companies, government agencies, retail outlets, and serviced apartments in one location. it supported an integrated space for working, living, playing and learning together. It is served by the One-north subway station connected to the basement of the building.

Universities are also viewed as an infrastructure in biotechnology cluster of Singapore. The main university is National University of Singapore (NUS) established in 1905, and it is the oldest and largest public university in Singapore. NUS has two campuses, Kent Ridge Campus and Outram Campus. The two campuses are closely related to clinical and translational research in biotechnology sciences. Singapore National University Hospital and Singapore General Hospital are located near the campuses respectively.

In Singapore's biotechnology cluster, One-North

Table 2. Two Campuses of NUS

Kent Ridge Campus	Outram Campus
- Singapore National University Hospital - Cancer Science Institute - Centre for Translational Medicine - National University Cancer Institute - National University Heart Centre	- Singapore General Hospital - National Cancer Centre - National Eye Centre - National Heart Centre - National Neuroscience Institute - Duke Graduate Medical School

should be mentioned. One-North, stylised as One-North, is a business area being a 200 hectares. It is designed to host a cluster of world-class research facilities and business space for Biomedical Sciences, Infocomm Technology (ICT), Media, Physical Sciences and Engineering. Therefore it combines educational institutes, residences and recreational amenities as well. One of the main aim in the construction of One-North is to create a community where expatriates and locals can gather to live, work and relax together in One-North.

4. Triple Helix of U-I-G Relations in Singapore

1) Universities

There are two major public universities closely related to biotechnology sciences in Singapore, which are National University of Singapore(NUS), Nanyang Technology University(NTU). NUS has played a main role in the area of medical sciences. The role of universities in the development of medical sciences in Singapore can be discussed in four parts, education, research, translational research and international research (Wong *et al*., 2010: 83-86).

In terms of education, the two universities have launched various programmes to support the manpower for the biotechnology cluster. Amongst them, the most ambitious program is a new medical school undertaken by NUS. The new school aimed at being professional medical school, and its students were recruited after postgraduate from various disciplines and faculties unlikely the existing medical school taking student from high school. Moreover, the new school was established in collaboration with Duke University of US, and is called the NUS-Duke Graduated Medical School (GMS). In 2001, NUS also established an Office of Life Sciences integrating and facilitating life science education and research in the university (Wong, 2007: 377). At the same year, NTU, Singapore's the second largest university, set up the school of Biological Sciences.

Secondly, NUS also supported various research programmes. the Office of Life Sciences has played a critical role in bringing together researchers from core faculties involved in life sciences, and new collaborations with other research institutions in the city and overseas were set up. In order to support the research of nano-engineering and boi-engineering, NUS organised the division of bio-engineering within the engineering faculty (Wong *et al*., 2010: 84).

Thirdly, the location of NUS's two campuses is closed to the large and main hospitals, General

Hospital and National University Hospital, and the physical proximity facilitates collaboration for translational research. The GMS also focuses on bringing up clinician scientist engaging in translational research. It located at Outram Campus being the Singapore General Hospital and the national research centres, which made it possible that researchers had access to specialized research support facilities.

Fourthly, an initiative for promoting international multidisciplinary research among Singapore universities was put in place by the National Research Foundation's Campus for Research Excellence and Technological Enterprise (CREATE). CREATE aimed to foster joint multidisciplinary research and linkages between top research universities and Singapore-based knowledge organizations. In 2007, the first research centre within CREATE was built on an existing relationship between Massachusetts Institute of Technology(MIT), NUS and NTU known as the Singapore-MIT Alliance (SMA), in which the three universities collaborate in graduate education and research. Since 2007, various alliance programmes have been launched with world famous universities such as Berkeley and Peking University (Official Website of CREATE).

2) Government

The approach to construct biotechnology cluster mainly controlled by government involves various initiatives such as establishing research infrastructure, supporting the industry, providing venture

Table 3. Summary of changes in the Triple-Helix of U-I-G relations for biotechnology cluster in Singapore

Triple-Helix Nexus	Up to the late-1990s	From 2000
Universities	Traditional model	Entrepreneurial model
	Compartment by traditional disciplines	Emergence of cross-disciplinary integration with university hospital.
	Ambiguous relationship with university hospital	New post-graduate medical school model introduced
Government	General policy in high technology industries	Specific policy for biomedical sciences
	General science park	Biopolis plan
	Public funding not significantly dedicated to BMS	Strategic public funding for BMS via BMRC
	General Venture Capital promotion	Sizable Venture Capital funding for BMS
	Scholarship not significantly targeted for students in BMS	Targeted scholarship for student in BMS
	General IP framework	Bio-ethics guideline
Firms	Primarily manufacturing operation	Continued expansion of R&D
	Recruitment for manufacturing operational needs	Recruitment for both manufacturing and R&D
	Relatively minor research sponsorship role	Increasing importance to support research
	Move in foreign multinational companies	Continued expansion of foreign multinational companies and their R&D activities

Source: summarized in Wong, 2007: 378

capital support and strengthening manpower capabilities. Four key agencies have worked in close coordination in order to support the BMS cluster.

The Biomedical Research Council (BMRC) of A*STAR[1)] supports public research and manages research institutions in Biopolis such as Institute of Medical Biology and Singapore Institute for Clinical Sciences. BMRC takes the lead in coordinating and funding public sector and academic research, as well as supporting the training of scientists.

The Economic Development Board's (EDB) Biomedical Sciences Group (BMSG) supports private sector manufacturing and R&D activities.

Bio*One Capital manages biomedical investment funds and makes strategic investments in companies with spin offs to Singapore.

The National Medical Research Council (NMRC) of The Ministry of Health's (MOH) funds and supports public research initiatives, as well as awards medical research fellowships for the development of medical research manpower. In 2006, the Ministry of Health established a new mandate to support translational and clinical research in areas where Singapore has great potential. With this in mind, NMRC's role became more important in the leading, promotion, co-ordinating and funding of medical research in Singapore.

Current biotechnology cluster in Singapore may be viewed as a result of long-standing efforts by the Singapore government. The government identified the aim of the policy and concentrated on the field of biotechnology sciences. It supported strategic public funding and venture capital for biotechnology sciences rather than general funding. The government provided not only infrastructure not also strategic policies such as incentives for biotechnology firms, scholarships and bio-ethic guidelines.

3) Firms

The biotechnology manufacturing in Singapore is largely dominated by foreign firms, in particular multinational companies such as GlaxoSmithKline, Schering-Plough, Pfizer, Wyeth-Ayest, Olympus, Philips Medical, etc. The majority of these firms are headquartered in the United States or European countries, and they established regional headquarters in Singapore.

The Singapore government, in particular EDB encouraged foreign companies to construct their R&D and clinical research centres in Singapore. It supported R&D infrastructure and accessible R&D resources from public research institutes and universities. Therefore, in Singapore, firms could easily operate the facilitations which might help manufacturing, and they also had R&D infrastructures.

The biotechnology industry is very capital intensive and risky as well. Therefore, it is needed start-ups to be to be supported in particular with fund. The government took a critical role in directly running funds for medical start-ups, which were centralized under one agent called Bio*One Capital.

From the viewpoint of firms, Singapore has several advantages as well as disadvantages. Singapore is very helpful in clinical research. There are seven public hospitals, six national speciality centres on cancer, cardiac, eye, skin, euroscience and dental care, and 16 private hospitals. It also has good amenities and infrastructure for research and interactions amongst researchers and medical doctors. Other advantages are that city's size and population with a mixture of several Asian ethic groups, which makes it possible for developing new treatments and technologies as well as drug trials customized to Asian(Wong *et al.* 2010: 81). However, Singapore has comparatively small domestic market for clinical trials comparing to other neighbor countries such as Taiwan, Japan and Australia, because of it, pharmaceutical firms may be reluctant to use the clinical trial centres in Singapore for an unproven track record (Finegold *et al*., 2004).

4) Characteristics in the developmental processes of the Triple Helix Nexus

This part investigates the triple helix of U-I-G relationships in terms of infrastructure, human resources and nourishment. These three different parts may help to understand the characteristics of the Singapore case because of the following reasons.

First of all, as Florida (1995) argues the importance of the knowledge and infrastructure in the innovative cluster and learning regions, the infrastructure for the cluster will be discussed.

> "… learning regions function as collectors and repositories of knowledge and ideas, and provide the underlying environment or infrastructure which facilitates the flow of knowledge, ideas and learning." (p. 527)

The infrastructure may be viewed as an essential element to enhance the regional triple helix of U-I-G relations in the cluster.

Secondly, retaining regionally based human resources, so called 'embeddness of human labour', can be viewed as a crucial factor to construct regional triple helix of U-I-G relations with the increasing emphasis of knowledge-based economy. Therefore, in the biotechnology cluster of Singapore, regional human resources should be examined.

Thirdly, as discussed earlier, the triple helix of U-I-G relations is unstable, and it can be stopped in some days if there is no the changing role in each helix and between helixes over time. It is needed to nourish for the helix being well operate in biotechnology cluster, therefore the nourishment for the development processes will be analysed.

Analysing the experience of Singapore with these three parts may helpful to grasp the dynamic and on-going features happening in the localised processes amongst university, government and industry. Moreover, this approach helps to identify the driving and binding forces of the triple helix model.

(1) Infrastructure

In order to create initial spark for the Triple Helix relations in a certain science cluster, infrastructures such as research institutions, facilities and estate for firms and reputed universities for students and researchers, are needed.

In terms of infrastructure, it is needed to look into JTC Corporation that, formerly the Jurong Town Corporation, is Singapore's principal developer and manager of industrial estates and their related facilities. It is a government agency under the Ministry of Trade and Industry. Most of biotechnology infrastructure such as Science Park, Biopolis and Fusionopolis was constructed by JTC. The role of JTC shows that to what extent the government involves in the construction of the cluster.

In Singapore, specialized infrastructure for biotechnology may be well explained with the Biopolis and the Tuas Biomedical Park. These are dedicated to support the biotechnology cluster, including medical science technology. The Tuas Biomedical Park is primarily focused on manufacturing activities, while the Biopolis is built specifically for R&D activities. The two-million square feet integrated

R&D complex provides state-of-the art facilities for medical companies near to research institutes and universities. Companies at the Biopolis can leverage on common facilities to lower R&D costs. These shared facilities include X-ray crystallography, nuclear magnetic resonance, electron microscopy, DNA sequencing as well as shared conference and teaching facilities. As for general infrastructure support, Singapore offers world-class logistics and supply chain management capabilities in Asia backed by international standard airport and seaport facilities.

The Singapore government has played an critical role in the construction of the infrastructure, as seen the case of JTC, most of the clustering were implemented by government planning.

(2) Human Resources

The small size of Singapore's population has raised some concerns about the shortage of local talents trained in biotechnology to meet the growing demands in this sector. Singapore government has recognized this shortcoming and has undertaken not only bringing up professional local researchers but also attracting excellent foreign researchers to address the manpower issue.

The government strategy to attract foreign famous scientists has resulted in recruiting junior scientists from their network and other young scientists from around the world under them. Moreover, the government provided the scholarships for top ranking local students, if they want to study in leading foreign universities for graduate science and business education, with a condition that they return to Singapore after their studies. A*STAR providing scholarships targets 1,000 trained PhDs by 2015 (Wong *et al*., 2010: 74-5).

The local manpower initiatives involve the active nurturing of local talents in biotechnology. The two leading universities in the country, National University of Singapore (NUS) and Nanyang Technological University (NTU), have both started their own bioengineering degree programs aimed at producing manpower cross trained in both engineering as well as biotechnology sciences. Additionally, the EDB's Biomedical Sciences Group also offers Training and Attachment Programs (TAP) in partnership with biotechnology companies to create positions for technicians and professionals to undergo on-the-job training in R&D, clinical research, and manufacturing practices locally or overseas. The government also supports the alliance between local universities and reputed foreign universities such as MIT, Johns Hopkins and Duke University, which may help local manpower. In addition, with respect to local manpower, one also cannot ignore the fact that Singapore does have a substantial pool of existing English-speaking and well-trained engineers with diverse expertise in electronics, materials and software en-

Table 4. R&D Manpower by Nationality in 2012

Sector	Nationality	Persons
Private Sector	Singaporean	16,844
	Foreigner	5,152
Government Sector	Singaporean	3,524
	Foreigner	282
High Education Sector	Singaporean	6,809
	Foreigner	8,114
Public Research Institutes	Singaporean	3,437
	Foreigner	839
Total	Singaporean	30,614
	Foreigner	14,387

* Singaporean includes not only singapore citizen but also permanent residents

Source: National Survey of R&D 2012 in Singapore, A*STAR(www.a-star.edu.sg) gineering that biotechnology companies can already tap into.

Table 4 shows that total researchers are 45,001 and 32% of them are foreigners. it means three amongst ten researchers are foreigner in Singapore's biotechnology industry. An interesting point is that in high education sector foreigners are 1,305 researchers more than Singaporean. The data implies that the degree of cooperation between government's initiatives and universities' performance.

(3) Nourishment

The biotechnology industry is capital intensive and risky compare to other industries. Therefore, the cluster needs a sustained flow of nutrients in order to support continuous growth. Since the government policies for the biotechnology cluster launched, it has offered a range of loans, incentives and financial assistance to attract foreign investment as well as to help enterprises grow their local businesses.

These incentives may be broadly classified into tax and non-tax incentives, which is seen in Table 5.

Table 5. Incentives and Grants Relevant to the Biotechnology Industry

Tax Incentives
○ Supporting Investment in Business Activities - Development Expansion Incentive (DEI): Tax reduction to encourage qualifying companies to expand their local operations, upgrade equipment and/or move into higher value-added business activities - Double Tax Deduction (DTD) for Internationalisation: Tax deduction to support local businesses' qualifying market development activities overseas. - Pioneer Incentive: Full corporate tax exemption on qualifying profits for up to 15 years for companies implementing strategic high value-added manufacturing or service projects. - Productivity and Innovation Credit (PIC): Tax deduction / cash incentive to encourage businesses to invest in qualifying activities that lead to improvement in innovation and productivity
○ Supporting Business Headquarters Activities - International Headquarters Award (IHQ): Tax reduction for companies managing their international headquarters activities such as strategic business planning and development, marketing control, planning and brand management and technical support services out of Singapore - Regional Headquarters Award (RHQ): Tax reduction for companies managing their Asia-Pacific headquarters activities such as strategic business planning and development, marketing control, planning and brand management and technical support services out of Singapore
○ Supporting Research and Development Activities - Liberalised Research & Development (R&D) Tax Deductions: Tax deduction on 150% of qualifying expenditure incurred on qualifying R&D activities performed in Singapore, both in-house and outsourced. - R&D Tax Allowance (RDA) Scheme: Tax allowance of up to S$150,000 to be deducted from a company's assessable income when profitable companies engage in qualifying R&D activities in Singapore.
○ Supporting New Venture Formation - Angel Investors Tax Deduction Scheme: 50% tax deduction for angel investors who invest at least S$100,000 in start-up companies and hold investment for a minimum period of 2 years. - Tax Exemption for Start-ups: Full tax exemption on the first S$100,000 and 50% exemption on the next S$200,000 of chargeable income for any first 3 consecutive years of tax assessment for start-up companies.

Non Tax Incentives
◯ Supporting Investment in Technology - Investment Allowance (IA): Allowance for purchase of qualifying equipment on hire purchases to improve efficiency or to introduce new technology to the industry.
◯ Supporting Research and Development Activities - R&D Incentive for Start-up Enterprises (RISE) Scheme: Cash grant of up to S$20,250 for at least S$150,000 worth of qualifying R&D expenses during the first 3 years of start-up activities. - Research Incentive Scheme for Companies (RISC): Grant on reimbursement basis to help defray cost of qualifying R&D activities in strategic areas leading to the local companies' improved industrial competitiveness - Technology for Enterprise Capability Upgrading Initiative (T-UP): Provides fund to cover up to 70% of costs to have a research scientist or engineer from A*STAR to be attached to a technology company to implement qualifying R&D projects. This initiative may be relevant to some biotechnology companies
◯ Supporting Manpower Capability Development - Precision Engineering (PE) Manpower Initiative: Training allowance for business to enrol their PE specialists into a 5-year structured in-employment PE training programme. This initiative may be relevant for some biotechnology companies.
◯ Supporting New Venture Formation - ACE Startups Grant: Singapore citizens or permanent residents receive up to S$50,000 matching grant from the government to start their first business. - Business Angel Funds: Investment by the pre-approved Business Angel group into seed or early stage start-up companies will be matched by SPRING SEED Capital Pte Ltd, a subsidiary of SPRING Singapore, for up to a maximum of S$1.5 million per investment. - Early-Stage Venture Funding Scheme (ESVF): Selected venture capital firms receive co-funding from the National Research Foundation (matching fund for up to S$10 million fund raised per VC) to invest in early-stage technology start-ups. - Incubator Development Programme (IDP): Provides up to 70% grant support to incubators and venture accelerators to encourage programmes to nurture start-ups and hiring of mentors and to offset operating expenses. - Startup Enterprise Development Scheme (SPRING SEEDS): Investment by private investor into start-up companies will be matched by SPRING SEED Capital Pte Ltd, a subsidiary of SPRING Singapore, up to a maximum of S$1 million per investment. - Technology Enterprise Commercialisation Scheme (TECS): Competitive grant to help individuals develop technology projects to a stage that may generate investors' interest, either via Proof of Concept or Proof of Value demonstration.
◯ Supporting Business Event in Singapore - Business Events in Singapore (BEiS) Fund: Qualifying Meeting, Incentives, Conventions & Exhibitions (MICE) projects will be offered a grant to offset a portion of the operating costs to organise the event.

Source: Singapore biotechnology Portal: www. biotechnology. sg; Lim & Wei, 2010: 5-10

They are usually administered by one of the economic and trade promotion agencies with the intention of encouraging the growth of biotechnology sector. The incentives make it possible that firms including start-ups choice the country as their main business site.

5. Conclusion and policy implications

This paper starts with the issue about the gap between theoretical consideration of the Triple Helix of U-I-G relations and the actual reality in biotechnology cluster, and the experience of Singapore was investigated. In terms of evolutionary perspective, biotechnology cluster in Singapore has gone through ongoing processes from a certain stage to other, and within the processes the Triple Helix nexus has been found.

Some conclusions can be drawn from the research questions and with reflections on the issues that were generated in the discussed literature and the experience of Singapore. With respect to the first question concerning the main actor in the triple helix of U-I-G relations, in Singapore the government has played a critical role in the development of biotechnology cluster. The government built up its agencies to support biotechnology industry, and it also provided facilities and various funding. Therefore, the government not only made a initial spark to the cluster, but also continuously promoted the developmental processes of it. The role of the government in Singapore is somewhat different from the theoretical framework of the Triple Helix Model which focuses on the role of universities. However, in many researches of biotechnology, government's role is stressed because the industry is knowledge and capital intensive characteristics (Rhee & Suk, 2014). Therefore, it was needed to exam the ways and degree of the government policies in order to compare the other case of biotechnology cluster. In the light of these considerations, the second question was raised.

The second question concerning the ways and degree in which the main actor leads the triple helix of U-I-G relations may be concluded from the above evidence explained in the specific features of the Singapore. The first concluding point is that the government implemented somewhat comprehensive policies including researchers immigration, student scholarship for local students, and tax and non-tax incentives for firms, rather than focusing on a targeted policy. These policies made it possible to collaborate universities and firms, and the stakeholders recognised the intention of the government that might help to construct trustful relation amongst them.

The second concluding point is that the government used direct as well as indirect policies to promote biotechnology cluster. One of indirect policies is the plan of One-North which aimed at the construction of research facilities and amenities for researchers.

Thirdly, in Singapore the state led the policies rather than regional or local government. In many countries such as Japan, USA, China and South Korea, there were some collaboration and conflict between central and local government. However, the Singapore, the city country, the central government dominantly controlled the policies.

In its final analysis, in Singapore, the binding forces for the Triple Helix nexus were critically decided by the role of the government from the stage of initial spark. Over time, the path of government dependancy has been maintained, which makes the government still plays an leading role in the triple helix of U-I-G relations.

The above conclusion leads us to the discussion of policy implications related to the triple helix of U-I-G relations. The first implication is the binding forces that the relations can be operated. If any country or region wants to construct the U-I-G relations, it should recognise the binding forces at the initial stage amongst the helices.

Secondly, generally the Triple Helix Model emphases the research capacities and human resources of regional universities for their supportive role as a knowledge stock. However, the experience of Singapore denotes that the innovative capacities of regional universities can be supported by the outside. In Singapore, reputed foreign universities such as Duke, MIT, Johns Hopkins University collaborated with domestic universities, which helps to enhance the research capacities.

This paper opens potential areas for further research, which are, at the same time, the limitations of the research. First of all, methodologically this research analysed the Triple Helix of U-I-G relations at the policy level, therefore, it could not grasp the interactive processes amongst the three helices. However, in order to catch the interaction of the trilateral relations, it is needed to obtain rich descriptions and explanations of interactive processes occurring through certain policies and within institutional context.

In additions, this paper studied the Singapore case from the perspective of the Triple Helix Model. But the comparison with other countries might produce a richer empirical knowledge theoretically and practically. The comparative research would be underpinned the comparison of different institutional setting and thickness with relation to the role of universities, government and firms.

Note

1) The Agency for Science, Technology and Research (A*STAR) is a statutory board under the Ministry of Trade and Industry of Singapore. It was established in 1991 to foster scientific research and talent for a knowledge-based Singapore.

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