MODERNIZATION OF THE HERBAL MEDICINE SECTOR: SCIENTIFIC RESEARCH NETWORKS AND CAPABILITIES IN SELECTED ECONOMIES

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MODERNIZATION OF THE HERBAL MEDICINE SECTOR: SCIENTIFIC RESEARCH NETWORKS AND CAPABILITIES IN SELECTED ECONOMIES

ABSTRACT

This study seeks to present a comprehensive overview of the research performance of the selected economies in relation to the herbal medicine sector. Additionally, this study aims to connect the concept of technology life cycle with the notions of convergence and UIG linkages. The study proposes that the structures of collaborative networks and comparative advantage influence the propensity for convergence in the technology life cycle which, in turn, dictates the ability of the innovation system to transition from one phase to the next. Technological convergence is defined as the unique, non-linear, complementary and cooperative step that blends incremental technology improvements from separate technological disciplines into new products that revolutionise markets (Kodama 2014). The study postulates that the herbal medicine sector transitions from one paradigm to the next as minor increments in scientific knowledge accumulate and take advantage of "windows of opportunity" to affect landscape changes in the technology life cycle. This is based on the configuration of actors in the research networks and the convergence of multiple streams of technology in developing new knowledge, and new technology. The study analyses trends in the technological life cycle in comparison with the growth in capacity in the various economies studied (Schmoch 2007). The study draws insight from case studies in Hong Kong, Malaysia, Singapore, Japan, South Korea, China and Taiwan. As the study is primarily concerned with the activity of scientists and researchers in the accumulation of knowledge and innovative capability in a science-based sector like herbal medicine, the study relies on a robust analysis of secondary data (scientific publications, patents and trademarks) as well as some qualitative data to generate the requisite insight into macro trends in the herbal medicine sector. This study first utilises broad descriptive indicators setting the scene for a global perspective of publications and patents in the herbal medicine sector, deriving inferences of the technology life cycle and patterns of convergence in the sector. This is followed by a focus on selected economies above as the most productive region; particularly measurements of growth, impact, capacity and comparative impact through indicators involving publications, patents and trademarks. The study also focuses on co-publication networks in the selected economies from East Asia. The study identified three archetypes of research network structures (university-centric, PRI-centric, and firm-centric) that are prevalent in the selected economies. The chapter also presents data projecting the core competencies in the herbal medicine sector and potential correspondence between publication and patent areas of specialisation. Qualitative insight into the configuration of research networks as well as the justification behind concerted research collaborations is also presented. Furthermore, the study also highlights the need for horizontal policies for sectoral development to transition from traditional phase to modernised phase followed by targeted policies to stimulate UIG linkages which would drive convergence in specific niche technologies.

Keywords: herbal medicine, technology life cycle, scientometrics, research linkages, convergence

MODENISASI SEKTOR PERUBATAN HERBA: RANGKAIAN PENYELIDIKAN SAINTIFIK DAN KEUPAYAANNYA DALAM EKONOMI TERPILIH

ABSTRAK

Kajian ini bertujuan untuk memberi gambaran keseluruhan yang lengkap tentang prestasi penyelidikan ekonomi terpilih yang berkaitan dengan sektor perubatan herba. Selain itu, kajian ini bertujuan untuk menghubungkan konsep kitaran hayat teknologi dengan gagasan tentang rangkaian penumpuan dan UIG. Kajian ini mencadangkan bahawa struktur rangkaian kerjasama dan keunggulan mempengaruhi kecenderungan untuk penumpuan dalam kitaran hayat teknologi dan seterusnya, menentukan keupayaan sistem inovasi untuk beralih dari satu fasa ke fasa seterusnya. Penumpuan teknologi ditakrifkan sebagai langkah unik, tidak linear, saling melengkapi dan koperatif yang menggabungkan penambahbaikan teknologi daripada disiplin teknologi yang berlainan ke dalam produk baru yang merevolusikan pasaran (Kodama 2014). Kajian itu mengemukakan peralihan sektor perubatan herba dari satu paradigma kepada paradigma seterusnya sebagai peningkatan kecil dalam himpunan pengetahuan saintifik dan memanfaatkan peluang untuk mempengaruhi perubahan landskap dalam kitaran hayat teknologi. Hal ini berdasarkan pola pemain dalam rangkaian penyelidikan dan penumpuan pelbagai aliran teknologi dalam membangunkan pengetahuan baru dan teknologi baru. Kajian ini menganalisis trend dalam kitaran hayat teknologi dan membandingkannya dengan pertumbuhan kapasiti dalam pelbagai ekonomi yang dikaji (Schmoch 2007). Kajian itu dapat menjelaskan kajian kes di Hong Kong, Malaysia, Singapura, Jepun, Korea Selatan, China dan Taiwan. Oleh sebab kajian ini menumpukan kepada aktiviti saintis dan penyelidik dalam pengumpulan pengetahuan dan keupayaan inovatif dalam sektor berasaskan sains seperti perubatan herba, maka kajian ini bergantung pada analisis yang

teguh data sekunder (penerbitan saintifik, paten dan tanda dagangan) serta beberapa data kualitatif bagi mendapatkan pemahaman yang diperlukan tentang trend makro di sektor perubatan herba. Di peringkat awal, kajian ini menggunakan penunjuk deskriptif yang meluas yang menetapkan perspektif global bagi penerbitan dan paten dalam sektor perubatan herba, untuk memperoleh kesimpulan tentang kitaran hayat teknologi dan pola penumpuan dalam sektor ini. Kemudiannya, ini diikuti dengan pemfokusan pada ekonomi terpilih yang dinyatakan di atas sebagai kawasan yang paling produktif terutamanya pengukuran pertumbuhan, impak, kapasiti dan kesan perbandingan melalui penunjuk yang melibatkan penerbitan, paten dan tanda dagangan. Kajian ini juga memberi tumpuan kepada rangkaian penerbitan bersama dalam ekonomi terpilih dari Asia Timur. Kajian ini mengenal pasti tiga contoh tipikal struktur jaringan penyelidikan (berpusatkan universiti, berpusatkan PRI, dan berpusatkan firma) yang banyak terdapat di negara-negara terpilih. Kajian ini turut menyajikan data yang memperlihatkan kecekapan teras dalam sektor perubatan herba dan kemungkinan hubungan antara bidang pengkhususan penerbitan dan paten. Penaakulan kualitatif ke dalam pola rangkaian penyelidikan serta justifikasi kolaborasi penyelidikan bersepadu juga dibentangkan. Selanjutnya, kajian ini juga mengutarakan keperluan polisi mendatar bagi pembangunan sektor untuk beralih dari fasa tradisional ke fasa moden dan diikuti oleh polisi yang disasarkan untuk merangsangkan hubungan UIG yang akan memacu penumpuan dalam teknologi khusus tertentu.

Kata kunci: perubatan herba, kitaran hayat teknologi, saintometrik, hubungan penyelidikan, penumpuan

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AIMST	Asian Institute of Medical, Science and Technology
CCMP	Committee on Chinese Medicine and Pharmacy
CUHK	Chinese University of Hong Kong
EPP	Entry Point Project
GMP	Good Manufacturing Practice
HKBU	Hong Kong Baptist University
HKU	Hong Kong University
IARC	International Agency for Research on Cancer
INPADOC	International Patent Documentation
IPC	International Patent Classification
KOM	Korean Oriental Medicine
MIGHT	Malaysian Industry-Government Group for High Technology
NKEA	National Key Economic Area
NTU	Nanyang Technological University
NUS	National University of Singapore
PEMANDU	Performance Management Delivery Unit
PRI	Public Research Institute
S&T	Science & Technology

SCIE	Thomson Reuters Science Citation Index Expanded
TCM	Traditional Chinese Medicine
TCMPB	Traditional Chinese Medicine Practitioners Board
UKM	National University of Malaysia
UM	University of Malaya
UMT	Universiti Malaysia Terengganu
USM	Universiti Sains Malaysia
UTM	Universiti Teknologi Malaysia
WHO	World Health Organization
WoS	Thomson Reuters Web of Science

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Since the early 1990s, there has been a sizeable focus on the development of sectors as innovation systems. Most authors highlighted the importance of the codified and tacit knowledge base as well as the relationships within these knowledge producers as a means for sectoral innovation development. Several distinguished authors have fleshed out sector specific themes and concepts that have formed the bedrock of the sectoral innovation system discourse (Geels, 2004; Klepper, 1996; Malerba, 2002; Utterback, 1994). Building on that, this study proposes to adapt sectoral innovation concepts utilising current science and technology indicators as a means to dissect and analyse convergence patterns and transitions in research and development in the sectoral innovation system of herbal medicine in Malaysia. Technological convergence (also known as technology 'fusion') has been identified as a unique non-linear, complementary, and cooperative step that blends incremental technology improvements from separate technological disciplines into new products that revolutionise markets (Kodama, 2014).

The past 60 years have seen a strong push for the modernization of herbal medicine. Modernization, in this case, refers to the scientific identification, cataloguing, and assessment (safety and efficacy) of components and products as well as the industrial upgrading of manufacturing capability and business practice for the purposes of export to international markets. Such efforts are designed to bring herbal medicine from 'traditional' to 'modernised' markets through modern procedures and manufacturing technologies. Basic academic research is vital to this process as peer-reviewed research published in reputable academic journals enhances the credibility of new drugs and health products, which in turn, builds the evidence base for the regulatory approval of said products (Quah, 2003). In that sense, modernization can also be interpreted as adherence to Western academic conventions; nonetheless, this is necessary as a means to internationalise the use of indigenous products.

The concept of herbal medicine in the Asian context carries with it a dual identity. Culturally speaking, it is associated with traditional medicine systems and generations of empirical knowhow that are subject to debate as to the veracity of its effectiveness. On the other hand, herbal medicine is also looked at as a systematic roadmap for the discovery – or rather, adaptability – of new drugs and therapies for modern medicine. The purpose of this project is to focus on the latter of these endeavours. The study sought to prove that the structures of collaborative networks and comparative advantage influence the propensity for convergence which, in turn, dictates the ability of the innovation system to transition from one phase to the next.

To spell it out plainly, the study investigates the role of science in the evolution of the herbal medicine sector. Apart from that, it is important to have a sense of the foundation of the modernization effort before delving into the crux of the study; thus, the study begins by exploring a broad perspective of traditional medicine in general.

1.2 UIG Linkages in Herbal Medicine

As science policies relevant to stimulating herbal medicine are administered, the study observed that the linkages between universities, government and industry are heavily emphasised. Traditionally, the role of pioneering product technology falls on industrial firms, profit-centric entities that bring technology applications to market with the state acting as facilitator, referee, and supporter whether in terms of funding, networking and collaborator (research and development) (Wong, 1999; Wong & Goh, 2015). However, in highly-regulated sectors with an infantile or relatively low-to-medium tech industry – such as traditional medicine – firm performance in knowledge building can be lacklustre, due to the high cost for research and development and the low likelihood of the return on investment. As a result of the absence or lack of highly innovative firms – due to high market and scientific uncertainty – the study argues that the role of academia and public research institutes is increased to compensate for the lack of participation from industrial firms in research and development.

For the purposes of this study, the study focuses on identifying capability and inter-firm organisation based on the network maps derived from the network analysis of the selected economies as well as the relative comparative advantage (Woolthuis et al., 2005).

The study noticed that the understanding of knowledge management and innovation in traditional medicine is generally confined to isolated case studies of national systems of traditional medicine. These are generally extensions to studies in the history of medicine, where the discussion is primarily focused on the viability of traditional medical systems and how it can coexist with conventional medicine within the context of a specific culture. To date, there is a gap in the literature with regard to traditional medicine innovation systems or an exploration of the knowledge production trajectory in traditional medicine despite its rapid modernization.

Academia, industry, and government exist in an evolving network of communication from which interactive learning and knowledge spill over occur leading to innovations which drive the advancement of technology industries (Caraça et al., 2009; Leydesdorff & Etzkowitz, 1998). The case of traditional medicine presents an interesting case study as the study notices varying strategies from the selected economies with regard to the development of research networks.

1.3 Transitions in the Technological Life Cycle and the Impact of Technological Convergence

Particularly in developing nations (as well as the diaspora of such ethnicities in developed countries), traditional medicine carries legitimacy based on cultural experience. Though the efficacy and safety of products might be disputed, market demand remains high as existing users value cultural legitimacy over scientific legitimacy. This paradox has led to a wave of scientific research agendas designed to alleviate concerns over the legitimacy of such products through scientific means resulting in the 'science push' phenomenon mentioned above. In that sense, both the "science push" and "market pull" were factors in triggering different evolutionary phases of the technological life cycle.

With regard to transitions, Geels (2004) discussed a model inspired by Kuhn's (1963) "Structure of Scientific Revolutions" that basically attributed the emergence of technological breakthroughs on "windows of opportunity" that appear based on factors outside of the scientific domain. Such windows of opportunity open up opportunities for catching up on latecomer economies (Lee & Malerba, 2017). With relation to the case study, the push from the WHO for the modernization of traditional medicine presented such a "window of opportunity" thereby propagating traditional medicine research in latecomer countries and accelerating such research agendas in first-mover countries. Notably, herbal medicines have been focused on mainly because it integrates into existing drug delivery practices and methodologies.

When it comes to technological life cycle, the study refers to the idea from Schmoch (2007) that tracked the trends for publications and patents over time. This sheds light on the research and development trends as well as the propensity of the economy for innovation. With respect to this case study of herbal medicine, the 'innovation chain' of producing products for commercial use largely depends on which class of technology specialisation that particular product belongs to. As a rough example, a focus on herbal pharmaceuticals would require expertise in molecular biology, chemical and genetic screening for drug discovery; pharmacology and toxicology for testing and standardisation, further clinical testing for regulatory approval, and biotechnological development for scaling up. However, for other nutritional supplements and beverages, the requirements are more straightforward. In this case, the study would hypothesise that a focus on pharmaceuticals and medical applications would take place in a matured phase of the technological life cycle with a high proportion of science-based technological advancement to alleviate the rate-limiting steps of herbal medicine research.

Thus, the study sees transitions as the emergence of 'windows of opportunity' that allows for the life cycle to move from one phase of development to another. In the same way that Kuhn describes the 'paradigm shift' and how one paradigm is incommensurable to another, so the transitions between different phases of development would elevate the comparative advantage of one economy from one level to another (Kuhn, 1963). This would essentially take the technological life cycle from one revolution to the next and so on and so forth.

The relationship between technological convergence and technological life cycles have yet to be explored in great detail in the literature. Based on the earlier hypothesis, one would argue that technological convergence is biased to specific product classes and the necessary product development processes attached to that specific class. This is where organisational and national strategies play a role in driving convergence, and thus the life cycle in a specific technology sector. The emphasis on specific herbs or diseases (in the quest to develop 'blockbuster drugs') has skewed funding for specific technology sectors that have the potential for higher gains. Such vertical investments in targeted sectors are necessary given the cost of drug development, though one could argue that such a 'top-down' approach would hamper diversification of innovation activity across the board and lead to a homogenisation of innovation pathways.

On the other hand, concentrated research and development in a specific field could also lead to technological spinoffs which could benefit other technological domains in the bio-based industries. Thus, the accumulation of a specific knowledge base has the potential to spill over into other subsectors. Thus the study argues that technological convergence has the potential to act as evolutionary catalysts in the technological life cycle.

In order to attain some insights on the modernization processes of traditional medicine in Asian economies, the study explores the changes in scientific knowledge and innovation landscape and key knowledge economies of traditional medicine of eight economies in the Asia Pacific region: China, South Korea, Japan, Taiwan, Hong Kong, Singapore, and Malaysia. The impetus for this study stems from the unique nature of the herbal medicine case study that combines the use of indigenous knowledge and modern science to achieve public health outcomes as well as market creation. Considering the global strategy to complement conventional medicine with traditional medicine products and treatments – as well as the large-scale research projects being carried out in this sector in the East Asian region – the study observes that there is significant interest in studying this sector from an innovation systems perspective. In addition, this study on herbal medicine is also compact enough to be used as a means to analyse the dynamics of scientific research and the technological and market diffusion, which may have implications for the way the literature interprets the transition of sectors from lab bench to products.

1.4 Analysing the Transition from Science to Market in Herbal Medicine

Technological advancement plays a crucial role in opening up novel areas of therapeutics in the pursuit of providing better healthcare. In their seminal paper, Nelson et al. (2011) argued that progress in three interacting, but partially independent paradigms need to be understood in order to gain a holistic perspective on biomedical advancement in specific diseases. Essentially, the evolution of medical know-how depends on the understanding of pathologies of specific diseases as well as the advance of technologies that provide new modalities of treatment and diagnosis and learning by clinical practice (Nelson et al., 2011).

In that sense, many of the technologies and processes developed for medical products (drugs, treatments, etc.) to be commercialised requires a range of scientific disciplines in order for it to meet the necessary regulatory requirements. These include – and are not limited to – expertise in biochemistry, pharmacology, toxicology, immunology, molecular biology, bioprocess engineering and bioinformatics. In other words, biomedical science provides a platform for the exploration of a multidisciplinary sector which is highly scientific and evidence-based. However, the challenge with mapping a multidisciplinary sector in scientometrics is that it requires novel methods of capturing data, as conventional publication and patent classification methods do not sufficiently represent the particular disciplines pertaining to a specific sector. Thus, this study proposes several methodologies proposed recently with some promise in demonstrating growth and value creation in the herbal medicine sector.

In this study, this mapping exercise takes one step further by attempting to predict potential niche applications in this field. As attaining technological capability for development becoming the dominant goal in public policymaking arena, policymakers and R&D managers of both public and private sectors sought to fashion a productive routine that is conducive to assimilate technology. While some executed a massive search program via implementing the perceived workable models that being inspired by successful few high tech industrial clusters, some capitalise on apparent core competencies of the economy and sought what technological knowledge bases to be bridged to allow the emergence of new industries. The entrepreneurial dynamism of the latter is evident for cases detailed in Wong et al. (2015b). The missing creative accumulation process of the former one may induce undesirable outcomes.

1.5 Research Questions and Objectives

There is limited information as to how the organisation University-Industry-Government (UIG) linkages and convergence affect the modernization of the herbal medicine sector in East Asia.

In order to address this problem, the key research questions of this study are:

- How the technology life cycle in herbal medicine evolved parallel to technological convergence in the sector?
- How has the landscape evolved with respect to innovative activities and government policy surrounding the herbal medicine industry in the selected economies?
- How has the University-Industry-Government (UIG) structure emerged in herbal medicine in the selected economies?

In order to answer those questions, the study established the following objectives:

- Analyse the development of technological convergence in comparison to the incidence of technological convergence in the herbal medicine sector.
- Assess the innovation landscape of the herbal medicine industry in selected Asian economies through bibliometric analysis, and comparative advantage analysis and government policies.

- Analyse the dominant UIG structures and determine the impact of translational research in herbal medicine. Synthesize a qualitative perspective on the evolution of institutions and linkages between University-Industry-Government.

1.6 Scope of the Study

This study frames the herbal medicine sector from the sectoral innovation perspective, with an emphasis on the interactions and network linkages between universities, industry, and government in developing scientific knowledge in herbal medicine (Malerba, 2002). The sectoral innovation system literature covers many different facets of innovation systems including institutions, processes of competition and interaction, agents, products, knowledge base, etc. What the study focuses on is how different actors contribute to the knowledge base utilising different basic technologies to create comparative advantage in their economy (Pavitt, 1984).

The study also analyses trends in the technological life cycle and how that compares with the growth in capacity in the various economies studied (Schmoch, 2007). In this case, the study looks at life cycle based on indicators derived from patent data, as patents are observed as a proxy for technological development, to draw some insight into the patterns of convergence within the sector. The timeframe of the study covers the years 1993 to 2016 as the introduction of policies and actors specific to herbal medicine in the selected economies emerged in the mid- 1990s (To be elaborated in **Section 2.2.2**). The study draws insight from case studies in Hong Kong, Malaysia, Singapore, Japan, South Korea, and China. The rationale behind this selection is to focus on the East Asian region where the certain economies have demonstrated some policy commitments to this sector in recent years (To be elaborated in **Section 2.2.2**).

The study concedes that there are many socio-cultural themes that are pertinent when discussing the herbal medicine sector, in particular with the issue of ownership and the misappropriation of indigenous knowledge (Amechi, 2015). There is an important discussion along these themes that is in the current literature; however, this study seeks to focus on the innovation aspect of herbal medicine in East Asia, where the herbal medicine system has been diffused into the conventional medical system prior to modernization, and is then brought into modern conventional medicine through science.

1.7 Organisation of the Study

This study is divided into seven chapters. Chapter one provides an overview of the study. In chapter two, the study looks at the relevant literature that inspired this study as well as the gap in the literature that the study is attempting to fill. Chapter three outlines the conceptual framework and also elaborates on the different methodologies utilised in this study. Chapter four expands on the relationship between technological convergence and innovative capability in the herbal medicine sector. Chapter five looks at the insights derived from the bibliometric analysis of patents, publications, and trademarks; identifying the key actors, and performance of the various case study economies. Chapter six looks at the analysis of research networks in the selected economies. Chapter seven summarises the study and provides policy implications.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The core of this study is heavily influenced by the discourse on sectoral innovation systems (Geels, 2004; Malerba, 2002), specifically to do with the role of knowledge producers which focuses on universities, government research institutes and industry in that order. As the study investigates the structures of collaborative networks and comparative advantage, and its ability to influence the propensity for convergence, as well as the ability of the innovation system to transition from one phase to the next; the study attempts to construct a dynamic perspective of the evolution of the innovation system in relation to the herbal medicine industry.

There are several themes that intertwined as the study presents the evolution of the herbal medicine sector from this perspective. The first is the concept of interactive learning and knowledge production which in this case is measured through bibliometric statistics, as well as network structures presented in the subsequent chapters. The study also posits the role of convergent research as a driver for innovative transition and investigates the role of government in stimulating such activities.

In this chapter, the study discusses the various sources that have inspired this perspective of the evolution on the herbal medicine sector.

Figure 2.1 summarises the main literature that will be discussed in this chapter that supports the conceptual framework that will be presented in more detail in **Chapter 3**. The roof of **Figure 2.1** relates to the overarching literature of innovation systems (national and sectoral) that acts as the foundation of the study. **Chapter 3** will discuss the three phases of development which are proposed in this study as introduced in **Section 3.2.1** (Traditional, Modernization, and Leading Edge). This study proposes that the configuration of UIG linkages acts as the driver from the first to the second phase and that convergence acts as the key to developing a leading edge sector. Underneath this evolution, this study has the literature of technology life cycle – characterised by the accumulation of scientometric metrics – that runs as the undercurrent for the technological development for herbal medicine.

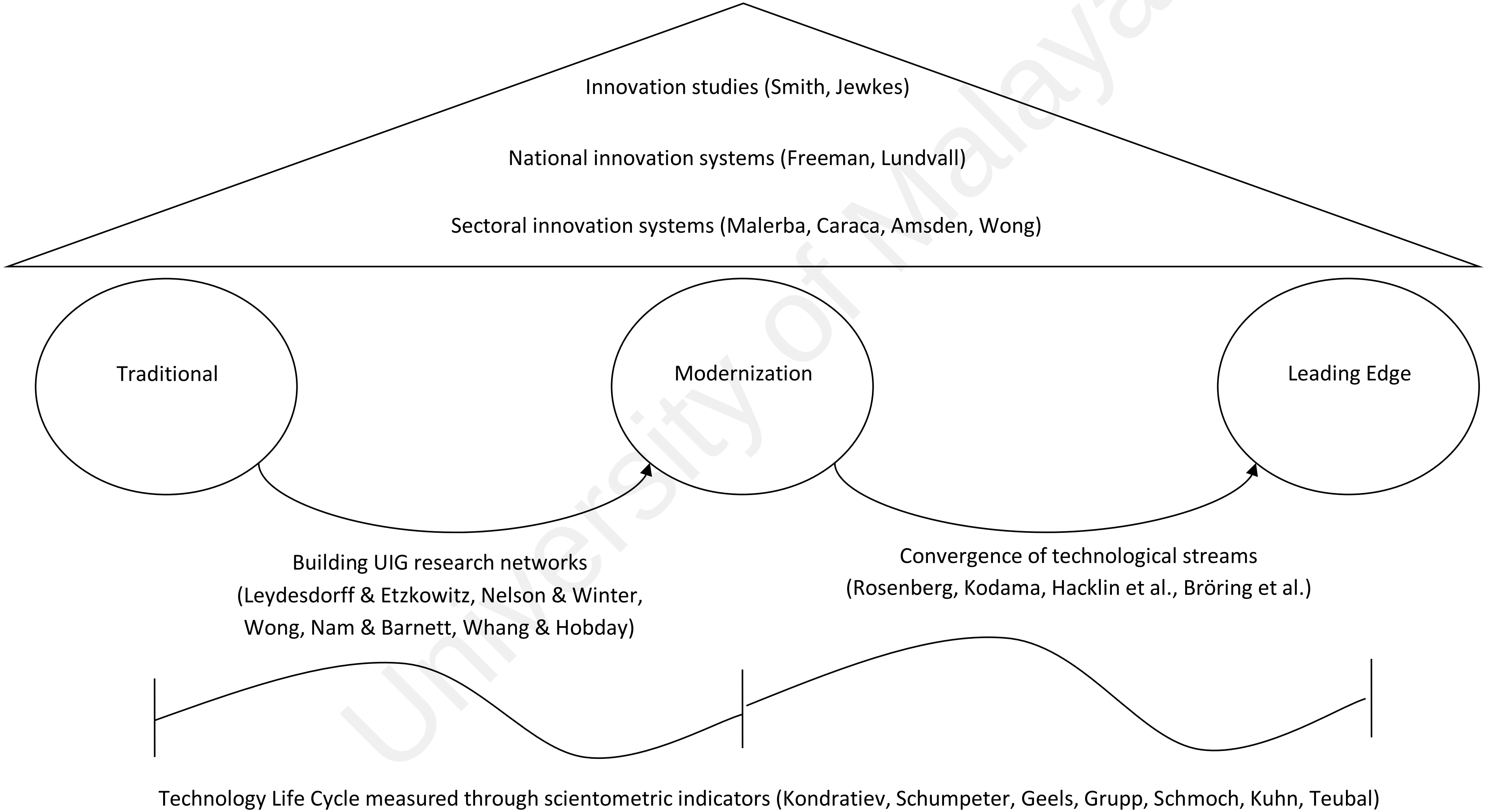


Figure 2.1: Summary of Literature Review

2.2 Introduction to Traditional Medicine in East and Southeast Asia

Traditional medicine finds its roots in the experiences of herbalists, medicine men, shamans, and physicians. Ancient systems of herbal medicine have been known to exist since more than 3000 years ago (World Health Organisation, 2005). The earliest known medical pharmacopoeia is the *Devine Farmer's Classic of Herbalism*, a compilation of Chinese traditional medical knowledge known to be existence for more than 2000 years (Xutian et al., 2009). Malaysia, as a multi-ethnic society, has several traditional medicine systems active within its borders. The indigenous, or Malay, traditional medicine system works in parallel with that of the large minorities of Chinese and Indian traditional medicine system – each of which has received recognition from the Ministry of Health.

Traditional Chinese medicine (TCM) remains one of the most developed traditional medicine systems currently available, encompassing a range of practices, such as qigong, acupuncture, moxibustion, cupping, as well as herbal remedies. TCM approaches the diagnosis and treatment of disease and injury from a unique ethos, expressed in terms of the balance of yin (represented by earth, cold, femininity) and yang (sky, heat and masculinity); controlled through 12 meridians which bring and channel energy (qi) (Engebretson, 2002, Xutian et al., 2009).

Traditional Korean medicine and Kampo, traditional Japanese medicine, are essentially offshoots of TCM (Institute of Natural Medicine, 2014; Kyung Hee University, 2014) though with certain modifications and use of indigenous herbs and medicinal plants. Korean medicine utilises a unique acupuncture technique such as Sa-am, Tae-guk, and hand acupuncture not found in TCM (Kyung Hee University, 2014). Malaysia's traditional medicine system is similar in that it uses indigenous herbs and massage therapy to promote balance in the body. Uniquely, Malaysia has a large Chinese and Indian minority and traditional medical systems have been intertwined with the various cultures to a certain extent.

The development and mass production of chemically synthesised drugs has revolutionised and standardised healthcare globally based on conventional Western medicine. Nonetheless, many non-Western (and Western) ethnicities still rely on traditional medicine for preventative care, as well as non-invasive therapy. In Africa (90%), India (70%) and China (40%) depend on traditional medicine to meet their healthcare needs (World Health Organization, 2005). Traditional medical therapies also exist in other cultures in Asia, Africa, and South America, though they have yet to penetrate into mainstream medical practice as much as TCM. TCM is currently widely used in China, Hong Kong, Taiwan and Singapore, economies with a predominantly ethnic Chinese population; and is used alongside conventional Western medicine as a complementary and alternative medication.

Herbal medicine research has come to the fore in the late 1990s as the 'biotech boom' was at its rhetorical peak. One of the key words bandied around that time was 'bio prospecting', the notion that there are countless active compounds in nature that may prove to be solutions to key challenges affecting the modern living. One of these key challenges is that of healthcare, which also provides an opportunity for Asian economies to tap into their indigenous knowledge of traditional medicine as a blueprint for targeted 'bio prospecting'. Thus far, there have been significant breakthroughs in this respect. These include – and are not confined to – the discovery of the anti-malaria drug artemisinin from the Chinese plant *Artemisia annua* by Youyou Tu et al. (2011), the isolation of the anti-cancer compound camptothecin from *Camptotheca acuminata*, by Wall et al. (1966), as well as the use of arsenic trioxide as a new adjuvant treatment for leukaemia (Shen et al., 1997).

The 'biotech boom' of the early 90s galvanised political will in several economies to pursue biotechnology programs to meet growing demand; China and Hong Kong in particular, were quick to promote Traditional Chinese Medicine (TCM) as a form of indigenous innovation (Chen, 2012). Nonetheless, the study speculates that the largest market for traditional medicine remains to be China. Thus, the Western market remains lucrative, but secondary, priority for the traditional medicine industry.

2.2.1 Herbal Medicine Development within the Context of Intergovernmental Cooperation on Traditional Medicine

The World Health Organization (WHO) acknowledges the role of traditional medicine as a complementary and alternative medicine for the improvement of public health. With a growing burden for public health, the WHO saw fit to announce the "*WHO Traditional Medicine Strategy 2014-2023*" in order to proactively support member nations in the development of the traditional medicine sector as a complementary and alternative medical system to conventional Western medicine (World Health Organization, 2013). The strategy was implemented in response to the Beijing Declaration on Traditional Medicine in 2008, which supported the safe and effective use of traditional medicine as well as the further development of traditional medicine through research and innovation (World Health Organization, 2008).

The documents referred to above mark the culmination of a long process of modernization and scientific acceptance of traditional medicine through national policies and interest groups particularly in Asia (World Health Organization, 2008; World Health Organization, 2013). In that sense, the traditional medicine subsector of herbal medicine warrants further study from an innovation paradigm as it is one of a few cases where a traditional knowledge base is being modernised heavily using scientific inquiry in order to meet regulatory standards for commercialisation and export.

In measuring the development of the traditional medicine, the WHO emphasises the need for there to be standards in quality, safety and efficacy in the manufacturing and administration of herbal medicines. The implementation of Good Manufacturing Practices (GMP) plays an important role in setting guidelines for quality assurance and has been adopted by several economies in the Western Pacific region including, China, Hong Kong (China), Japan, Malaysia, Republic of Korea, and Singapore. Several of these economies have also established national pharmacopoeias and research institutes for traditional and herbal medicine, as well as university and related training programmes in herbal medicine to ensure a standardised use of traditional medicine focused on safety and effectiveness (World Health Organization, 2012).

Across the Western Pacific region, the WHO reported an increase in government activities in establishing bodies, regulations and policy applicable to the management and promotion of traditional medicine in recent years (World Health Organization, 2012). This direction can be attributed to not just a desire to improve healthcare, but also to open up new economic opportunities in the traditional medicine services industry. The global herbal medicine market was valued at USD71.19 billion in 2016 and the annual industrial output for China listed on the herbal database Chinese Materia Medica was USD 47.84 billion in 2010 (Hexa Research, 2017; World Health Organization, 2012), which represents a 29.5% increase from the previous year. Similarly encouraging signs can be found in Japan, and South Korea. This trend points to a wide acceptance for traditional medical therapies, particularly in populations that are ethnically predisposed to accepting the ethos and practice of traditional medicine.

The introduction of traditional herbal medicine into Western economies remains a tricky one though there is a resurgence of interest in herbal medicines due to the popularity of holistic medical systems (Tyler, 2000). Consumers have shown to be positive to medicines that are 'natural' in origin rather than 'synthetic'; nonetheless, the main concern held by conventional Western medical practitioners is the lack of demonstrated efficacy using modern scientific investigations (International Agency for Research on

Cancer, 2002). Conventional pharmaceuticals adhere to a strict protocol of, not just GMP, but also a string of clinical trials that are vetted and published in established medical journals. This way, the body of evidence is documented and measurable thus lending the product the credibility necessary for mass consumption.

2.2.2 Modernization of Herbal Medicine

The study observed that different countries (termed as economies for this study as Hong Kong is considered as a separate economy) have different approaches and timelines to modernising their herbal medicine tradition though with similar themes. The majority of China's TCM institutes of higher learning were established in the 1950s, and by the 1990s, there were almost 3,000 TCM-specialised hospitals while 95% of Western medicine hospitals in China had TCM units (Xu et al., 2013). Xu et al. (2013) also reports that by the end of the 2000s, China had 32 education institutes specialising in TCM and an additional 52 with TCM majors, with some 270,000 students in training at all levels. Hong Kong passed the Chinese Medicine Bill in 1999 after a series of consultations beginning in 1989 (Chinese Medicine Division, 2010). The research was led by three of Hong Kong's leading universities who subsequently established research centres in TCM, with strong government support. Though primary healthcare in Hong Kong is still very much dominated by conventional Western medicine, the city state does exhibit medical pluralism – the coexistence of both Western and traditional medicine, supported by both the SAR and Beijing government (Chung et al., 2011).

Taiwan also has shown a strong commitment to modernising TCM and incorporating it with primary health care through the Committee on Chinese Medicine and Pharmacy (CCMP) under the Department of Health which has evolved into the Ministry of Health and Welfare, established in 1995. Chi et al. (1996) noted the advanced development in the modernization of processes among TCM practitioners in their analysis of Chinese medical practitioners, and the wide public acceptance in Taiwan for TCM once the national insurance infrastructure embraced TCM.

Traditional medicine in Korea and Japan is primarily adapted from TCM, though it has evolved into what is known as Traditional Korean Medicine and Kampo respectively (Institute of Natural Medicine, 2014; Kyung Hee University, 2014). Singapore also show promise in developing their traditional medical systems. Singapore has an ethnic Chinese majority and has established their Traditional Chinese Medicine Practitioners Board (TCMPB) in 2000 (Traditional Chinese Medicine Practitioners Board, 2011). Additionally, Singapore has a strong biomedical research backbone that – though is largely centered on modern conventional medicine – has spilled over to TCM to a certain extent.

Malaysia, on the other hand, is a late entrant in the traditional medicine sector. A multicultural economy with a sizeable Chinese minority, Malaysia has shown political will in exploiting the traditional knowledge of the indigenous population through the establishment of the Malaysian Herbal Corporation in 2001, under the supervision of the Malaysian Industry-Government Group for High Technology (MIGHT). The herbal industry was identified to be a potential industry group under the Specialty Natural Products Industry under the Third National Agricultural Policy (1998-2010). Eventually, the Economic Transformation Programme, launched in 2010 by the Performance Management Delivery Unit (PEMANDU) under the Prime Minister's Office, listed High Value Herbal Products under the Entry Point Project I (EPP1) under the Agriculture National Key Economic Area (NKEA) (Performance Management Unit 2010).

The WHO has reported the presence of traditional medicine policies in 69 member states and regulatory policies in 119 member states (World Health Organization, 2013). Of these member states, there have been 73 national research centres in traditional medicine established including those in herbal medicine. WHO Collaborating Centres on Traditional Medicine can be found in the US, Norway, Italy, India, Australia, China, Hong Kong, Macau, Japan, South Korea, and Vietnam. In most of these cases, the main policies aimed at promoting the herbal medicine sector is particularly driven towards regulation and promoting awareness.

As stated in **Section 1.6**, this study concerns itself with technological development and policies designed to stimulate innovation and collaboration between actors in countries for the advancement of herbal medicine. This study selected China, Hong Kong, Japan, South Korea, Taiwan, Malaysia and Singapore as its collection of economies. Each has their own policies and vehicles for developing herbal medicine and have shown activity in both scientific research as well as technology development. As an example, China spells out traditional Chinese medicine as a focal point of their research agenda, which goes a long way in freeing up resources and mobilising human capital towards research and development in herbal medicine as compared to other countries that lack such focus.

However, there are some isolated cases where there is government intervention in promoting herbal medicine as an economic driver. In India, the Indian Systems of Medicine have been thoroughly researched through universities and research institutions through the National Ayush Mission by the Ministry of Health and Family Welfare (Department of Ayush, n.d.). Nonetheless, this initiative is driven towards driving the establishment of such clinics in various parts of India to promote use.

In regions such as North America, Europe and Oceania, herbal medicine is not spelled out in their economic policies but are researched on in independent institutions. Nonetheless, these economies also serve as thought leaders in herbal medicine research and are active in conducting research on new products as part of their regulatory activities.

The WHO has noted that there is significant activity in the African region surrounding traditional medicine ranging from raising awareness, research, to commercialisation (WHO, 2013). 22 countries have been noted to be running research on traditional medicine sources for current diseases as well as running training programs in adherence to WHO guidelines (WHO, 2013).

2.3 Elements of the Sectoral Innovation System

Before the discussion on sectoral innovation system literature, it is important to review the innovation system literature, in general, to set the scene for the conceptual framework of this study.

The idea of technological innovation as a driver for economic growth has been a part of the literature since the time of Adam Smith's *Wealth of Nations*, which highlights the discussion of 'improvements in machinery' and divisions of labour as promoters of specialized inventions. Various authors have expounded on the role of technical innovation as central to capital goods and progress to the economy, though it was only in the 1950s when Jewkes and colleagues (1969), in their classical study *The Sources of Invention*, outlined a series of inventions from the 19^{th} and 20^{th} century that highlights the activities and products of industrial research and inventions in order to discuss the causes and consequences of industrial innovation.

Freeman & Soete (1997) expanded on the concept of the research and development system which is a small, but central element to the wide complex of 'information' industries. Without undervaluing the contribution of education systems, vocational training, information services and mass media; professional research and development and other such technical activities have been lauded as "perhaps the most important social and economic change in twentieth-century industry" (Freeman & Soete, 1997, pg 5).

This leads to the concentrated attention in the formation of new scientific ideas, inventions and innovations; and with that, national science and technology policies, the diffusion of technical change, the variety of science and technology services and the various activities that promote efficiency in science and technology activities (Asheim et al., 2011; Freeman & Soete, 1997; Hobday, 1998).

The concept of the national innovation system was also put forward a few years prior to this (Lundvall, 1992). Built on the assumption that technology develops in a certain direction – neither totally accidental nor predetermined – but with a strong degree of randomness that will always remain. As the research and development system becomes professionalised and more complex with the convergence of separate sets of knowledge, the idea of factory-level process innovation becomes obscured by the challenge of science-based innovation which requires more resources and specialised knowledge.

This is where the state and the public sector play a significant role. Though most of the national innovation system literature is focused on the internal organisation of private firms – particularly their flow of information, learning processes and innovative capability – the public sector also plays an important role in supporting science and development, as well as enforcing regulations and standards (Lundvall, 1992). Thus, the process of innovation is particularly affected by the interactions between various actors in the public sector as well as the private sector.

The sectoral innovation system literature points out several salient factors that contribute to its success (Malerba, 2002). What this study is primarily concerned with is knowledge capabilities, where systems may be locked into existing technologies due to the lack of learning capability or manpower, thus not being able to progress into more advanced technologies (Malerba, 2002; Smith, 1999). This is particularly true for the case of indigenous technologies and traditional knowledge where economies are forced to rely on local capabilities in order to bring products to market, as opposed to imported technologies or knowledge that has been developed elsewhere.

The classic building blocks of the sectoral innovation system of actors, links, learning processes and institutions figure heavily in the synthesis of the dynamics of the herbal medicine sector in this study (Malerba, 2002). The sectoral innovation framework sits on a foundation that includes literature on change and transformation related to industry life cycles (Klepper, 1996; Utterback, 1994); links and interdependencies and innovation systems (Lundvall, 1992).

It is also important to refer to Pavitt's taxonomy (1984) which refers to a classification of sectors based on sources of innovation and appropriability mechanisms. As opposed to supplier dominated sectors, scale intensive sectors, and specialised suppliers; this study views the herbal medicine sector as a science-based sector, characterised by a high rate of internal R&D, and scientific research done at universities and public research laboratories.

However, the unique feature of this sector is the existence of two separate classes of firms: the traditional firm that utilises time-honoured products and processes, and the modern firm that brings laboratory-derived products to market. Thus the study proposes two forms of science-based firms – one which uses science to discover and produce new products (modern) and another that uses science to validate and improve existing products (traditional). Both utilise similar learning mechanisms and interact with universities and public research institutes to conduct research, but to varying degrees based on personal networks and availability of funding for the specific materials.

The synthesis presented in this study sought to map the impact of collaboration and convergence patterns on the transition and evolutionary process of the herbal medicine industry.

Caraça et al. (2009) proposed a multi-channel interactive learning model which portrays the innovation landscape as intertwining loops of relationships between firms, research institutions and market forces. One strategy to streamline this is through academic collaboration with local and foreign universities/institutes, thus stimulating knowledge flow; sharing of resources and building of personal networks; all of which have contributed to the health of the innovation system. This can be visualised using network analysis of bibliometric data, focusing on co-authorship.

The development and build capability of local entrepreneurs is crucial to the sustainable development of indigenous production capacity, which will, in turn, lead to the enhanced continuous cycles of science and technology evidenced by statistics taken from scientometric data (publications and patents) (Amsden, 1989; Wong & Goh, 2015). Thus, local universities and PRIs play a crucial role in developing knowledge workers and entrepreneurs that will spearhead this industry through their research activity and a pool of active researchers or staff.

2.4 The Significance of Scientometric Indicators in Measuring Technology Life Cycle

This study leans heavily on insights derived from scientometric data, namely scientific publications, patents and trademarks as a means to measure the technology life cycle. As the study is primarily concerned with the activity of scientists and researchers in the accumulation of knowledge and innovative capability in a science-based sector like herbal medicine, a robust analysis of scientometric data would be able to generate the requisite insight into macro trends in the herbal medicine sector.

Scientific publications, primarily produced in universities and public research institutes, indicate the production of credible scientific knowledge. The rigorous peer-review process which accompanies scientific publication would also indicate credibility and transparency on the part of the knowledge producer, thus the production of scientific publications remain a significant activity for researchers and scientists. The Thomson Reuters Web of Science (WoS) is noted for its widespread international use in rating the research output of scientists in every discipline (Lazzeretti et al., 2014). Although research in traditional medicine does not necessarily follow Western conventions, the study argues that the modernization efforts of the various economies in question stem from a desire to enable TM products to cross over to global markets, which would put pressure on research institutes and scientists to publish in reputable journals in English, which makes the WoS database a relevant source of data for bibliometric data.

Nonetheless, the underlying purpose of the development of the herbal medicine industry is not just for the enhancement of public health but also for the development of a potentially lucrative commercial export market, which is inherently Asian. Thus, the development of innovation capabilities cannot be taken lightly. The significance of patent data has had a long legacy in innovation studies as a means to study technology diffusion and innovation at national, sectoral and regional level (Archibugi, 1992). The various patent databases available are compiled based on INPADOC families which allows for the reduction of duplicates (Pavitt, 1984).

Trademarks are an essential process in intellectual property protection to protect the identity and product of any business and indicate commercial activities and capabilities of firms in regulated markets. In the case of herbal or traditional medicine, a trademark registration can be used as a proxy to determine an economy's footprint in the US market within a certain industrial sector (Mendonca et al., 2004). The primary actors, in this case, that would be involved in trademarks are business firms who have viable commercial products ready to penetrate into the US market. Trademark data was sourced from the United States Patent and Trademark Office (USPTO). The purpose of utilising the

USPTO as a source is to understand the diffusion of traditional medicine products into the US market, which this study considers as the largest and most highly-regulated Western market.

This study observes that there are basically two major types[1] of bibliometric approaches that have been used to identify the core competencies of a technological system and its prospect for development. One of the types utilise joint-publishing and joint-patenting data to map the innovation system network (Leydesdorff & Meyer, 2007; Wagner & Leydesdorff, 2005, Wong et al., 2007) and provide policy inference for emerging technologies via examining the research fields that led to collaboration between scientists performing research and those performing productive activities. Joint-publishing or joint-patenting are instances where multiple organisations collaborate and have their affiliations listed as the authors, inventors or assignees of the publication or patent. They can extend their study on potential emerging technologies via assessing the impact (through statistics on publication, patents and citations) of particular scientific findings or inventions (Fagerberg, et al., 2012; Leydesdorff & Gauthier, 1996; Porter et al., 2005; Tijssen & Leeuwen, 2006). Such an approach provides important information to policy makers, particularly those from developed countries[2] to target and mobilise resources to support the development of emerging technologies. However, such an approach may not be of help to those from the developing economies where joint-publishing[3] and joint-patenting activities are not common. Many capable agents of innovation in the developing world tend to produce "sole-owned" sort of patents ownership and perform scientific research with their peers. University-industry links in the developing world (Wong and Salmin, 2016) may be found inadequate to allow agents of innovation to perform in high-

[1] Be noted that there are other non-bibliometric approaches (e.g. exploring the kind university-industry joint research activities/investment or understanding the type of export from trade data) used to study the core competencies and capability of different kind of science and technological system (see Porter et al., 2005 and Wong et al. ,2013, 2015a).

[2] Routinized joint publishing and joint patenting activities between industrial players, university scientists and researchers from public research institution are common in the context of industrialized countries (Tijssenet, al. 2009, Wong and Singh, 2013 and Shiu, et al. 2014).

[3] See CWTS Leiden ranking on impact and collaboration at www.leidenranking.com/ranking/2015.

technology science-based sectors as the mismatch between science (push) and technology (pull) is prevalent in the context of developing economies.

Grupp et al. (1998) expanded on the merits of measuring the science base of technology in order to track the technological spillover effect of scientific knowledge into inventions, which are tracked as patents. Typically, scholars would track a patent's non-patent references in order to identify scientific influence within a patent. Thus, this study can track the flow of knowledge from scientific literature to patent literature. Grupp (1998) also employed a coarse concordance to tie the patent technological specialisations to existing product classes in order to gauge the potential economic impact.

Another type of bibliometric approach utilises correlative indicators in assessing the potentials or emerging technologies. This approach sought to connect fields in scientific classification of bibliometric measure with fields in technological classification of patent statistics. The connection leads to lists of correspondence (termed as concordance tables) and metrics that reflect the links between science, technology and industrial outputs (Grupp, 1998, p. 167).

Thus, the study believes that there is much value in employing a scientometric approach –analysing indicators that measure scientific/innovative activity to draw conclusions with regard to the overall system – to analyse the growth of this industry across several active nations, considering observations in knowledge production which will be elaborated in detail. A scientometric approach utilises readily available data which indicate innovative activities, allowing this study to identify key actors based on their productivity in knowledge production and innovation and contrast the development stages of different economies. This permits the link between government policy instruments and research institutes within the modernization process.

2.5 Technology Life Cycle

For the purposes of this study, the technological life cycle is defined as the accumulation of the relevant knowledge base and technologies in the development of a specific sector (Schmoch, 2007, Utterback & Abernathy, 1975). Several authors have linked long-term economic growth with the rise and fall of technologies (Kondratiev, 1925).

Geels (2004) argued that small increments in technological advancement eventually accumulate to affect landscape changes in the socio-technical regime. This concept borrows heavily from the work of Kuhn (1963) in “The Structure of Scientific Revolutions” that observes the accumulation of anomalies in “normal science” that eventually lead to a “crisis” which, in turn, would affect a paradigm shift in the science in question. The study draws several parallels between these observations in philosophy of science and adapts that to the case of herbal medicine.

Grupp (1998) argued that science-driven markets are accompanied at all stages by high scientific activity. This is highly influenced by institutions within the innovation system that translates scientific research into technological innovation (Malerba, 2002). The continued generation of knowledge through scientific research is imperative for actors who are looking to develop a leading edge over others. It is the activities of these actors that contribute to the process of creative accumulation that ultimately leads to the creation of a ‘virtuous cycle’ of development.

Schmoch (2007) argues that technological innovation follows a ‘double boom’ cycle; the first attributed to a ‘science push’ based on curiosity and experimentation, which is followed by a second boom fuelled by ‘market pull’ that is mainly focused in applied research for commercial gain. This is based on his analysis of scientometric data (publications and patents) which Schmoch (2007) conducted his research on complex, science-based technologies (specifically ‘robotics’ and ‘immobilised enzymes’) through the relevant International Patent Classification subclass. This indicates a relative impact of science on technology, the presence of non-linear characteristics and feedback loops (Schmoch, 2007).

2.6 The Role of University-Industry-Government Linkages within the Sectoral Innovation System

The concept of hierarchies and network structures has been an oft-discussed topic in the literature. Geertz (1963) discussed the economic development of two Indonesian cities highlighting the 'verticality' of relationships between merchants and the role of the elites in dictating market dynamics. The vertical – or rather, authoritative – structured network has been a hallmark of East Asian national innovation systems and has been well documented in cases such as that of South Korean *chaebols* (Hamilton & Feenstra, 1995; Kim, 1997) or the Japanese *keiretsu* (Gerlach, 1992). In these cases, the large firms at the top of the hierarchy exercise a high degree of control over the supporting industries and services.

Nonetheless, in science-based industries, it is imperative that commercial enterprises and public entities work together to create both economic value and public good. The triple helix model that surfaced in the 1990s highlighted the interaction between academia, industry and government in an intertwining dynamic that acts as a laboratory for knowledge-based economic development (Leydesdorff & Etzkowitz, 1998).

The role of the university as a source of academic entrepreneurship has been covered in greater detail by Wong (2011) and Etzkowitz (2003) highlighting the emergence of university technology transfer and commercialisation in Asia. Universities also act as an immediate conduit linking state intervention with scientific research, due to the presence of existing research clusters in the respective fields of indigenous technologies. Public research institutes (PRIs) are also key actors in this network, though quite different from universities as they are primarily interested in developing industrial applications and meeting local or export demand (Foray, 2004, pp. 193-195).

The strategic development of the traditional medicine industry occurred concurrently with the case studies described by Etzkowitz et al. (2000) in the late 1980s to 1990s. The passing of the Bayh Dole Act in 1980 triggered a chain reaction for universities around the globe to adopt an entrepreneurial perspective on science and research (Mowery & Sampat, 2005; Wong & Salmin, 2016). Universities thus play a three-pronged role, as institutions for higher learning providing graduates to meet human capital requirements of the industry, for research activities and the creation of knowledge; as well as an incubator for the commercial application of said research activities.

Hence, as opposed to the local market demand becoming the 'test bed' for industrial transition (Whang & Hobday, 2011), this study argues that universities and PRIs assume that role for the purposes of path creation, identification of commonalities and as a vehicle for State intervention in building technological competence. Through traditional academic processes of peer review and academic publication, products and therapies are evaluated for their efficacy and safety, which in turn proves validity in meeting regulatory standards (Sismondo, 2009).

However, depending on the State's willingness to dispense resources to universities as champions of the technology in question. With the presence of highly-centralized regimes in Asia, this study argues that there is a stronger emphasis on the formation and empowerment of PRIs as vehicles for sectoral growth and to a lesser degree universities (Chen & Kenney, 2007).

Ultimately, the State would commit to developing a conducive environment where such public research institutes can spin off their research into either state-owned or private enterprises that will focus on commercialisation. Therefore, this study projects that the ultimate goal for the innovation system is to be firm-based with high collaboration between firms, universities, and PRIs (Lundvall, 2010; Malerba, 2002). This has been documented in various case studies in Taiwan, South Korea and Japan, and remains a template for innovation in Asia (Mazzoleni & Nelson, 2007; Wong et al., 2015b; Chen & Sewell, 1996).

Nelson & Winter (1982) argued that technological change is incremental, consisting of small steps built into established practice resulting in an accumulation of evidence that would eventually lead to technological change. The field of herbal medicine is one such sector as the high regulatory standards hamper the introduction of disruptive, radical innovation. In some cases, the introduction or convergence of new technologies in certain areas of the value chain will necessitate a landscape change; however, this is traditionally held by leading organisations as they possess the resources (equipment, facilities, human capital, etc.) to exploit such opportunities (Chandler, 1992). This is especially true in the case of herbal medicine, as organisations with a highly developed research protocol for drug discovery are highly sought after within the region for their expertise and know-how.

This status quo hampers the traditional Schumpeterian forces of creative destruction (1942), where new firms with new technologies are at a disadvantage as their competitive advantage get eroded by the lead time required to penetrate the market. Moreover, the cost of bringing a product to market in this case, is very high, as the materials and services required to adhere to the regulatory standards require a significant amount of investment with a high degree of risk, particularly in the field of herbal medicine. Kuhn (1963) noted that ‘normal science’ is characterised by scholars observing phenomena in the natural order within a set of accepted rules, which elegantly sums up the current process of herbal medicine research. However, this stage of research is typified by confusion and anomalies, particularly in the life sciences.

Network analysis has been utilised in the past for the purposes of measuring the diffusion of technology and theorising university-industry relations in high tech sectors such as biotechnology as well as in assessing scientific excellence at a macro level (Bornmann et al. 2015; Leydesdorff, 2004; Rogers, 2010; Valente, 2010). It has also been used to describe trends in the globalisation of technology through intellectual property analysis (Nam & Barnett, 2011). In this case, Nam & Barnett (2011) demonstrated the use of patent and trademark data in understanding how intellectual property networks change longitudinally.

This is tied closely to 'strong network failures' (Carlsson & Jacobsson, 1997) which highlights potential 'blind spots' in technology development due to actors being too closed and unaware of outside developments. Franceschet (2011) has also utilised this methodology, referred to as network science, to study the co-authorship as a proxy for collaboration among scientists; which are generally associated with higher quality, impact and productivity (Kronegger et al., 2014).

Malerba (2002) expanded on the role of links and complementarities, particularly in a sector where firms are generally heterogeneous. This has been expanded upon utilising network analyses and bibliometrics to visualise sectoral collaboration in biomedical research in Vancouver (Lander, 2013). The same can be applied to the field of traditional medicine which generally see a convergence of knowledge workers from chemistry, pharmacology, medical science and biotechnology.

Nonetheless, the development of technological innovation systems, such as herbal medicine, is exposed to potential pitfalls that can be deduced from network characteristics (Hafsi & Hu, 2016). Although the topic of innovation system failures has been covered extensively (Arrow, 1962; Weber & Rohracher, 2012), Woolthuis et al. (2005) outlined a framework that incorporated the systemic imperfections observed by various authors, otherwise known as the system failure framework, specific to institutional networks. There has been recent work that looks at building a typology of network archetypes. Tatarynowicz et al. (2016) looked at various network types in explaining inter-organisational structures which is similar to the approach used in this study. Tatarynowicz et al. (2016) investigated several configurations of networks that contributed to the dynamics of technology development proposing an association between the characteristics of actors and the processes of network formation.

2.7 Convergence

This study argues that convergence is a driver for technological life cycle and is facilitated by linkages between diverse actors and research units that contribute to the development of new niches. It was first attributed to Rosenberg (1976) in relation to the machine tool industry. Convergence refers to the blurring of boundaries between industries, disciplines and sectors and has been often studied in relation to the Information and Communication Technologies (ICT) (Hacklin et al., 2009). Technological convergence has also been proposed as the result of a dominant design integrating distinct knowledge or innovation from another technology or industry sector (Gauch & Blind, 2015). Though notions of technological convergence have been primarily based in the ICT domain, there are parallels that can be drawn to the health innovation sector.

The concept of technological convergence has also been linked with the concept of technological advancement in biomedicine; with Balser & Baruchin (2008) arguing that many of the rate-limiting steps in biomedical research rest in the interstices between biomedical sciences and classical scientific disciplines such as physics, chemistry, engineering and mathematics. This is echoed by Steinmueller (1996) that also argued for continued research in how different technologies interact in cross-disciplinary or multi-disciplinary research. Bröring et al. (2006) also studied the convergence of different R&D competencies in the food and pharmaceutical industries in the development of the nutraceutical and functional food industries.

2.8 Linking Science, Technology and Economy

The link between scientific activity, technological advancement and economic impact is a difficult relationship to quantify. The link between technological advancement and economic impact has been closely studied as far back as the Industrial Revolution where multiple authors have discussed the transition from cottage production of textiles to factory production, which required political will, conflict and cultural changes (Supple 1963). This seismic shift was made possible by a series of inventions and improvements in productivity that was made possible by factory-based production (von Tunzelmann, 1995).

But the challenge with measuring this is the fact that many such inventions or innovations are carried out by the manufacturing firm at the process level, which largely goes undocumented. However, in the research-intensive industries, such as pharmaceuticals or electronics, professional research and development laboratories generate such innovations on a regular basis due to their access to dedicated funding (whether public or private), commitment to experimental development, and concentration of human capital. Thus, in this case, the link between science and technology can be determined through the metrics afforded by scientific publications and patents.

However, it is noteworthy that building correlative Science and Technology (S&T) indicators to identify the core competencies of innovation system can be complicated.

One must be cautious in building the concordance tables as classification systems in science (explicit knowledge) and technology (tacit knowledge) are inevitably different. There are only some fields in science that are related to technology. Even though devising a functional relationship between science and technology emerged to be a challenge to many scholars, there are few sought to attain the issue and depict the correlation via identifying the common link in certain keywords used in publications and patent documents (Gittelman, 2016; Grupp, 1998, pp. 166-181). Nonetheless, mining the S&T data from different databases and using it as empirical measures to pinpoint technical progress and highlight the prospects for successful commercialisation of research outputs can be daunting and laborious.

Many scholars design various methods to attain the matter in a more systematic way and be capable of generating action knowledge that can support decision making. Porter & Newman (2004) suggests a systematic process[4] to mine data from patent documents on a given topic and use it as indicators for policy and management purposes[5]. Their approach that is deliberately designed for a lead to policy implication draw on the concepts of a technological life cycle, structure of innovation system and product value chain. The approach led to many similar studies pursuing researches that has informed policy-makers on the core competence of a system and potential for commercialisation of an interesting technology (Grupp, 1998, pp. 166-181; Newman, et al. 2005; Porter et al. 2007; Porter & Rafols, 2009; Robinson, et al. 2013).

This study found that the proposition of Gittelman (2016) on (re)search logics provides a context to apply and frame the proposed methods on the cases identified in this study.

[4] From specifying and selecting the data sources, search and retrieval, follow with basic and deep analyses to interpretation and utilisation of the indicators.

[5] This includes R&D program management, merger and acquisitions, new product management, intellectual asset management, technical human resources management, foresight and forecasting and strategic planning. While there are massive studies on S&T related matrices and indices, there are few attempted to utilise it to study the core competencies of innovation system and pinpoint the prospects of innovation.

She proposed four quadrants with two dimensions that define the search paradigm (see **Figure 2.2**). Upper right quadrant and lower left quadrant represent the searching commitments being oriented toward advancing scientific theories and develop useful products respectively. Scholars working in university labs and adhered to publishing norm for high visibility of their research findings pursue their searching agenda at the higher left quadrant. This seems to correspond to Stokes's view on "Bohr scientist" who is keen to build a pure basic research that is oriented to the pursuit of knowledge that has limited potentials (not being seen as immediate useful) applications in the industrial world (Shichijo et al., 2015; Stokes, 1997). On the other hand, scientists or engineers (as Edison scientist) working for the firms search in the lower left quadrant for products that offer immediate market value.

The lower right and upper left quadrants provide a rather mix depiction of searching commitments. Those who perform research in these quadrants are being considered as Pasteur scientist. Their research activities are featured with high socio or market values and capable of improving both understandings of nature (science) and technology. Gittelman (2016) observed that there are hybrid organisations and institutional arrangement emerged to accommodate these mixed mode search quadrants. The upper left quadrant represents the research commitments of those who wish to fill gaps between basic science and technological research. The pursuit towards an abstract type of knowledge is very much led by an experiential oriented type of search (tacit knowledge). There are many applied fields such as electrical engineering and computer science which were founded by those who work in the upper left quadrant. The eventual fundamental understanding resulted from technological research would contribute to basic research activities that endow practical knowledge in the lower right quadrant. Those who wish to develop practical knowledge from basic sciences (e.g. biotech firms) perform in lower right quadrant.

Those economies that have executed the horizontal type of S&T policy (supports for R&D across sectors) and ultimately attained a general search routine would aspire to perform in producing emerging technologies (Lall & Teubal, 1998). Nonetheless they would realize their lacks in complementary assets to perform in these two quadrants and thus, sought to mobilise their resources to support those who invest in science-based technological firms.

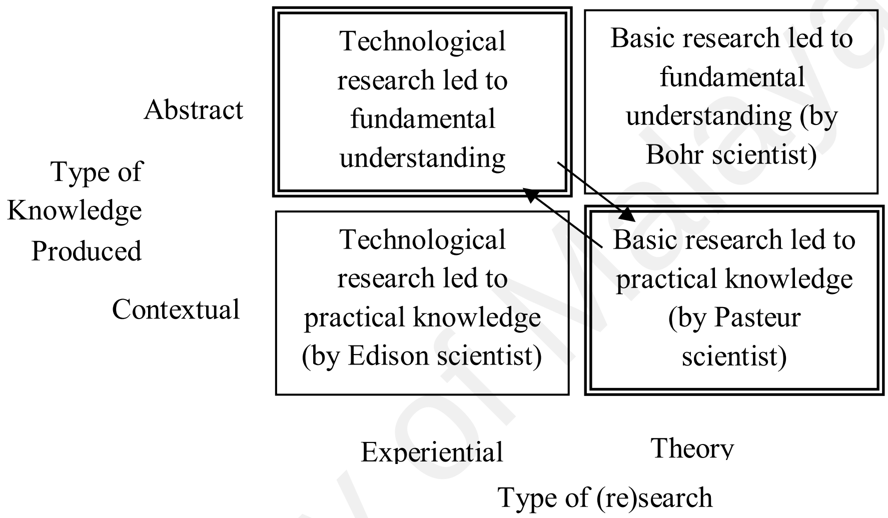


Figure 2.2: Search Logics (Adapted from Gittelman (2016))

2.9 Summary

The review of the literature motivates an understanding of how science plays a role in the modernization of the herbal medicine sector. This study does so by mapping scientific activity in building the knowledge base and its impact on the innovation chain in herbal medicine. This study postulates that there are two major factors in the building of said knowledge base which would induce transitions in the development of the knowledge base; namely, the configuration of actors in the research networks and the convergence of multiple streams of technology in developing new knowledge, and new technology. On the one hand, the configuration of actors relates heavily to university-industry-government linkages which would have implications on research agendas, access to research funding and commercialisation potential. This would set the stage for the modernization of herbal medicine. On the other hand, the convergence of technology streams would confer a greater degree of novelty and drive the development of research capacity within a specific economy. This would induce the leadership stage which is defined by the emergence of niche competence and international leadership.

This study measures capability development through bibliometric output and comparative advantage of specific economies in traditional medicine. This study argues that a comparative advantage analysis reveals the accumulation of competency over time which would serve as a useful proxy for capability development.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter aims to present the conceptual framework of this study and to iterate the various elements that are needed for evolution in the herbal medicine sector. The chapter will then explain the evolutionary phases and the necessary elements (UIG linkages and convergence) in detail. Following this, the chapter will discuss the techniques and analyses used for investigating these phases. It will also discuss the data sources used in this study.

3.2 Conceptual Framework

The conceptual framework for this study is presented in **Figure 3.1**. As elaborated in **Chapter 2**, this study concerns itself with two specific themes that are identified as drivers of the transition from traditional to modernization to leading-edge sectors, namely UIG linkages and convergence. UIG linkages are identified as a period of organisation for the research network as a precursor to the modernization phase of the sector. In this case, innovation policy and governmental actors determine the overall strategy and degree of openness in order to create the optimum setting for the innovation ecosystem to flourish. The organisation of the research network would lead to the proliferation of research material (publications) which then translates or "spills over" into technological diffusion (patents) which would build the knowledge base to the point where novel technologies or research platforms are developed that would drive the technological life cycle to larger revolutions. This would spark the transition to the third phase, leading edge, where the economy in question attains a technological level that allows it to dictate research standards and best practices in the international arena.

This study will dissect each element in the framework presented in **Figure 3.1** in detail in the following subsections.

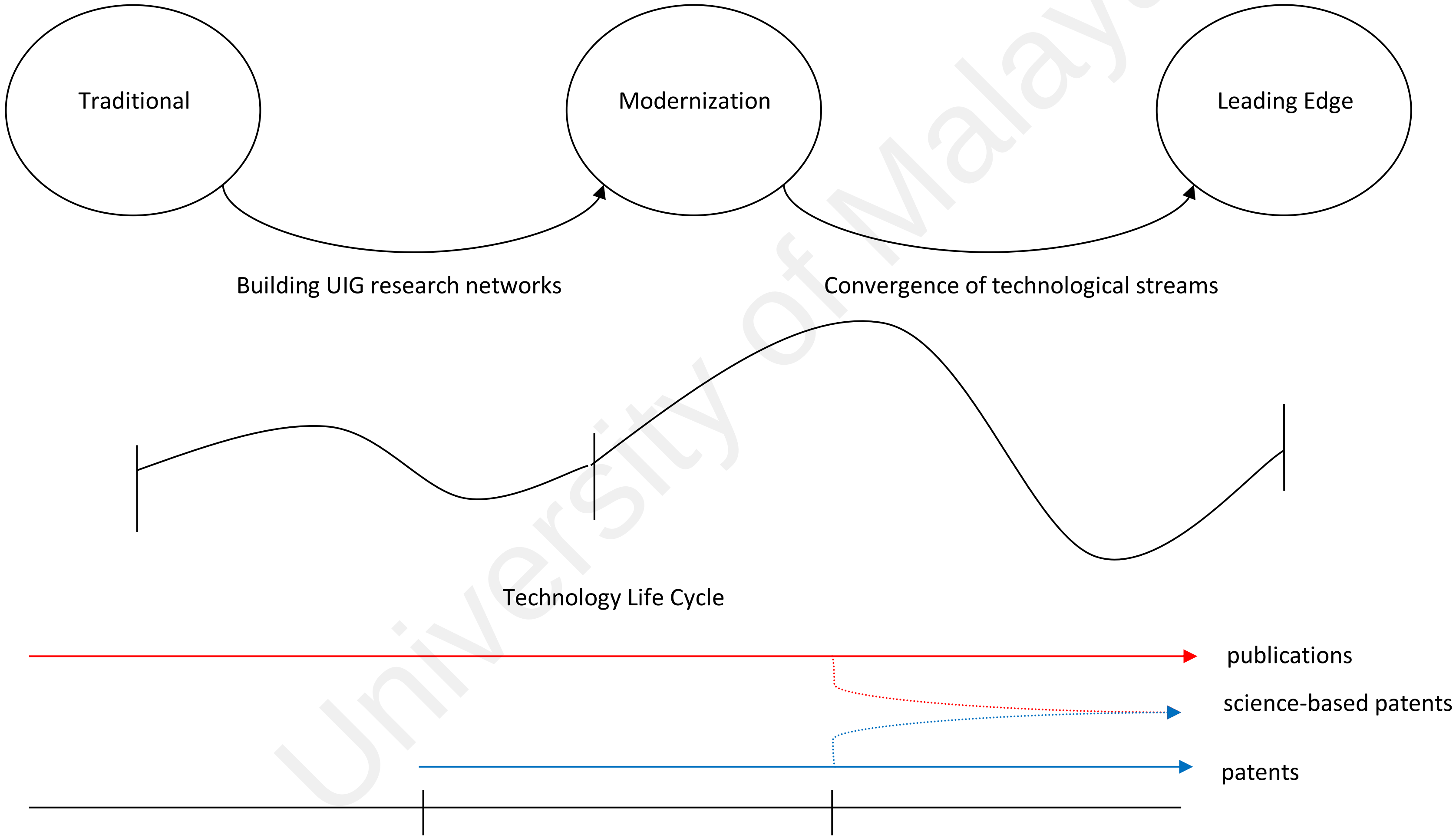


Figure 3.1: Conceptual Framework

3.2.1 Evolutionary Phases in Scientific Development

This study employed an evolutionary perspective of the industry, adapting a transitions approach focusing on goal-oriented long-term transformation processes (Geels, 2004). Weber and Rohracher (2012) built on the work of Geels (2004) to propose a framework for transformational system failures to describe the industrial transitions towards sustainable development. This was adapted by Wong et al. (2013) to present a stylised trajectory of the economic development of Taiwan, transitioning from traditional industries to the formation of high technology industries.

This study adapted this approach to the case of herbal medicine stylising a development trajectory that was perceived from Xu et al. (2013) based on a historical analysis of the past 60 years in traditional medicine development in China. Xu et al. (2013) provided an analysis of the history and modernization efforts in TCM, providing insight into the integration of TCM in the Chinese primary healthcare system as well as the several modernization and human capital building efforts that were put in place in China after World War II.

The phases that he alluded to summarised the different levels that the Chinese TCM industry has evolved from and described the various characteristics related to these phases. This study extended this perspective with relation to the roles of university, industry and government. Borrowing from Leydesdorff & Etzkowitz (1998), this study analysed the productivity of these actors in knowledge management (representing university/academic activity), commercial prevalence (industrial activity), and government intervention. A synthetic framework of scientific activity in traditional medicine is outlined in **Table 3.1**.

In this perspective, Phase I denoted an undeveloped system where the herbal medicine industry is confined to cultural practice with limited regulation and innovation. Phase II, where most countries would be in, is characterised by modern approaches to product development, gaining regulatory approval, IPR protection and integration into the public healthcare system. Phase III, which is currently unchartered, is projected to include international acceptance of products and development of an international industrial standard.

This framework was proposed based on a cursory analysis of the industrial development of the various economies scrutinised in this study. As stated previously, the eight nations covered in this study made announcements with regard to the development of the traditional medicine sector during the 1990s, and subsequently followed that with the establishment of various research organisations, institutions and research grants. These research organisations were tasked with investigating the medicinal properties of targeted herbs and plants commonly used in traditional medicine and providing research support to industry in developing products for commercialisation.

Table 3.1: Evolutionary Framework of Traditional Medicine (Adapted from Xu et al. (2013) and Leydesdorff & Etzkowitz (1998))

	Knowledge management	Commercial Prevalence	Government intervention
Phase I (Traditional)	Indigenous knowledge practised by traditional tradesmen.	Cultural acceptance within ethnic bounds.	Little or no government regulation.
Phase II (Modernization)	International recognition of product safety and efficacy. Adherence to global standards in manufacturing practice. Modernization through scientific research. Cataloguing and legitimisation of medicinal products.	Cross-cultural marketing and acceptance. Acceptance by healthcare organisations. Presence of contract manufacturing organisations. Internal R&D for product enhancement and new product development.	Robust regulatory framework (licensing, registration, quality control and intellectual property protection). Research funding available for TM research. Integration of traditional medicine with public healthcare.

Table 3.1, continued.

	Knowledge management	Commercial Prevalence	Government intervention
Phase II (Modernization)	Accredited colleges and university programmes available for the training of practitioners.		Develop industrial architecture to promote innovation pathways through public research institutes.
			Provide oversight and direction towards building commercial capabilities.
Phase III (Leading Edge)	Thought leadership in the development of industrial standards.	Export products received in international markets.	Promote competitiveness within the industry.
	Strong UIG collaboration leading to commercialisation of research and proliferation of SMEs.	International brand presence.	Identify growth opportunities and 'next steps' for industrial evolution.

3.2.2 Building UIG Linkages

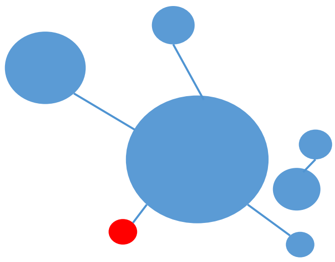
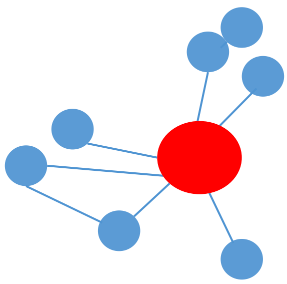
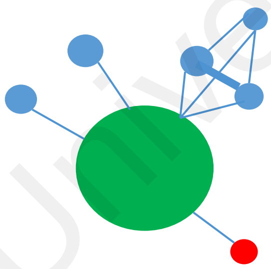
In this study, a similar hierarchy in scientific activity of specific economies was observed. On the other hand, there are some networks that are distinctly 'horizontal', where the market is segmented into equivalent units that all act according to the same organisational rules (Hamilton & Feenstra, 1995). Thus, each firm or unit occupied specific niches based on market needs within the value chain. Such horizontal structures are characteristic of pre-capitalist economies where guilds and associations monopolise the economic sphere and are self-regulated (Weber, 1978). In this study's perspective of research networks, this is perceived in the networks that are primarily university-based; where there are no distinct central nodes and distribution of output (papers) are typically uneven based on the distribution of resources.

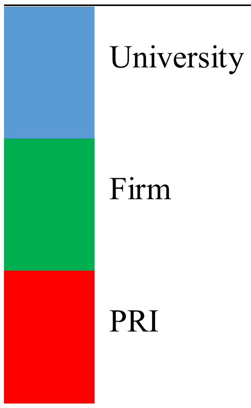
Mirroring the structure of vertical hierarchies, this study associates the centrality of specific organisations in the research network to indicate the importance of specific organisations in relation with others. This study interprets this as an indication of the allocation of resources, the concentration of human capital as well as the distribution of power and organisation of institutions in the sectoral innovation system.

In this study, the interaction between university, industry and government in the knowledge production within the herbal medicine sector is the major focus. As knowledge plays a more dominant part of innovation, the university, as a knowledge producing and disseminating institution, plays a larger role in industrial innovation (Etzkowitz et al., 2000). Etzkowitz et al. (2000) expanded on the academic revolution necessary for universities to straddle the university-industry divide based on the experiences of several universities spread out globally, thus evolving from an ivory tower to an academic entrepreneurial paradigm.

In the wake of the State's agenda and interventions, different actors in certain selected Asian economies have shown strong commitment to the field of herbal medicine; such as the Chinese University of Hong Kong (Hong Kong), China Medical University (Taiwan), Kyung Hee University (South Korea), Chinese Academy of Sciences (China), National University of Singapore (Singapore), Tsumura & Co. (Japan), and University Sains Malaysia (Malaysia), to name a few (**Appendix A**). With the increased role of academia in basic research for this field, this study expected to see a high concentration of publications focusing on this sector which will shed light on the development of capability in this sector. This can be traced using a measurement of relative comparative advantage that will shed light on the developed capability of the country in terms of research activity. Adapted from the works of Keith Pavitt (1999), this study utilises this index to assess the competency of the economy in relation to the volume of research being done in the given sector. In summary, this study proposed three forms of research network structures observed in traditional medicine research across the selected economies (**Table 3.2**).

Table 3.2: Network Structures based on Research Framework

Network Structures	Key characteristics
University-centric network 	- Universities dominating the research landscape. - PRIs play a supporting role to universities. - Firms play a limited role in research. - The research focused on pre-commercialisation and academic interest.
PRI-centric network 	- PRIs assuming a central role in the research landscape. - Multiple universities tied to a dominant PRI. - Firms play a limited role in research. - PRIs act as an agent of the State in distributing funding and agenda setting in research.
Firm-centric network 	- Firms actively involved in basic research. - Collaborations between firms and universities/PRIs. - Heavy focus on research and development of commercially-viable products.



In **Table 3.2**, this study sketched the types of networks that are expected based on current understanding of university-industry-government linkages. The focus is on the centrality of specific entities in the network in relation to other nodes, as well as the connectivity of the nodes to others. In this case, the size of the nodes denotes the number of papers being produced by the entity while the thickness of the line between the nodes denotes the degree of similarity in the papers in the two entities (therefore, a higher degree of similarity would mean a higher number of joint publications). This study argues that the complexity and reach of network linkages indicate the maturity and strength of the innovation system, implying strong research connections among actors and high potential for knowledge spill over through interdependency (Malerba, 2002). This study contends that one model is not necessarily superior to the other as the existence of these networks is determined by the political landscapes and past experiences of the economies in handling technology industries. As different innovation systems draw inspiration from different case studies, one is not necessarily better or worse than the other, but each has exhibited their own pros and cons.

3.2.3 Convergence in the Technology Life Cycle

As detailed in **Section 2.5**, the concept of 'technology life cycles' in this study is largely derived from the work of Schmoch (2007) which tracked growth in certain scientometrics in order to describe the relationship between research and innovation in specific sectors. As a sector, the case of traditional medicine is relatively unique in the sense that it is in a relative infant stage, considering that this study only tracked significant growth in scientific publications in the last 20 years or so. However, it provides an elegant case study to understand the co-evolution between technological convergence and creative accumulation, otherwise defined as the accumulation of scientific and innovative knowledge.

Additionally, this case study is unique as it discusses the emergence of a new socio-technical regime (Geels, 2004) branching off from conventional medical research and innovation. "Modernised" traditional medicine products are subject to the same regulatory requirements as conventional medicine but what separates "modernised" traditional medical products from conventional synthetic medicine is the user demand, as herbal medicine products and services have been in general use in informal settings (**Section 2.2.1)**. Particularly, many non-Western (and Western) ethnicities in the global South still rely on traditional medicine for preventative care, as well as non-invasive therapy. In Africa (90%), India (70%) and China (40%) depend on traditional medicine to meet their healthcare needs (World Health Organisation, 2005).

In this case, this study argues that the emerging herbal medicine sector provides an example of a technological niche that developed off the convergence of molecular biology (B_i), genomics (B_2), plant sciences (B_3) and pharmacology (B_4); and then proceeds to spin off into multiple directions through convergence with other sectors (**Figure 3.2**). In addition, this study also assumes that such activities are geared towards commercialisation; leading to the emergence of novel therapeutic products or production processes – which is evidenced through academic publications and patents.

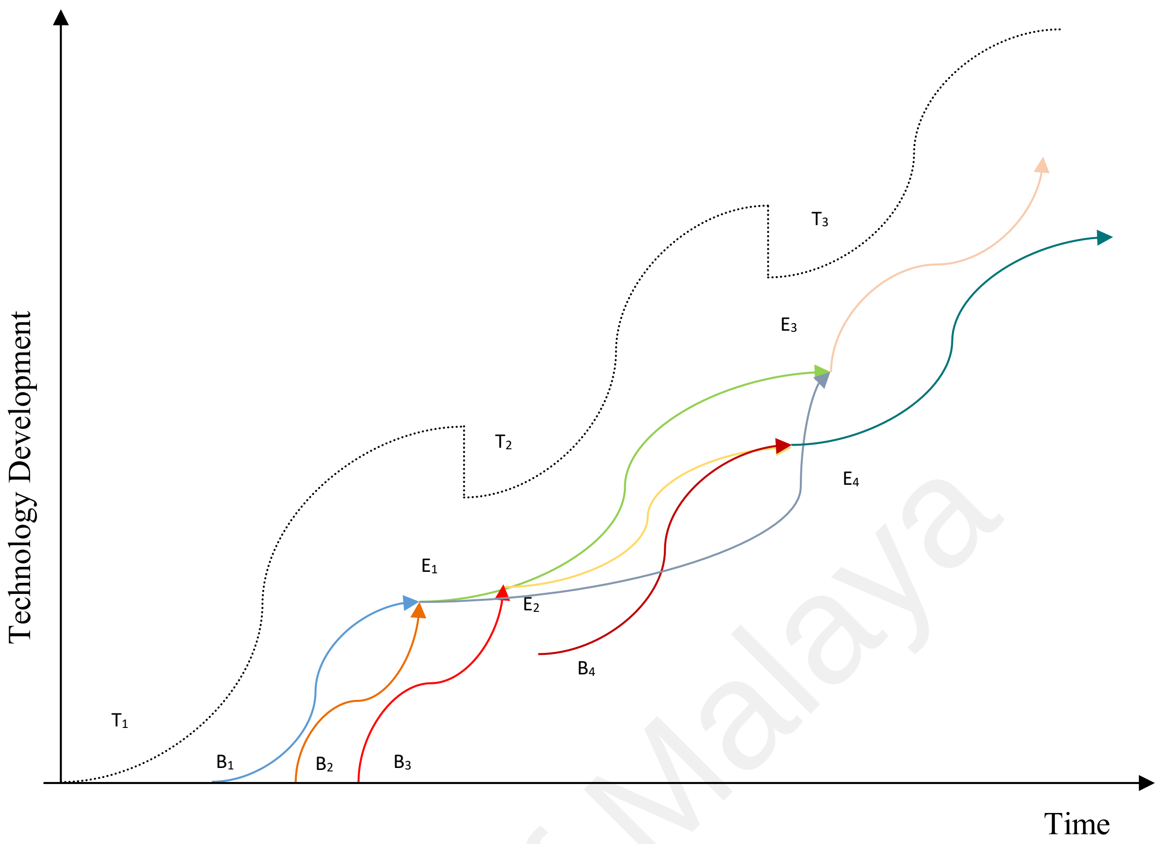


Figure 3.2: A Conceptual Visualisation of our Interpretation of Convergence

The framework for this study was built on the foundation of Schmoch's (2007) work using scientific publication statistics as a proxy for research; and patent statistics as a proxy for innovation activity. Particularly in a science-based sector such as herbal medicine, where research publications are often used as documented, qualified evidence for meeting regulatory standards; this study argues that publications in academic journals reflect knowledge production activity in scientific research. This study also conjectures that the heavy investment required to pursue such research and development of indigenous products require government intervention and the participation of universities, which generally translates into academic publications as productivity in universities is generally measured by such means. On the other hand, patent statistics provide insight into innovation activity as it denotes an original invention with potential commercial value as well as knowledge production in the firm – which can be a university laboratory, organisation or individual (Ramani et al., 2008). Both publications and patents have been used extensively in the literature as such proxies due to the ease of access, as well as the tools available for classification and analysis of such data.

Working along the same lines, this study divides the proliferation of research and innovation in herbal medicine into three phases: knowledge generation (I), product innovation (II), knowledge-based product innovation (III). This study theorises that publishing and patenting activities work independently in early stages, with publishing activity the forerunner as compared to patenting activity (T). The rationale for this is that once the knowledge base reaches a specific critical mass, innovation activity takes place to exploit existing knowledge in the form of commercially viable products (T') (**Figure 3.3**). This first transition could be due to the protection of existing products or those with proven inventiveness or novelty that are considered to be valuable enough to be protected in international markets (hence the rationale for patenting).

However, this study postulates that these two activities converge into an interdependent form as the knowledge base increases and the sector moves into more high-value products, which require scientific evidence as part of their developmental process (T'') (**Figure 3.3**). The emergence of such science-based patents, or patents that cite other literature (that is, excluding other patents), reflect inventions developed based on scientific literature with potential commercial viability (Wong, 2013). This study attributes this phenomenon as an evolutionary step of the technological life cycle for the entry of products developed through the involvement of universities or public research institutes.

This attribution is based on the assumption that the research performance of research organisations such as universities or public research institutes is primarily measured through academic publications, which would incentivise academic entrepreneurs/collaborators to publish certain novel aspects of the innovation in peer review journals prior to patenting. As mentioned earlier, this study expects technological convergence to happen in the interstices between different technological disciplines within the sector (Steinmueller, 1996).

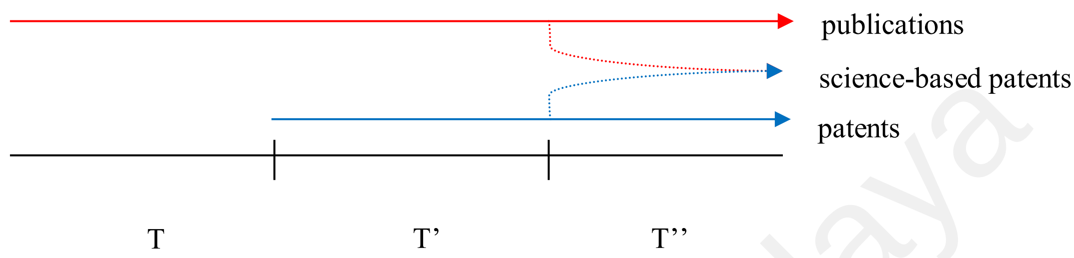


Figure 3.3: A Visualisation of the Convergence of Publications and Patents

3.2.4 Projecting Transitions from Science, Technology to Economy

In "Foundations of the Economics of Innovation", Grupp (1998) proposed a coarse concordance to link science and technology based on 20 balancing units. This study adapted that concordance and updated it with new categories that have surfaced since the publication of the seminal book in 1998. This study was built on the concept that the life cycle of a science-based technological sector is driven by the emergence of technological niches within a specific sector that accelerate the development of a technological discipline at different points. This perspective was inspired from the dynamic multi-level perspective on systems of innovation proposed by Geels (2004) who articulated the emergence of radical innovations through technological niches, which then link together to form a stabilised configuration; which then breaks through into the socio-technical regime during windows of opportunity, leading to changes in the technological landscape.

Nonetheless, this study appreciates that there are numerous instances of multidisciplinary activities that make it difficult to demarcate and define such categories based on the balancing units. Still, for the purposes of this study, this method is proposed as a useful means for deducing the link between scientific and technological activity at a regional or sectoral level. In this case, this study argues that publications are indicative of scientific activity by academic scientists while patents are indicative of technology development for commercial or market potential.

This study used the same parameters for the patent data extraction through Patsnap, a patent search engine and analytics portal that was utilized in this study. For patents, patent records were gathered from PCT, US, China, Japan, Malaysia, South Korea, Taiwan, Singapore, and EU to develop a composite dataset which represented the largest markets for herbal medicine. In order to avoid duplication in the herbal medicine dataset, the dataset was limited to one record per family through the VantagePoint text mining software.

Utilising the proposed updated concordance (**Appendix B**), this study mapped the WoS categories into the IPC Technology Classification based on the balancing units proposed. The IPC Technology Classification was designed to map IPC subclasses to relevant fields of technology. In this study, the classification was utilised as a means to deduce and compare the anticipated technology to be developed through scientific research against the existing technology found in the patent data.

In this study, a bibliometric approach was utilised for an empirical evaluation of modernization in traditional medicine through scientific activity, as well as an assessment of the transition between science and commercialisation within said industry. This analysis allows for the drawing of conjectures based on the Triple Helix framework, established by Leydesdorff and Etzkowitz (1998). Leydesdorff & Etzkowitz (1998) highlighted three main actors in the knowledge economy: universities, industry and government. In this study, the roles of the three main actors across the different economies in the development of the herbal medicine industry were assessed.

Although China is the largest market for traditional medicine products, trademark registration in China is done in Chinese and the Trademark Office in China does not have an online database for searching (Trademark Office of the State Administration for Industry & Commerce of the People's Republic of China, 2003). According to the Global Brand Database (World Intellectual Property Office, 2014), the USPTO (27,353) has the largest collection of trademarks related to herbal and traditional medicines as compared to other trademark offices registered under the Madrid Protocol. Schmoch (2008) found a high correlation between trademarks and innovation, justifying its use as a complementary indicator of innovation particularly in the manufacturing sector. As trademarks denote the entry of new consumer products, as opposed to technological innovation, it is closer to commercialisation. Some trademarks are filed to protect products with no substantive differences in relation to competitors (Mendonca et al., 2004). This actually suits this study as traditional medicine products struggle to fulfil the necessary 'invention' necessary for other forms of intellectual property protection (World Intellectual Property Office, 2014). Also, trademarks are cheaper and a wider range of SMEs are more likely to apply for trademarks as a form of IP protection (Mendonca et al., 2004).

In order to link the use of publications and patents, this study employed an approach used by Grupp (1998) and others (Lybbert & Zolas, 2014; Organisation for Economic Co-operation and Development, 2011; Schmoch, 2007) on the list of correspondence to study the core competencies of a technological system and its potential in commercialisation. This study sought to contemplate a sequence of steps in connecting the fields of science, technology and industrial products. The eventual concordance tables will have the roots of Grupp's (1998) view on science and technology linkages and the proposed method for linking different classifications. The presented method will allow for a postulation of the potential development of technology in science and industrial products in technology.

This study considered herbal medicine as a perceived high potential technology that have been sought by the selected economies to generate multiplier effects for their industries as case studies for the proposed method. The proposed method is particularly helpful in benchmarking the performance of the selected economies with that of the world (national) average. It is useful for policymakers to target potential technologies and establishing development policy portfolios. The findings can be used as a guide or observatory of technological system complex for those economies that have executed functional types of S&T policies (Lall & Teubal, 1998) and been searching for niche position in the technological value chain. In this study, a concordance cascade to track the potential technologies and products stemming from the science and technology activities observed in the herbal medicine sector is proposed.

The purpose of this translation is to update the concordance for patents and publications, in order to provide the most accurate representation of potential areas for translational research. IPC Subclasses were grouped into the respective balancing units using the Thesaurus Editor function found in the VantagePoint based on the concordance table published by Grupp (1998). The publications from the same economies were then translated to the publications section using their WoS Categories in order to determine the anticipated technology classes. This exercise is summarized in **Figure 3.4** and aims to determine if there is a match between fundamental research and invention. Based on the Science-Technology Concordance proposed in **Appendix B**, this study layered the natural log values of the patents or publications. This study presented three comparative plots for this case study: one comparing publication-publication output, another, patent-patent output; and the last – publication-patent output. The plot enabled this study to compare the strength of technology of the herbal medicine sector for each economy in relation to the values of the world average in herbal medicine. The values of the performance for each case and the strengths of the comparative cases can be traced through the radial plot.

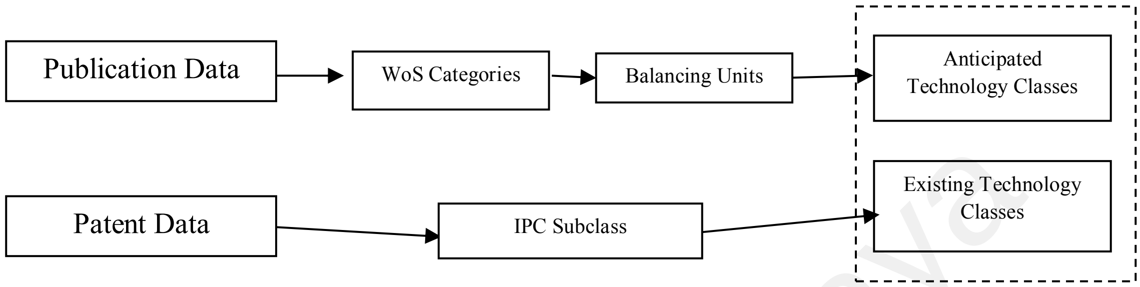


Figure 3.4: Flowchart of Concordance Cascade

3.3 Techniques of Analysis and Measurements

This section will detail the various methodologies used in investigating the various elements that have been presented in this chapter.

3.3.1 Methodologies for Investigating Evolutionary Phases

In Chapter 5, the publication and innovation statistics, involving trademarks and patents, for the selected economies are presented in detail. This study presented some of the statistics regarding trends, capability and impact in this section.

The measurement for the Research Impact Index involved the ratio between the total number of forwarding citations (5 years) over the number of papers for the years in question (1993, 1998, 2003, and 2008). This study selected the 5-year impact measure based on the observation of a significant tapering off in forwarding citations after the 5-year cycle. This presented an indication of the paper's contribution to future research done in this or similar scientific fields.

As a proxy measure of scientific capability, this study measured the proportion of publications against population based on 5-year averages from 1993 to 2012. The purpose of this measure is to normalise the research volume (defined as the number of publications) based on the population of the country in order to provide a comparable standard for the various economies being measured.

The growth rate of scientific capability was measured as a proxy for the impact of policy mechanisms introduced during the study period. This study used the ratio of the difference between a specific year with the preceding year; over the total publications per population of the specific year to measure the growth rate. These values were then collated into 3-year averages to develop this normalized view of the various economies. The organisational affiliations of the authors were also sorted into specific entities (universities, PRIs, industry, hospitals) based on the names of the particular organisations and the organisational website of the particular organisations when the entity type was not apparent through their names.

Citations were also a point of interest as a proxy for measuring the impact of scientific research over time. Lagendijk (2003) pointed out that 'the success of a concept is not much an achievement of the original author, but primarily a product of the way other authors quote and use these concepts in follow-up work'. An analysis of forwarding citations was included to shed light on the influence held by papers published in subsequent papers, and has been utilised in prior studies for the same purposes (King, 2004; May, 1997). The results were analysed for forwarding citations to determine the scientific impact of papers published during this period (Hu et al., 2011). This was calculated based on a 5-year average of citations per paper. This is summarised below:

$$\text{Average Citations} = \sum(\text{year}_1\text{:year}_2)/\text{N(papers)}$$

In order to assess 'comparative advantage' across the economies, this study adapted the Revealed Technological Advantage (RTA) Index (Nesta & Patel, 2004; Pavitt, 1999) to determine the strength or weakness of the research sector.

Keith Pavitt (1999) utilised this methodology to classify firm technology profiles through patenting data in specific areas. The dimensions provided a normalised context in order to compare the competencies of different actors. However, as this study focused on bibliometric data and scientific output, this indicator was adapted as a means to determine the comparative advantage of selected economies in research. The RTA-Index is commonly used in patent analysis to approximate advantages in certain technology fields and consists of the ratio of the number of patents of a country in a particular technological sub-discipline, divided by the total number of patents in the technological sub-discipline; and the number of patents of the country in the discipline, divided by the total number of patents in the discipline (Miyazaki & Islam, 2007; Patel & Pavitt, 1997). As this study used this index to map for scientific advantage (using publications (P)) as opposed to technological advantage (using patents), the indicator was re-termed as Revealed Scientific Advantage (RSA) for the purposes of this study. The index was adapted from Nesta & Patel (2004) and was defined as follows:

$$RSA_{it} = [P_{it} / \sum_{t} P_{it}] / [\sum_{i} P_{it} / \sum_{it} P_{it}]$$

In order to map the scientific profile of the countries, this study plotted the Revealed Scientific Advantage (RSA) (based on publications) of the selected economies against the share of publications (Pavitt, 1999), based on an average of values between 2008 and 2012. This approach determined the type of competencies developed in the selected economies based on the adaptation of Pavitt's (1999) classification of firm technology profiles in this study. This study also plotted the average values for the countries between 1998 and 2012, thus providing an idea of the dynamics behind the national development of the traditional medicine industry. Thus the ten-year dynamic shift from 1998-2002 to 2008-2012 was observed.

This study adapted Pavitt's (1999) classification of technological profiles as a means to describe the breadth and degree of priority of specific economies in the field of traditional medicine research. Pavitt (1999) defined the quadrants – divided according to the average values of both axes – on the following basis:

- *Quadrant I (core competence)* – where the technology in question is defined as an integral part of the technology profile; with an expanded share of the publication and higher than the average comparative advantage, represented by the RSA value.
- *Quadrant II (niche competence)* – where the economies have niche advantages in small sub-technological fields within the broader technology.
- *Quadrant III (marginal competence)* – where the economy neither allocates a large share of resources nor achieves a distinct advantage.
- *Quadrant IV (background competence)* – where the economy has a large share of the field but due to the size or maturity of the local industry, it does not achieve a high comparative advantage compared to other economies.

3.3.2 Methodologies for Investigating UIG Linkages

For the purposes of this study, this study utilised social network analysis to derive conjectures regarding the agglomeration, connectedness, and centrality of the various research networks studied (Prell, 2012). The networks are plotted based on the raw records extracted from the searches carried out in WoS above, mapped using the Vantage Point text-mining tool.

This study began with a cleaned list of "Author Affiliations – Organisations" using the built-in thesaurus for 'Organisation Names' in order to detect duplicates. The research networks were then generated using the Cross-correlation function for "Author Affiliations – Organisations" and "Authors" for the top 30 organisations in the list of author affiliations. This allowed for the visualisation of the number of researchers (agglomeration denoted by the size of bubbles), organisational linkages through co-authorship (connectedness indicated by the presence of lines between organisations), and position of the organisation (centrality in relation to other organisations). It was also noted the number of publications for specific key actors that were observed in these networks.

Different types of organisations were colour coded based on the description of the organisation on their website (university, PRI, hospital, firm). The weight of the line (based on the degree of similarity, and weighted based on quartile) depict the strength of the co-occurrence between papers originating from these two organisations, while the size of the bubbles depicts the volume of research being done by the organisation in relation to other organisations on the map. For example, if a paper is published by both the University of Hong Kong and the Hospital Authority, both bubbles will have the publication with a line in the middle to denote the co-occurrence.

3.3.3 Methodologies for Investigating Convergence

The analysis presented in this thesis begins with a descriptive analysis of the bibliometric data set derived from the WoS Science Citation Index Expanded (SCIE) database focused on herbal medicine and patent data to look at the overall trend of the sector as well as the patent keyword clusters that is emerging at specific points in the cycle; this is followed by a look at the statistics of the selected economies and revealed comparative advantage of selected Asia Pacific economies over time, lastly, an analysis of three distinct network types observed in the specific economies studied. This study is structured in such a way so that it first presents a landscape view of the dataset and the keywords emerging during this period; followed by a dynamic view to assess the change in the landscape over time based on comparative advantage; which is then followed by an insight into selected case studies of networks in specific economies to describe implications of different network structures on the landscape changes. The analysis presented in this study is built on the quantitative assessment of bibliometric – articles and proceedings published in journals captured by the WoS database under the SCIE index. Articles carrying keywords related to herbal or traditional medicine (Field: Topic) are included in the overall count which is segmented according to their economy of origin (Field: Address).

To investigate the notions of technological convergence in this study, a keyword cluster visualisation tool developed by Patsnap was utilised in order to present the evolution of keyword clusters over time.[6] The visualisation tool measured connectedness between commonly occurring groups of keywords and clusters them based on similarity in a three-dimensional landscape. The landscape also presents the intensity of specific clusters through peaks and troughs allowing for the observation of different patterns of technological convergence over the period of study. This study also classified the top 100 assignees as Universities, Public Research Institutes (PRIs), Firms and Individuals to get a sense of the kind of actors that are patenting at the time.

Four snapshots were collected to provide a perspective of keyword clusters during various points in the timeline for this study which covers 1993 to 2016. The years selected for analysis are 1998, 2003, 2008 and 2012. Since the majority of the policies stimulating the growth of this sector, particularly in the selected economies began in the mid-1990s, 1998 would see an upturn in publication activity which should then eventually spill over into

[6] Patsnap is a patent database covering 90 countries with a built-in analysis platform. This study utilized their recently launched 3D patent landscaping application to visualize groups of keyword clusters in the dataset based on an algorithm designed to detect commonly occurring or similar keywords.

other innovative activities. Therefore, the four snapshots were sourced to evaluate the changes in patent keyword clusters over time and describe the role of universities, firms and research institutes during this period.

The maps are three-dimensional topographies of the keyword clusters. Essentially, the clusters of keywords were generated by the engine which considers the proximity and context of particular keywords as well as the commonality in IPC subclasses. The greater the concentration, the higher the peak in the topography. Different IPC clusters were colour coded differently to provide a sense of the variety in patent subclasses in the landscape. This study presented the assignees and labels for the three most prominent clusters of each landscape and examined the profile and characteristics of the actors involved at each stage.

3.4 Data Sources

2016 was the end-point as the most recent year prior to the study, with the study conducted over a 23-year period (1993-2016). The rationale behind this is that most of the policies related to traditional medicine (as outlined in the Introduction) were generally established in the mid-1990s.

The search string used to capture articles regarding traditional medicine was developed using keywords derived from the WHO General Guidelines for Methodologies on Research Evaluation of Traditional Medicine (World Health Organisation, 2000). The heuristic search string captured the nouns stated in the WHO Guidelines (herbal or leaf or leaves or flower or fruit or seed or wood or bark or rhizome or plant or herb or juice or gum or oil or "essential oil"...) in context with the general keywords associated with traditional medicine ((traditional AND medicine) OR (herbal AND medicine) (**Appendix C**). The search results were then filtered for errors and cleaned accordingly.

3.4.1 Secondary Data

Peer-reviewed publications were sourced from the expanded version of the SCIE accessed as part of the WoS (apps.isiknowledge.com). The SCIE database provides a comprehensive database which indexes highly reputable journals that form the international standard for academic publishing in numerous institutions. The timeline for this study ranged from 1993 to 2016 as this study observed that the majority of policies related to herbal medicine research were passed in the mid-1990s (as detailed in **Section 2.2.2**). The SCIE provided a sizeable database of the world's top-ranked journals cutting across all fields of science and social science.

Individual economies were searched for under the field tag 'Address'. An exception was made for the People's Republic of China, to exclude the keywords 'Hong Kong' and Taiwan, in order to prevent the inclusion of papers authored in these economies as both can carry the keyword 'China' under specific circumstances (for example, Hong Kong can be referred to as Hong Kong, China while Taiwan is sometimes referred to as the Republic of China). The WoS database is also allowed for refinement according to organisations, which in turn allows for the measurement of scientific activity among research institutes and universities in the target economies.

The USPTO defined trademarks as 'any word, name, symbol, device or any combination, used or intended to be used to identify and distinguish the goods/services of one seller or provider from those of others and to indicate the source of the goods/services' (United States Patent and Trademark Office, 2011).

For the purpose of the section on general statistics (Chapter 4), this study utilised the World Intellectual Property Organization's (WIPO) trademark database (available at http://www.wipo.int/branddb/en/) to present an overall view of trademark activity in various trademark offices worldwide. However, this study focused on trademarks found using the USPTO's trademarks database (uspto.gov/trademarks). The reason behind this is that although the WIPO database provides a wider net for trademarks, it does not provide the address of the trademark owner. For trademarks, the search string 'herbal OR (traditional AND medicine)' was used under the field 'Goods & Services' [GS] and the individual Economies were searched using the Owner's Name and Address [OW].

For patent data, this study utilised the same search string used in searching the publication data in order to extract patents granted in the USA, Europe, China, South Korea, Japan, Malaysia, Singapore and Taiwan as well as patents filed under the Patent Control Treaty (PCT) at the WIPO using the Thomson Innovation patent analysis platform. The search was limited to one patent per patent family in order to eliminate duplicates. The rationale behind this is to capture data from the largest global markets in general as well as for herbal medicine specifically.

To measure the accumulation of science-based patents, this study counted the number of other references (non-patent references) captured in the data set over time. Other references are typically scientific papers but could also be monographs, technical documents or reports; which still has credibility as a scientific basis due to the fact that it is still documented codified knowledge.

This study then analysed the patent data using Vantage Point to classify the patents according to Technological Specialisation. This is based on the Technological Specialisation Concordance released by WIPO which classifies patents based on subclasses into 27 different technology classifications.

3.5 Primary Data: Interviews

In addition, this study also included qualitative insight from several notable academics within Malaysia, Singapore, South Korea and Hong Kong to discuss current trends in herbal medicine research. The interview subjects were typically directors of herbal medicine research centres or academics with significant experience in some aspect of herbal medicine research (pharmacology, chemistry, or administration). This study included their thoughts on the modernization of herbal medicine as a means to cross-reference as well as provide "on the ground" insight into the bibliometric findings. The interviews were semi-structured and aimed to provide context as well as opinions into the development of the sector over time.

3.6 Summary

This study seeks to investigate the trends and activities of the selected economies in the field of herbal medicine and the concepts and methodologies explained in this chapter provide the outline of the following three analytical chapters that focus on scientific activity and how that translates into innovation and potential commercialisation. This study utilised patents, publications, trademark and interview data to understand how economies organise and position themselves and their scientific agendas to best exploit technological niches and develop competencies that complement their target markets. The following chapter is focused on the overall technology life cycle and patterns of convergence. This is then followed by **Chapter 5** that looks at the selected economies and the developmental phases that were observed through the various indicators covered in this study. **Chapter 6** will then delve into the network configurations in the various economies as well as track the transitions between science and technology using the concordance cascade that was explained in **Section 3.2.4**. This study then supplements this information with qualitative insights that were derived from interviews with various experts in the field around the selected economies.

CHAPTER 4: TECHNOLOGY LIFE CYCLE AND CONVERGENCE IN HERBAL MEDICINE

4.1 Introduction

Chapters 4 to 6 answers the research questions set out in **Section 1.5** accordingly. In this chapter, this study sets out to develop an overview of the development of science in the herbal medicine sector. This chapter looks at the total publications and patents for the herbal medicine sector globally. This chapter begins by looking at several case studies of policies in herbal medicine globally and then some general statistics of world data for publications and patents in herbal medicine. This is followed by an analysis of the trends to see if the notion of the tri-phase pattern is valid. After which, this study analyses snapshots of patent clusters to draw some inferences regarding the technology life cycle, in order to compare and draw parallels of the impact of herbal medicine policy on the dynamics of the life cycle.

4.2 Descriptive Statistics

The statistics presented in **Table 4.1** showed the research volume and patents from WoS and PCT filings respectively. The publications and patents were mainly from China and Hong Kong followed by USA, India, South Korea and Japan (**Table 4.1**). As detailed in **Chapter 3**, the data was collected from WoS for publications and a composite of various patent offices (limited to one member for each INPADOC family) for patents.

In this case, this study included Hong Kong together with China due to the close collaboration between the Special Administrative Region (SAR) and the mainland. Publications and patents are produced and filed from a variety of countries typically in the upper middle income and high-income nations. The countries selected for this study

– China, Hong Kong, Japan, South Korea, Malaysia and Singapore – account for 46% of the total publications and 73% of the total patents in the world. There is also a significant activity among other countries, notably in North America, Europe, South Asia, and Australia.

Table 4.1: Sources of Publications and Patents of Selected Countries (1993-2016)

No.	Country	Publications	Patents
1	China	13,915	109,556
2	USA	10,058	23,889
3	India	3,933	1,316
4	South Korea	3,637	5,116
5	Japan	3,125	1,111
6	Germany	2,393	1,555
7	Taiwan	2,330	177
8	England	2,252	1,380
9	Hong Kong	1,521	65
10	Australia	1,465	645
11	Canada	1,421	1,246
12	Italy	1,388	622
13	Brazil	1,304	108
14	Iran	1,292	-
15	South Africa	1,106	58
16	Turkey	1,009	41
17	France	791	697
18	Spain	643	256
19	Pakistan	642	-
20	Malaysia	638	76
21	Singapore	383	310
22	Others	1,052	21,310
	Overall	57,389	196,665

4.2.1 Classification of Science-based Patents

Table 4.2 shows the distribution of technology classifications for the science-based patents captured in this study against the IPC sections. Science-based patents are patents that cited at least one non-patent literature, typically journal articles or monographs. Typically the patents were mainly under Section A (Human Necessities) which points to the development of finished products for human consumption. These range predominantly in the Pharmaceuticals, Chemicals, and Technology applications to do with the former. These include medical formulations, elements in the product (packaging or drug delivery mechanisms), or processes in developing finished products. There is also a concentration of patents under section C (Chemistry, Metallurgy) which alludes to Chemical processes to support the development of such products. These typically include manufacturing processes that are involved in the production of such products as well as the various processes used in herbal standardisation and chemical composition analysis.

There is also a cluster of patents that have to do with Physics and Measurement or Pharmaceuticals, which points to the development of measuring equipment for the testing and development of herbal medicine products. Essentially, the patents in this section will be inventions relating to machinery, mechanical innovations as well as analysis processes that involve fingerprinting or chromatography.

It is important to note that patents can have classifications in more than one subclass or section depending on the application of the invention. Nonetheless, this study observed from **Table 4.2** that the science-based patents for herbal medicine are typically in Pharmaceuticals and Food Chemistry for human consumption (finished products) as opposed to manufacturing processes or mechanical designs. This is unsurprising as such inventions require a substantial amount of scientific work before the concept can be proven before patenting.

Table 4.2: Section and Technological Classifications for Science-based Patents

		Top 10 Technology Specialisations									
		Pharma-ceuticals	Food Chemistry	Organic Fine Chemistry	Measure-ment	Basic Materials Chemistry	Medical Technology	Bio-technology	Other Special Machines	Chemical Engineering	Other Consumer Goods
1	A - Human Necessities	1952	307	66	42	51	34	21	28	6	12
2	C - Chemistry, Metallurgy	91	52	42	4	20	2	32	7	2	3
3	G - Physics	42			76	2	2	4		9	
4	B - Performing Operations, Transporting	7	1		9	1		1	3	20	1
5	D - Textiles, Paper	1					1	1	2		2
6	F - Mechanical Engineering				1					1	
7	H - Electricity				1					1	
	Total	1952	314	78	76	57	34	32	30	20	13

4.3 Evolution of the Technology Life Cycle

Figure 4.1 shows a cumulative frequency chart based on the number of publications, patents and science-based patents. The growth of literature in herbal medicine over the 20 year period has been dramatic. This study has also noticed a dynamic co-evolution between the growth in publications together with patents and science-based patents at different stages (**Figure 4.1**).

This is similar to the notion of a tri-phase development of herbal medicine mentioned previously – with knowledge generation (I) evidenced by an increase in publications, product innovation (II) evidenced by increase in patents, and knowledge-based innovation (III) evidenced by increase in science-based patents in the snapshot of the 20 year technology life cycle (**Figure 4.1**). The tri-phase alluded here are elaborated in more detail in the discussion on the different phases of development in **Section 3.2.1**, as part of the proposed evolutionary framework of development for the herbal medicine industry. This tri-phase development was extended from the work of Xu et. al (2013) which broke down the development of China's traditional medicine system into three separate phases.

In Phase I, this study noticed that the publication activity grows at a steady rate with no patenting activity observed. This correlates with the inception of related policy mechanisms to stimulate research and development in herbal medicine research around the mid-1990s. As universities started pursuing research in traditional medicine backed by public funding, this study observed a steady increase in knowledge generation activities in screening and discovery of viable products.

This is very much the case in Malaysia where the early years were dedicated to cataloguing the existing traditional knowledge base into a working pharmacopoeia or monograph (Forest Research Institute of Malaysia 2006). This was done on a much larger scale in China where the herbs catalogued in the Chinese Materia Medica was systematically and rigorously screened to scientifically establish the medicinal properties of each herb (Xu et al., 2013).

This phenomenon relates to the ‘science-push’ observation by Schmoch (2007). In this case, the government plays a major role in developing actors (public research institutes) and encouraging universities to research in the sector.

In Phase II, this study observed firms starting to patent products with limited scientific involvement. This could be existing firms in herbal medicine looking to protect their existing intellectual property after extensive exposure to the intellectual property regime. Additionally it also points to firms looking to export their herbal medicine products into international markets with a reduced risk of being infringed. This study relates this to the concept of “market pull” where the industrial demand for innovation in the sector begins to grow. The presence of market demand for such products will stimulate the need for industry-academic linkages as the expertise for such research services are not readily found in the industry. Additionally, such professional services are very exorbitant, thus firms are open to the idea of collaborating with academia to reduce their research cost.

In turn, publication activity continues to rise as research organisations mature and develop their research capacity in this field of study. The continued rise can also be attributed to continued government commitment to the sector, which is what has been observed in the previous literature (Xu et al., 2013). This corresponds to continued support from the public sector looking to advance this sector as an economic driver. The commitment of the government through policy and national grant schemes drive the continued scientific activity which will ultimately lead to better research processes and standards, as well as the development of notable drug discoveries over time. In Phase III, this study noticed an acceleration in patenting activity and the emergence of science based patents. This could be down to university involvement in patenting based on scientifically developed herbal medicine products – bringing their products from the lab bench to potential commercialisation (to be discussed in the next section).

Patenting activity and publication activity also continued to rise sharply, which is evidence of a ‘market pull’ as larger private firms start to get involved in developing herbal medicine products. The synchronised growth of publications and patents alluded to a co-evolution of both research entities and commercial entities in developing knowledge and innovation capacity in this sector. Either university are spinning-off their own commercial entities based on their own research, or commercial firms and universities are working hand in hand to develop products in herbal medicine.

There have been such incidents in Singapore and South Korea as academics in the National University of Singapore have been approached by local private firms to conduct research on local medicinal herbs with the intention of marketing it in the future (Interview with Professors in NUS and Kyung Hee University). The other alternative is that commercial firms are engaging in their own research and development processes; however, this is counter-intuitive as firms would look to protect their results as trade secrets and avoid publishing in academic journals. In the case of the university-industry collaboration in Singapore, a compromise was struck whereby the university team was allowed to publish enough scientific evidence to fulfil their academic obligations but refrained from publishing the full extent of their research to protect the novelty and inventiveness of their findings.

In that sense, the observation of a sequential growth – of publications followed by patents and then science-based patents – is consistent with the concept of the tri-phase development of herbal medicine as presented in our Conceptual Framework. This finding provides an indication that the construct of a tri-phase development in herbal medicine is valid.

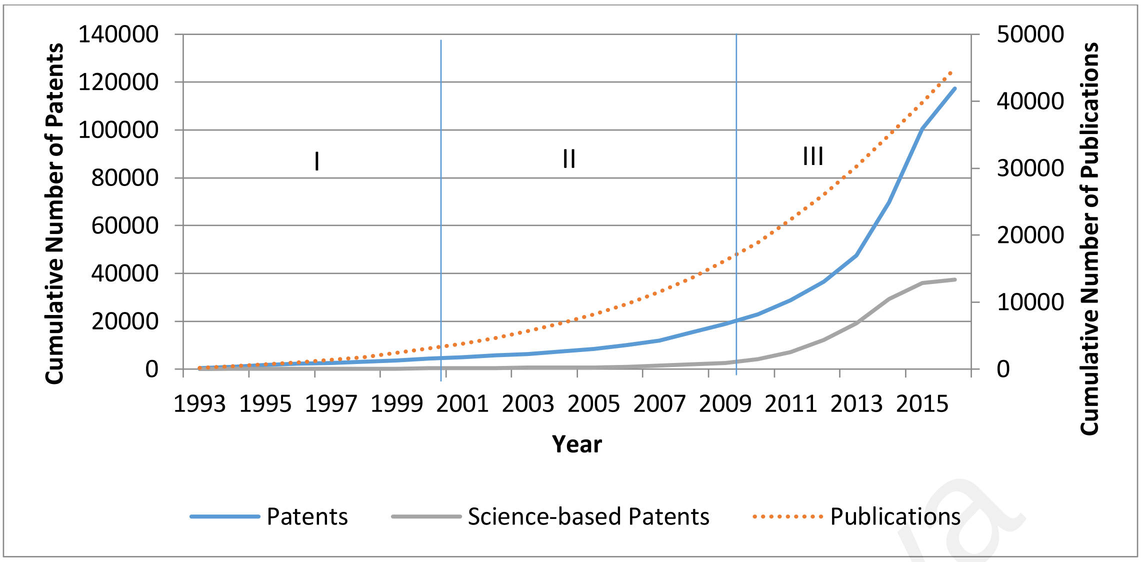


Figure 4.1: Growth in Publications and Patents (1993-2016)

The argument for this study rests on the concept that the life cycle of a science-based technological sector is driven by the emergence of technological niches within a specific sector that accelerate the development of a technological discipline at different points (Steinmueller, 1996). These technological niches not only deepen specific knowledge bases but also creates a platform for the emergence of new technological niches that capitalise on knowledge developed from different niches to emerge as hybrid technologies. This is related to the dynamic multi-level perspective on systems of innovation proposed by Geels (2004).

This conscious endeavour has more to do with the government intervention than it does with academic or commercial interest. Some quarters are of the opinion that without significant government intervention, the research and development engine would lack the critical mass to have an impact on commercial spinoffs.

4.4 Patent Keyword Clusters at Different Stages of the Technology Life Cycle

The patent keyword clusters presented in this section are generated by the Patsnap 3-D Patent Keyword Clustering tool. This tool groups patents based on the occurrence of groups of keywords that are mentioned in context with one another. Four snapshots were collected to provide a perspective of keyword clusters during various points in the timeline for this study which covers 1993 to 2016. The years selected for analysis are 1998, 2003, 2008 and 2012 based on five-year periods as this study noticed such a gap between the upturns of the various metrics in **Figure 4.1**. Since the majority of the policies stimulating the growth of this sector, particularly when the selected economies began in the mid-1990s, 1998 would see an upturn in publication activity which should then eventually spill over into other innovative activities. Therefore, this study took four snapshots to evaluate the changes in patent keyword clusters over time and describe the role of universities, firms and research institutes during this period. The maps are three-dimensional topographies of the keyword clusters based on IPC subclass commonality and keyword proximity. To read the maps, this study focused on the assignees and labels for the three most prominent clusters of each landscape to examine the profile and characteristics of the actors involved at each stage.

What this study observed in 1998 (the end of phase I of the evolutionary timeline) is the presence of several discrete clusters of patenting activity in herbal medicine (**Figure 4.2**, **Table 4.3**). As shown in **Figure 4.2**, there is one large keyword cluster in "Chinese medicine and herbal preparations" and others in "Oral allergen", "emulsion" and "food material". However, a lot of these clusters are based on the isolated incidence of patents which have little connection with each other. This is primarily because the number of patents at this point is relatively low; as the engine calculates the distribution of patents based on relative similarity and IPC commonality, this allows for peaks to be built from a smaller number of patents when the number of patents is low. Additionally, it is observed that a lot of the players at this point are individuals and firms, which allude to the patent filing of existing products, or of products with little or no scientific research base.

At this point in the evolutionary cycle, this study believes that a lot of the university activities were still at the basic science level with little evidence gathered for the development of science-based patents. Therefore, the absence of university participation in patenting sees the domination of traditionally developed herbal products for common usage such as analgesics and scalp care products which are generally sold “over the counter”.

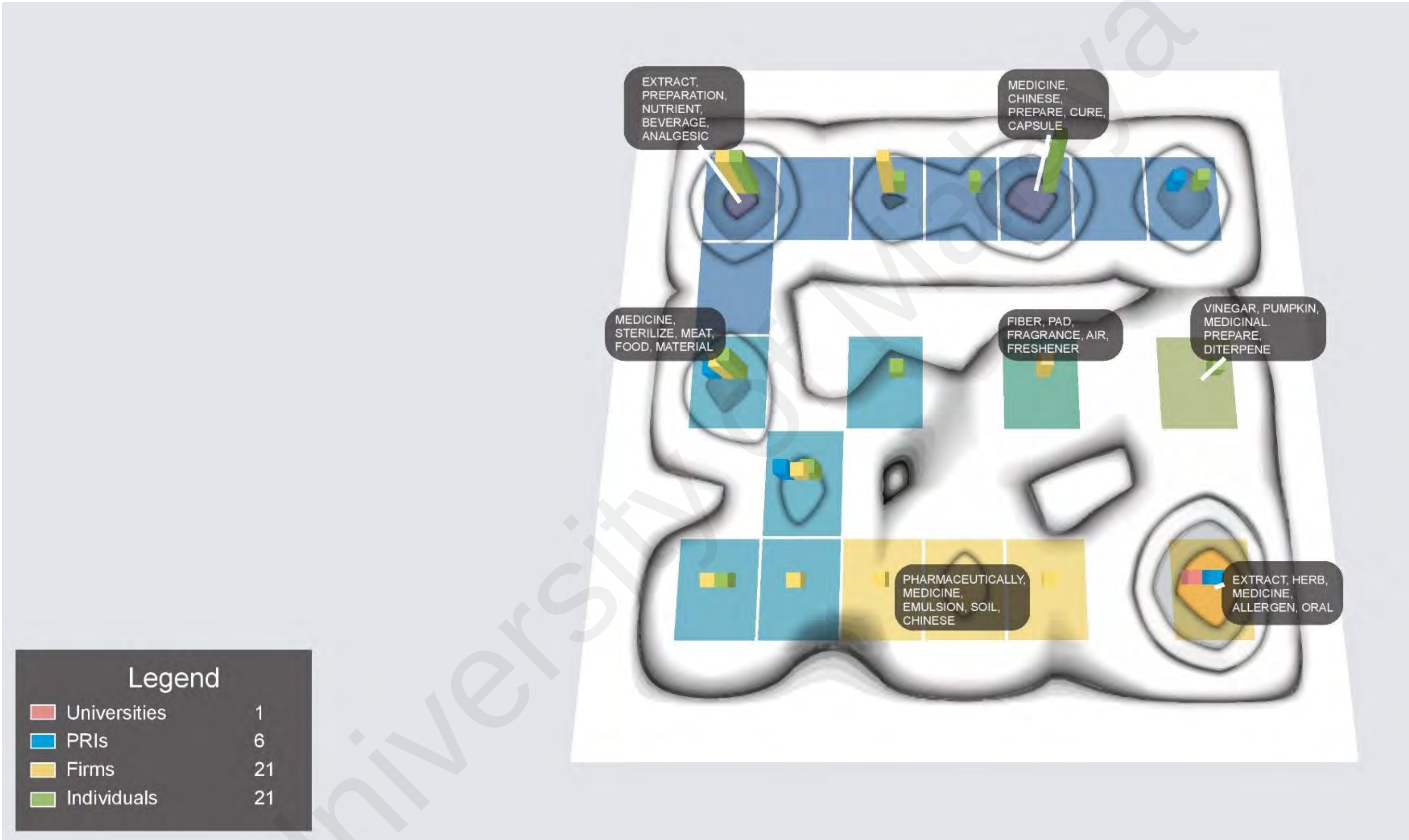


Figure 4.2: Patent Landscape in 1998

Table 4.3: Description of Selected Patents from 1998 Patent Landscape.

	Cluster	Keywords	Products	Assignees
1998		Extract, Preparation, Nutrient, Beverage, Analgesic	Pharmaceutical composition for hypersensitivity; essential oil composition; crude drug composition for constipation	Han Nan Su, Choi Hyung Ki, The Riley Fletcher Foundation
		Medicine, Chinese, Prepare, Cure, Capsule	Catheter for injecting medicaments; process for preparation of pyon-za microcapsule; Use of plant extracts for treatment of retroviral infections	Bavaria Medizin Technologie; Dong Kook Pharm Co Ltd; Sage R&D
		Extract, Herb, Medicine, Allergen, Oral	Herb composition method for treatment of baldness; toothpaste composition including herb medicines extract	Han Nan Su, Ae Kyung Industrial

This trend expanded in 2003 (**Figure 4.3**, **Table 4.4**), where the expansion of the same clusters in 1998 is observed, but with more firms and some PRIs involved in patenting activities. In this case, there is still limited university involvement in patenting activities.

A shift in the concentration of patents in certain clusters is also observed, which can be attributed to the emergence of different firms in specific product classes though the majority are still in herbal medicine for health supplements and patents related to ginseng products. Nonetheless, the medicinal application of herbal medicine (blue) is still a prominent cluster.

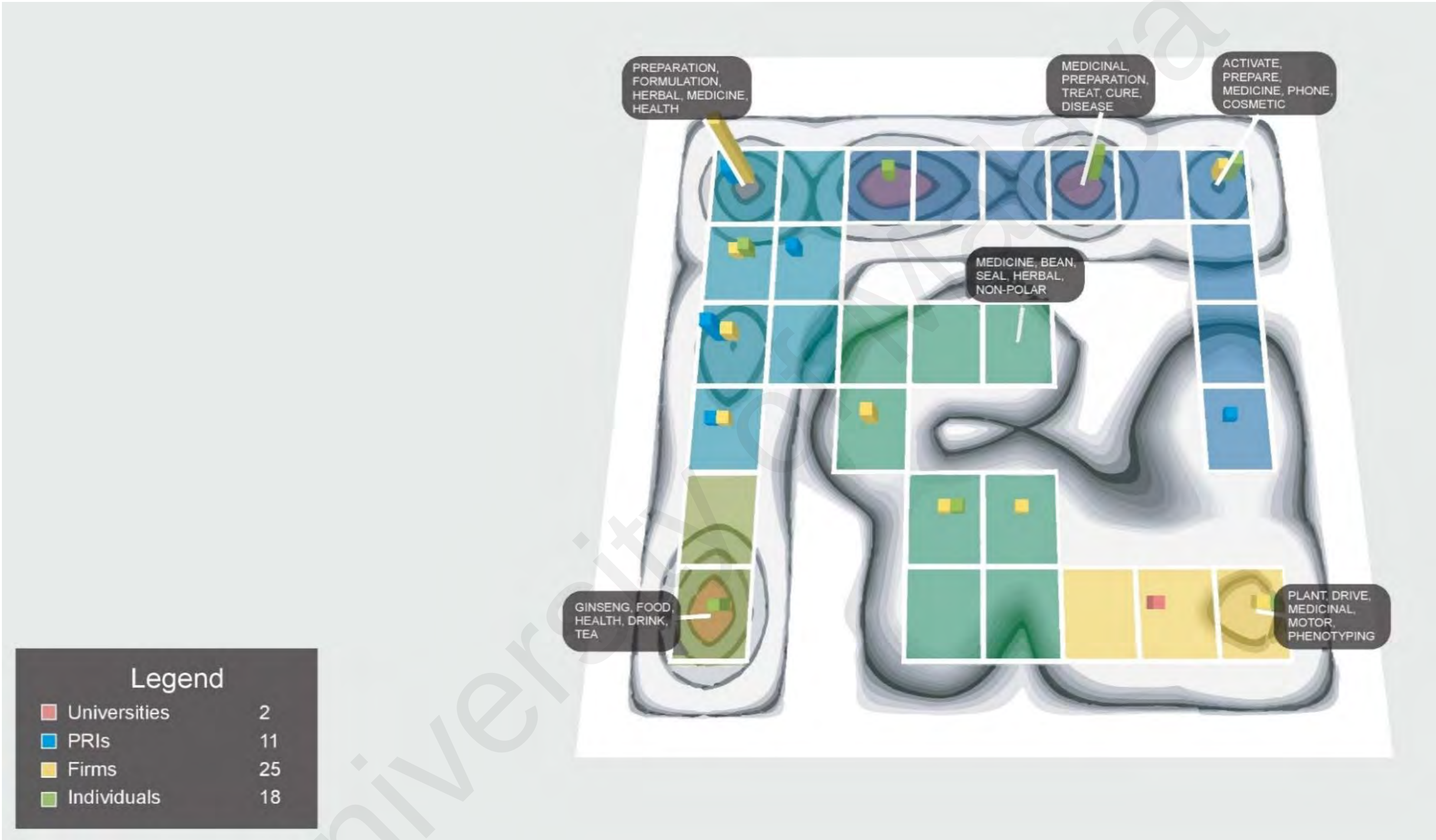


Figure 4.3: Patent Landscape in 2003

Table 4.4: Description of Selected Patents from 2003 Patent Landscape.

	Cluster	Keywords	Products	Assignees
2003		Medicinal, Preparation, Treat, Cure, Disease	Chinese medicine for curing non-gonococcal urethritis; fat loss medicine; extraction process of Chinese herbal medicine	Wang Guangyu, Kedi Pharmaceutical
		Preparation, Formulation, Herbal, Medicine, Health	Medicinal herb extract for remediation of tobacco related illness, Composition for removal of toxins, herbal formulation for treatment of cancer	Sahajanand Biotech Private Ltd; Michael Riley; Royer Biomedical
		Ginseng, Food, Health, Drink, Tea	Ginseng chicken manufacturing method, manufacturing method of charcoal fire meat, pickled sea foods with oriental medicine extracts	Jun Soon Hee; Lee Ji Ho; Kim Jong Sub

As the number of patents and publications accelerated, a very different snapshot is observed in 2008 (**Figure 4.4**). The keywords emerging from these clusters are also very different from the previous landscapes in **Figure 4.2** and **Figure 4.3**. This includes the emergence of innovations to do with “tea”, “fingerprinting”, “fermentation”, “arthritis”, “moxibustion”, “pill”, etc (**Table 4.5**).

In this case, it is noticed that the emergence of a wider variety of patent clusters in different fields which point to the entry of different technologies into the herbal medicine space. The increased diversity in the collection of patents in 2008 can be attributed to product or process development in the fringes of existing technological disciplines associated with herbal medicine or the adaptation of modern biotechnological processes into the herbal medicine innovation chain.

In relation to the evolutionary timeline (**Figure 4.1**), 2008 is when this study observes the emergence of science-based patents. The evolution of such highly scientific processes can also be due to the presence of several university players emerging into the innovation space. This study also interprets this as evidence of a shift in university policy from doing contract research on behalf of firms, to creating potential spinoffs of their research for commercial purposes. An example of this is in Hong Kong where the Chinese Medicine bill which was initially drafted in 1989 was ultimately passed in 1999 which outlined a concerted effort and investment in the development of Chinese medicine in Hong Kong. With it, came the resources to develop industry-standard research protocols and quality assurance processes, which serve as the benchmark for herbal medicine development in the region. In this endeavour, the six universities in Hong Kong have been actively involved in product development and regulatory activities, acting as a conduit with industry and government. Evidence of such case studies is presented in detail in **Chapter 5** where other members of the selected Economies are examined with regard to the extent of the relationship between research policy and technology development.

Figure 4.4: Patent Landscape in 2008

Table 4.5: Description of Selected Patents from 2008 Patent Landscape.

	Cluster	Keywords	Products	Assignees
2008		Prepare, Medicine, Treat, Herbal, Pill	Traditional medicine preparation for laryngopharyngitis; antiviral agent from plant extract; traditional medicine for treating hepatism	Army Medical College; Zhongshan University; Michael Kaufman; Zhi Nan
		Medicinal, Prepare, Treat, Disease, Arthritis	Therapeutic hydrogels for atopic dermatitis; herbal drug for inflammatory diseases; traditional medicine for rheumatoid arthritis	Korea Atomic Energy Research Institute; Tsinghua University; Sichuan Institute of Materia Medica
		Medicinal, Treat, Prepare, Extract, Disease	Herbal composition for sleep apnea, herbal mixture to improve metabolism and immunity; Herbal medicine additive for cigarette	Bio-FD&C, Kyung Hee University, Guangxi Cigarette General Factory

In 2012 (**Figure 4.5**) however, the patent clusters are observed to be shifting back to the clusters as in the early part of phase II (**Figure 4.3**) albeit with a substantially larger concentration of patents for each cluster. In this case, the keywords have reverted back to that in the earlier years with more emphasis on the base clusters (**Table 4.6**).

One explanation for this is the incubation period required for university research to be translated into viable commercial innovations, particularly when they target medical applications in the ones listed above. A possible scenario is that university-industry collaborations that were developed at the beginning of phase II required about 10 years (until the beginning of phase III) before they can be patented.

Another explanation is that the technologies noted in 2008 have been assimilated into the product innovations in the base clusters resulting in a strengthening of the base clusters higher up the value chain in herbal medicine.

However, a larger presence of university patents in this landscape is observed compared to the previous landscapes (**Figure 4.5**). The emergence of a large cluster in "medicament, cancer", "medication, blood" and "medicament, hair" is also observed, which is more technologically advanced than those in 2008 (**Figure 4.4**).

Based on the findings, it is observed that there is an evolutionary cycle of technological entry and convergence in the creative accumulation of technologies in the herbal medicine space. 2008 (**Figure 4.4**) has also observed the emergence of clusters which were generally related to different processes for medicinal preparation and treatment. This has evolved into medicinal treatment products in 2012. Additionally, a diversification of product types is observed with the re-emergence of food and beverages with herbal medicinal properties, herbal additives for livestock feed and herbal compounds used in functional foods.

All of this point to an upgrading of the technological knowledge base in herbal medicine innovation which ties back to the initial notions of convergent innovations happening in the interstices of technological disciplines presented in this study, resulting in the herbal medicine sector penetrating into new niches.

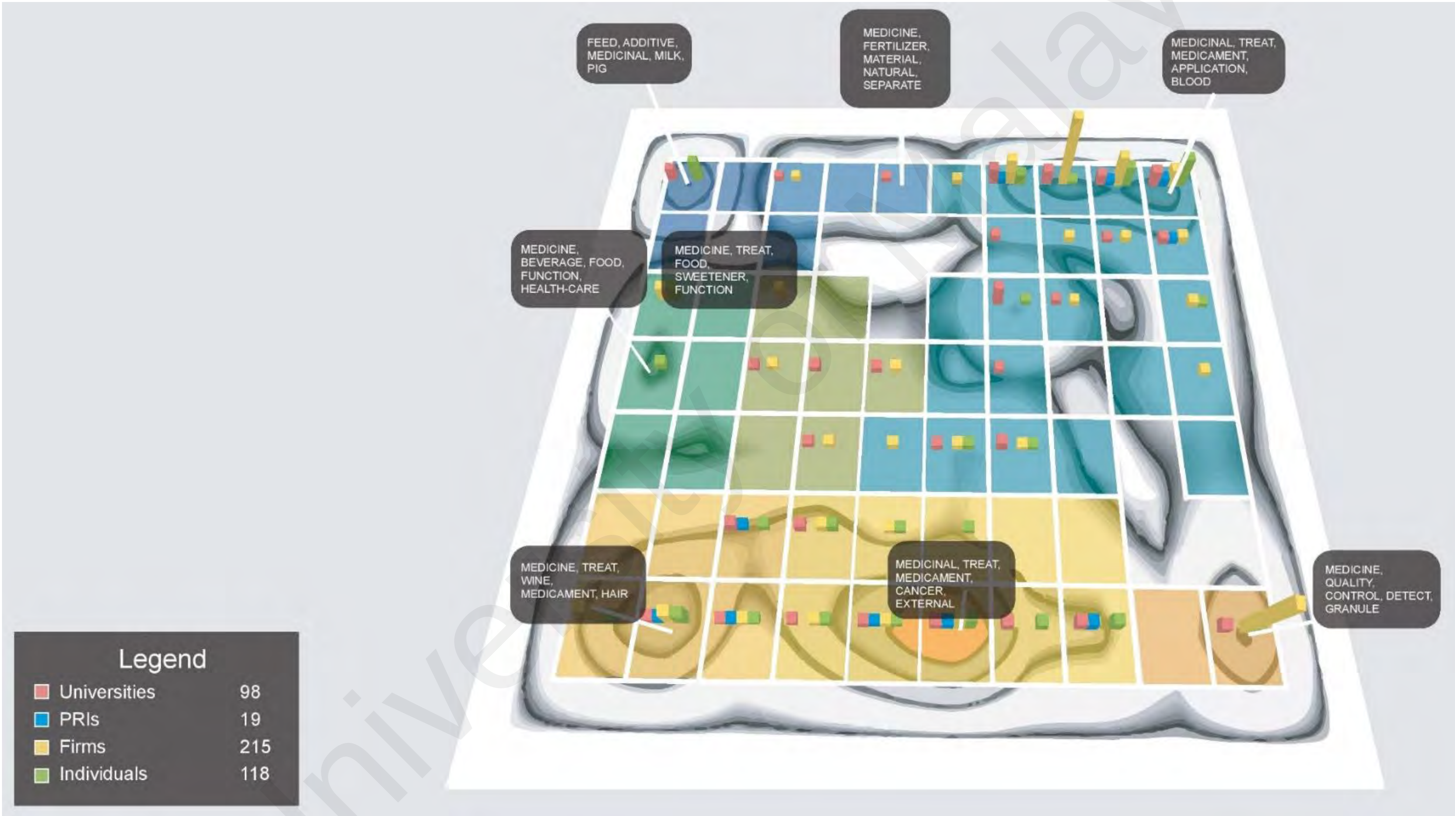


Figure 4.5: Patent landscape in 2012

Table 4.6: Description of Selected Patents from 2012 Patent Landscape.

	Cluster	Keywords	Sample of Products	Sample of Assignees
2012		Medicinal, Treat, Medicament, Cancer, External	Medicament for treating gout; Chinese medicine preparation for invigorating blood circulation and relieving pain;	Increase Pharm; Collab; Guangzhou University of Chinese Medicine
		Medicinal, Treat, Medicament, Application Blood	Application and preparation of bitter orange extract, Manyflower tickclove herb extract, Chinese medicine composition for treating hernia, Chinese herbal medicine for treating rhinitis	Fudan University; Guizhou University; Guzhi Pharm;
		Medicine, Quality, Control, Detect, Granule	Method for detecting quality in traditional medicine pills, Pu'er tea extract, quality control of xuezhining pill	Zhejiang University; Jiangnan University; Kunming Zhongyao

4.5 Summary

This chapter looked at the overall technology life cycle of herbal medicine in particular the trends of publication, patents and science based patents and deduced insights with regard to the emergence of the various indicators over time. The general statistics of the various economies involved in herbal medicine have presented the economies in question behave as regional or national actors in the development of the herbal medicine sector which drives the technology lifecycle over time. The productivity of the various economies would contribute to the transitions of the technology lifecycle from one phase to another, at an agglomerated level. This study also analysed the patent subclasses globally and looked into snapshots of the patent clusters over time and visualized how the different technologies converged over time. The emergence of a dominant patent subclass is observed after a period of time which points to a convergence of different subclasses. It is also noted that the role of universities in patenting increases over time which increases the capacity for innovation. The patent keyword cluster analysis seeks to address the notions of convergence and its role in the technology life cycle. By taking various snapshots of patent keyword clusters during key points in the technology life cycle (observed in **Figure 4.1**), this study sought to draw observations regarding the converging technologies and inventions of the time.

The results presented in this chapter was to give an overview of the technology life cycle of herbal medicine and test if there are parallels between the tri-phase concept that were proposed in the conceptual framework. Based on the emergence of the indicators here (publications, patents, science based patents), it was noticed that there are indeed three phases that can be observed (**Figure 4.1**). One observation is that there is a lack of competing technologies that have emerged as the keyword clusters revert to a dominant cluster over time. This indicates a concerted effort to move towards a "best practice" technology as opposed to a more experimental volatile landscape. This would discourage convergence over time as new technologies will be stifled and not have the resources to eventually replace or fuse with the dominant design. A deeper perspective into these indicators in the selected economies will follow in the coming chapters. **Chapter 5** will drill down into selected economies in East Asia that were studied in more detail as they demonstrated significant activity in herbal medicine research.

CHAPTER 5: INNOVATION LANDSCAPE OF HERBAL MEDICINE IN THE SELECTED ECONOMIES

5.1 Introduction

Following on from the previous chapter, this chapter delves deeper into the innovative activities that are happening in variously selected economies in East Asia. The chapter begins with a look at publication statistics, focusing on the selected economies and looks at the growth over time of publications in the selected economies as well as the research areas, and is followed by patent and trademark statistics. This is accompanied by a running comparison with research policies in the various economies together with an insight into the activities of various actors in the selected economies. The chapter is concluded with a discussion of other pertinent factors that the informants alluded to for the development of the herbal medicine sector.

5.2 Trends in Publication Statistics in Herbal Medicine in Selected Economies

This section is divided into three parts: scientific publications, trademarks and patents. For the three statistics, this study presents a case by case analysis of leading and catching up economies within each dataset to describe the active UIG actors in the specific economies. For publications, this study also presents some analysis on impact and capability, based on citation data as well as population data measured against the publication data.

Section 5.2.1 covers findings related to bibliometric analyses using the WoS and are further broken up into subsections that detail observations in separate economies, zooming in on specific characteristics that are unique to said economies. **Section 5.4.1** covers findings related to trademark and patent analyses respectively and are organised along the same lines as the previous section. As stated in **Section 3.4**., the trademark data were derived from the USPTO. **Section 5.4.2** looks at descriptive patenting trends overall with some insight into the trends for science-based patents.

The goal of this chapter is to provide an analysis of the evolution of research and innovation activity in herbal medicine over time. From there, this study sought to identify productive actors and specific policies that have driven this sector in the selected economies.

5.2.1 General Publication Statistics

The economies selected are based on similarity in terms of traditional medicine ethos being East Asian in origin (primarily Sino-centric) or having a significant Chinese population to affect the traditional medicine practice in the country (such as in the case of Singapore or Malaysia).

The selected economies have accounted for more than 40% of the world total publication share (based on ISI data) in the past eight years (**Figure 5.1**), peaking at roughly 50% and has been one of the leading regions for the growth and modernization of traditional medicine.

In total, this study considered 27,883 scientific publications. Within the dataset, the publications were mainly concentrated in China and East Asia in general with the South East Asian countries only emerging after 2003 (**Table 5.1**). When the study broke this down into WoS Categories to observe the research themes, a high concentration in the "Pharmacology Pharmacy" category was observed across the board and also in the major life sciences such as "Plant Sciences", "Chemistry", and "Biochemistry" which is conjectured to encapsulate the major fields of study relevant to herbal medicine research.

Figure 5.2 is extracted from an overall perspective of the seven economies being studied in this paper to understand the type of research being done in traditional medicine. The classifications of research is taken from the 'Research Areas' classification under the WoS, which is both exhaustive and inclusive of most disciplines in modern science.

Understandably, 'Pharmacology and Pharmacy' (32%) and 'Integrative and Complementary Medicine' (23%) takes up the largest slices of the pie chart pointing to a strong clinical component to the research landscape in traditional medicine (**Figure 5.1**). Notably, the herbal medicine policies in these economies are themed around the concept of medicine, though some have spun off into food with functional health properties, the papers with regard to the health benefits are still typically Pharmacological by nature. The presence of randomised clinical trials is required by the US Food and Drug Administration (FDA) and other regulatory bodies for the approval of new drugs and health products in the US and other markets. 'Chemistry' (20%) is the second largest area of research and alludes to research the identification, purification and chemical analysis of bioactive compounds and natural products. This commonly intersects with 'Biochemistry and Molecular Biology' as well as 'Plant Sciences', which are also prominent in the pie chart (**Figure 5.2**).

Table 5.2 breaks down the composition of Research Areas by the selected Economies. It was noticed that the breakdown in terms of Research Areas per Economy is consistent with the overall trend, however there are some minor discrepancies. For example China focuses heavily on basic Chemistry compared to the others, while Taiwan and Malaysia have a larger proportion for 'Food Science Technology'.

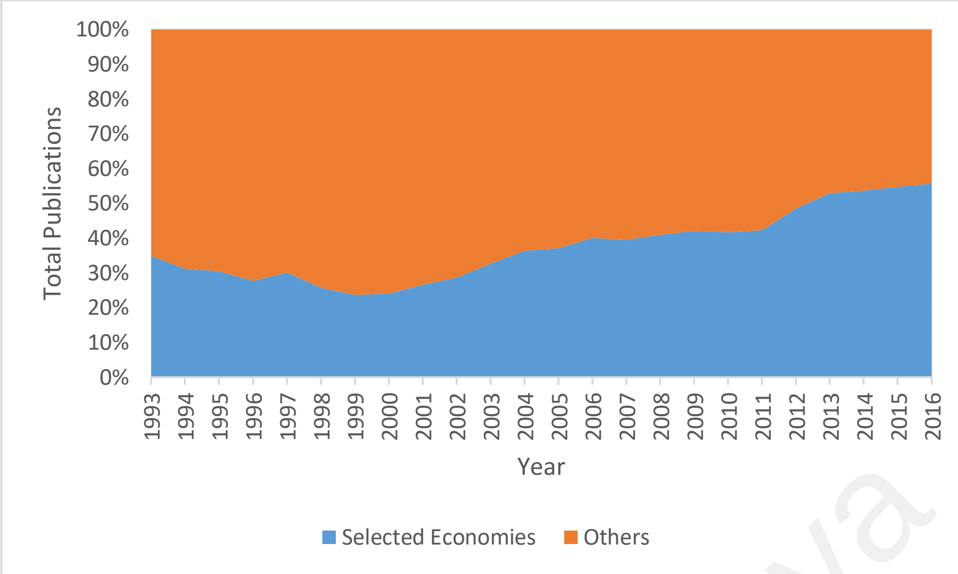


Figure 5.1: Share of Research Volume for Selected Economies (1993-2016)

Table 5.1: Research Volume per Economy for Herbal Medicine

Economy	**1993-1997**	**1998-2002**	**2003-2007**	**2008-2012**	**2013-2016**	**Total (%)**
China	111	296	1682	4850	8696	**15635(56)**
Hong Kong	51	120	402	645	632	**1850(6.6)**
Taiwan	78	150	404	836	911	**2379(8.5)**
Japan	305	475	708	940	846	**3274(11.7)**
South Korea	16	136	534	1283	1718	**3687(13.2)**
Singapore	17	31	115	120	110	**393(1.41)**
Malaysia	4	17	39	262	343	**665(2.38)**
Total	582	1225	3884	8936	13256	**27883**

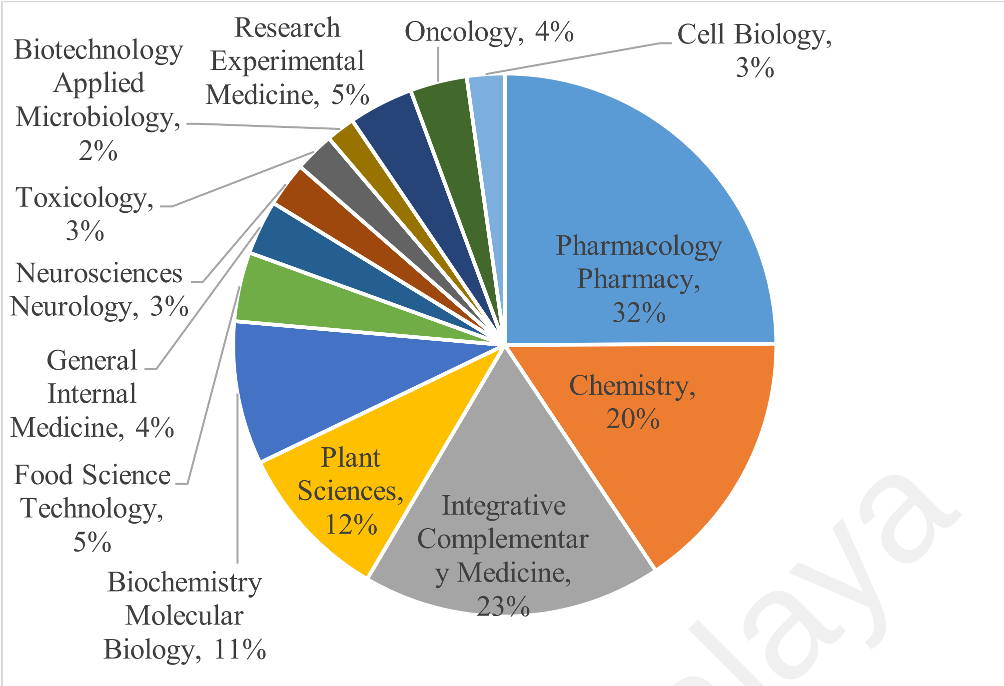


Figure 5.2: Research Areas from the Selected Economies (1993-2016)

Table 5.2: Research Areas for Selected Economies (1993-2016)

	China	Hong Kong	Taiwan	Japan	South Korea	Malaysia	Singapore
Pharmacology Pharmacy	5143	614	628	1324	1353	205	99
Chemistry	4041	307	324	300	290	83	75
Integrative Complementary Medicine	3887	444	688	572	1092	151	43
Biochemistry Molecular Biology	2213	196	178	192	330	22	45
Plant Sciences	2106	263	260	323	541	78	24
Research Experimental Medicine	922	61	122	134	170	12	11
Oncology	781	71	112	137	161	13	11
Food Science Technology	697	74	256	126	330	49	21
General Internal Medicine	645	104	172	145	133	35	41
Science Technology Other Topics	642	54	83	55	77	33	10

5.2.2 Average Citations: Impact of Knowledge Production

It was observed that Singapore has the highest growth over time in terms of average citations (**Table 5.3**). A closer look at the papers published during the 2003 and 2008 period shows several notable, highly cited papers. However, the sudden increase is more due to the significantly lower number of papers published during this timeframe, thereby exaggerating the average citations as compared to the other values.

The same could be said of Hong Kong as there was a significant decrease between 2003 and 2008 more because the number of papers doubled during this period thereby reducing the average of citations drastically. Thus, the economies with the highest impact were observed to be Taiwan, China and Hong Kong in that order.

It is also observed that the average citations in this case also points towards collaboration between universities in specific materials in traditional medicine that has warranted deeper study. This is a similar case to clinical trials, whereby extensive research is required to establish the efficacy and safety of drugs and chemicals. In that way, Taiwan shows the greatest cohesion between knowledge production and impact, based on the high ratio between citations and publications.

The rising trend of citations points to a greater impact and influence of scientific publications in from the economies below (**Table 5.3**). This would point towards internationalisation of research being carried out as well as the accumulation of the scientific knowledge base of traditional medicine.

Table 5.3: Average Forward Citations per Publication (1993-2011)

Cited Publication Year (Forward Citation Period)	Average Forward Citations (within 5 years) per Publication				
	1993 (1994-1999)	1998 (1999-2004)	2003 (2004-2009)	2008 (2009-2014)	2011 (2012-2016)
China	2.20	6.03	8.30	11.93	8.17
Hong Kong	10.63	6.00	14.77	11.43	10.61
Taiwan	7.57	7.69	10.11	14.28	8.33
Japan	4.27	5.60	6.86	11.13	8.84
South Korea	4.00	9.27	7.11	9.01	5.66
Malaysia	0.00	0.00	4.44	2.46	1.80
Singapore	2.33	1.00	16.54	17.62	18.52

5.2.3 Research Landscape and Capacity

It is observed in **Figure 5.3** that China has the largest research volume and shows the greatest amount of growth in the past 20 years. Chinese medicine has been a mainstay in China for the thousands of years and is firmly ingrained in the national medical system (Hesketh 1997). In China, approximately 60% of the population has consulted Traditional Chinese Medicine (TCM) practitioners (Cheung, 2011). TCM Is commonly practiced alongside Western medicine in Chinese hospitals at every level (Hesketh, 1997). The 1990s saw the beginning of randomized, controlled clinical trials to investigate claims for a series of TCM drugs internationally. This set off a trend of clinical trials on TCM-derived products and herbs, leading to the estimate that approximately 25% of botanical investigational new drug applications were from TCM herbs, though many were found to be inconclusive due to the low quality of trials coming from China, which correlates to the 30% for Pharmacology and Pharmacy in **Figure 5.2** (Xu et al., 2013).

Nonetheless, this explains the steep rise in research volume coming out of China since the 1990s (**Figure 5.3**). Considering the scale of the national agenda and the size of the Chinese population, estimated to be about 1.3 billion in 2013 (World Bank, 2014), it is unsurprising to find China at the top of the number of papers produced in traditional medicine.

South Korea comes in second in the research volume (**Figure 5.3**). Surveys conducted showed that use of complementary and traditional medicine in South Korea ranges from 29% to 53%, though it was noted that there is a way to go for the integration and definition in the role of physicians (Hong, 2001). Korean Oriental Medicine derives its roots from traditional medicine in the region, though there are differences that have evolved over time. The Kyung Hee University, established in 1965 with 4,053 graduates, is one of the top universities in this field of study and claims that there are 11,000 practitioners of Korean Oriental Medicine currently operating in South Korea (Kyung Hee University, 2014). The Korea Institute of Oriental Medicine was established in 1994 and focuses, not just on medical research, but also on IP creation, innovation, policy and standardisation.

The same can be said of Taiwan, another East Asian Tiger or Newly Industrialised Economies. Taiwan sits in a unique position as it is ethnically Chinese with the same TCM base as China and Hong Kong. It currently sits in third behind China and South Korea but is rapidly catching up based on the trajectory post-2009. Herbal medical research is closely tied to agriculture biotechnology in Taiwan which is a major part of Taiwan's national innovation system. Academia Sinica is highly involved with this through their Agricultural Biotechnology Research Centre, consistently publishing papers as well as patents since their inception in 1998. Dodgson (2009) notes that the scale of investment in the biotechnology sector is substantially higher than that in the IT-related industries.

Taiwan's Industrial Technological Research Institute (ITRI) – a key driver Taiwan's SME sector – does have a Herbal Medicine GMP Production Plant for Clinical/Pre-clinical Use, which is positioned as a service provider for SMEs to conduct research and testing compliant to international regulations (Industrial Technological Research Institute, 2014). The China Medical University in Taichung is responsible for 395 papers within this timeframe and is home to a Chinese Herb Experimental Farm as well as a Biotechnology Incubation Centre (China Medical University, 2014).

Japan has shown steady growth in the herbal medicine sector with the leading institute being the University of Toyama (238 papers) (**Figure 5.3**, **Appendix A**). The Japanese traditional medicine system is known as Kampo and, similar to the Korean traditional medicine system, is adapted from TCM. The Institute of Natural Medicine at the University of Toyama claims to be the only institute for traditional medicine in Japan (Institute of Natural Medicine 2014). The second largest producer of papers is Tsumura & Co. (147 papers), which is unique as most other Economies have universities or public research institutes as leading knowledge producers. Tsumura & Co. is a private firm based in Tokyo with research facilities based in Ibaraki, Japan (Tsumura & Co., 2011). Hong Kong has also shown strong capabilities which are illustrated in detail later in this section.

In terms of research volume, China, Hong Kong, Taiwan, South Korea and Japan all fulfil the criteria of modernization through scientific research. Nonetheless, China, Hong Kong, Taiwan and South Korea have stronger University-Industry-Government linkages based on the analysis of active research organisations and policy instruments. Japan does have the various components but not quite at the scale and volume of the other countries, which explains the lack of momentum in the modernization process through scientific activity. There is some resemblance to a double-boom cycle in **Figure 5.3** which is a characteristic of complex, science based technologies (Schmoch, 2007). This justifies the perspective of herbal medicine in this study and the bibliometric approach used to understand it.

The Southeast Asian countries of Singapore and Malaysia are clearly lagging behind the five other countries with a much smaller volume of research articles published in this timeframe, however after. Even after normalising for population, they are the third and fourth lowest in terms of growth (**Figure 5.4**). Despite the rhetoric of the various government agencies, there is some way to go before these economies can compete with the other Asia Pacific economies in this sector. The intensity of scientific research activity in herbal medicine supports the hypothesis that the Asian economies in question are pursuing a concerted effort to modernise traditional medicine through university research and public funding – which denotes government intervention through the various policies and public research institutes outlined above.

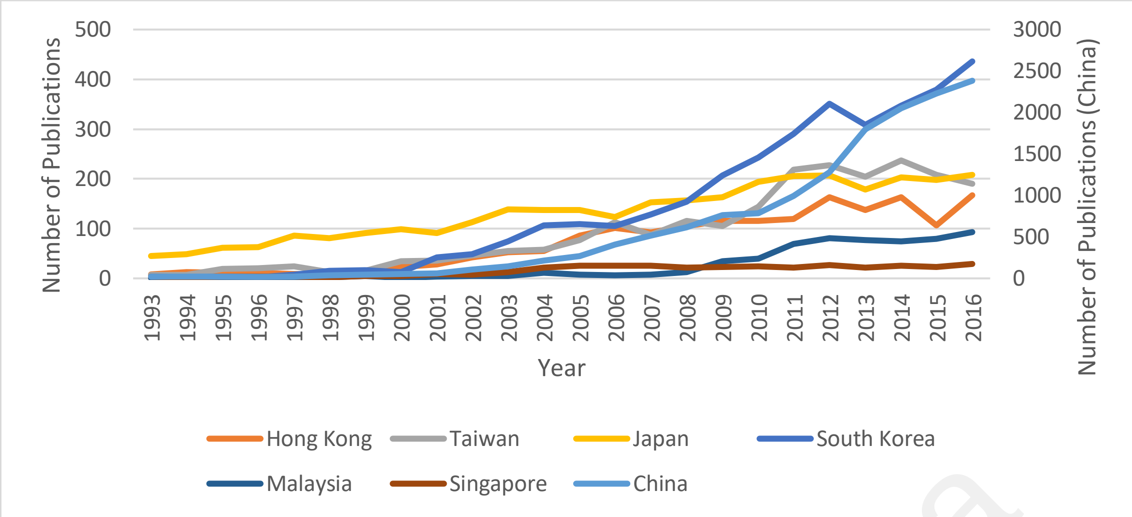


Figure 5.3: Research Volume over Time (1993-2016)

Hong Kong shows the greatest amount of scientific capability and growth in research volume per million population based on **Figure 5.4**. This is in line with the government's push for progress in the TCM sector and coincides with the establishment of the Institute of Chinese Medicine at the Chinese University of Hong Kong (CUHK) in 2000, the institute happens to be the most prolific publisher of scientific papers during this period. Also, the University of Hong Kong established the School of Chinese Medicine in 1998, thereby setting the foundation for the spurt in the early 21st century.

Also, 1999 saw the formation of the Chinese Medicine Council of Hong Kong, thereby implementing the licensing system for Chinese medicine traders as well as evaluating the safety, efficacy and quality of proprietary Chinese medicine products before release. This came as a culmination of several levels of policy development beginning with the Working Party on Chinese Medicine in 1989. Following several reports and public consultations the Chinese Medicine Bill was passed in a legislature in July 1999, kick-starting the concerted effort to develop the TCM sector in Hong Kong (Chinese Medicine Division, 2010).

The Innovation and Technology Fund under the Innovation and Technology Commission, Government of Hong Kong SAR, has spent HKD99.9 million on projects related to Chinese Medicine and a further HKD502.3 million on projects related to Biotechnology (which also covers the modernization of TCM) (Innovation and Technology Fund, 2014). Additionally, a consortium of universities coordinated by CUHK approved funding of HKD33.92 million to promote the modernization of TCM and provide clinical trials for TCM development. This has led to the development of a 'unique evidence-based scientific model for Chinese medicine research' (Chinese University of Hong Kong, 2014).

These various factors, (i) legislative willpower, (ii) financial backing, and (iii) quality human capital, supports the surge in scientific activity in Hong Kong. It took 10 years between the initial conceptualisation of the innovation system to the establishment of the Chinese Medicine Bill.

This study conjectures that the strategic push in the direction of TCM is a knock on effect of the biotech boom that was abuzz at the turn of the millennium. In an effort to jump on the biotech bandwagon, TCM was identified as a sizeable knowledge base that had strong links with the biological sciences. Regardless of the success of the biotechnology sector, Hong Kong has shown the will to plan, invest and execute its TCM agenda; which has lead to its position in the TCM market today. Recent years (2012-2016) has seen some turbulence in the growth of the research capacity, nonetheless, Hong Kong is still very much ahead of the other selected economies in this regard.

Taiwan and South Korea also show a growing capability in this sector. As mentioned earlier Malaysia and Singapore are in the middle of the pack, while Japan and China are lagging behind in this regard. The high population of China in respect to the other economies does distort their capability, but upon further inspection, this study noticed a distinct collaborative relationship between the innovation systems of China and Hong Kong in this sector, which presumably owes itself to the unique political and cultural relationship between the mainland and Hong Kong.

Thus –in terms of research volume and capability – Taiwan, South Korea, Hong Kong and China would fit into Phase III of the conceptual framework. By the same logic, Japan, Malaysia, and Singapore would be placed in Phase II due to the absence of capability, volume or both.

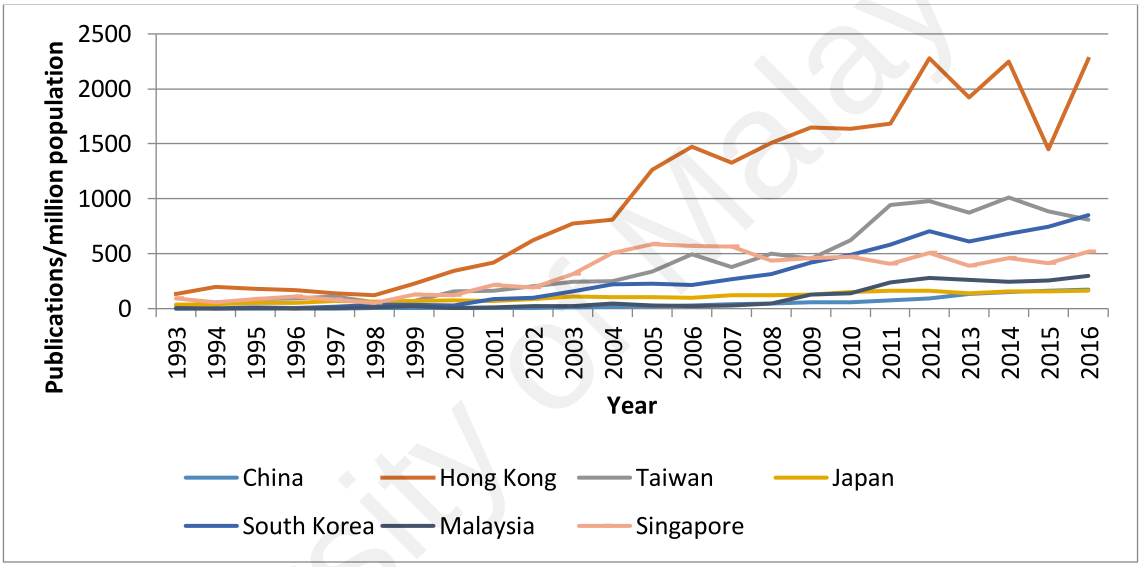


Figure 5.4: Research Volume over Time per Million Population (1993-2016)

As far as research impact is concerned, Singapore and Taiwan have shown the greatest impact, well above the world average (**Figure 5.5**). This shows that Singapore has the potential to produce impactful research, but does not have the research volume as shown in **Figure 5.4**. Economies such as China, Hong Kong and Japan are hovering below the average while South Korea and Malaysia are lagging behind.

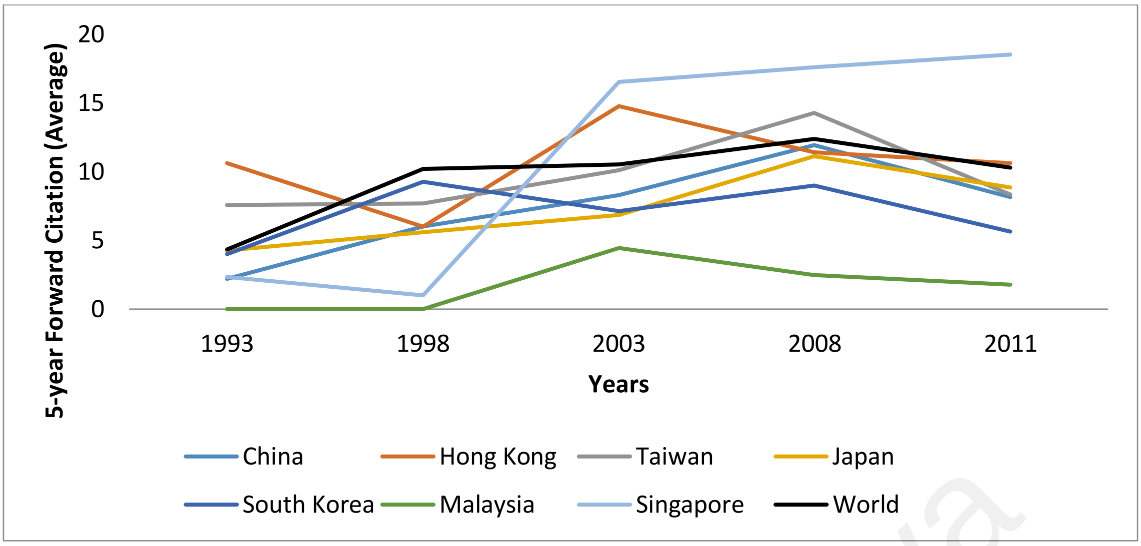


Figure 5.5: Research Impact of Selected Economies (1993-2011)

Hence, while the selected economies have been responsible for a sizeable research volume, the impact has been relatively average which mirrors the niche nature of the research being conducted and the routine nature of the methodology in herbal medicine drug/product discovery and development. **Appendix A** presents a breakdown of the top twenty organisations involved in publications for the selected economies. The study also noticed a sizeable number of universities and a major presence of PRIs. Japan, uniquely, has a firm (Tsumura & Co.) high on the list of authors. The study also noted the Chinese Academy of Sciences heavily involved in collaboration with several other countries, Hong Kong, Japan and Singapore; while China Medical University Taiwan is also prominent in the list of organisations found under the China bracket.

5.2.4 Growth in Scientific Capability

The selected economies have shown a significant growth in capability in the past 20 years, represented by the growing proportion of research volume against population statistics.

In this case, Hong Kong shows the greatest capability followed by Taiwan, South Korea and Singapore (**Figure 5.4**). This study conjectured that the fast growth of capability is due to the fact that universities take the lead in the innovation of this industry as compared to the other countries. Universities are primarily focused on the production and dissemination of knowledge, where effectiveness is measured in the quantity and quality of papers published. Moreover, the nature of universities as teaching institutions enhances the assimilation of new researchers; which means that over time, university teams become larger and more active provided that ample funding is provided. This study also noticed the interest of Chinese organisations in collaborating with various organisations from outside of China, most notably in Hong Kong. This will be explored in greater detail in the following chapter.

Countries such as South Korea, Taiwan and Japan show a stable rate of growth in capability (**Figure 5.4**); which can be attributed to the fact that science is being led by PRIs or industry (**Table 5.4**). As PRIs and industry are more focused on the commercial application of knowledge, the research is more targeted towards specific goals in line with either government or corporate strategy. It is observed that most PRIs are more interested in patenting or technology licensing (which would require non-disclosure), thus although they still publish, the primary concern of the PRIs in producing and protecting intellectual property would supersede the need to produce academic publications.

In Japan, capability growth is slower in comparison to the other countries, but yet significant. This study conjectures that herbal medicine has less priority in national innovation compared to other growth areas. Nonetheless, Japan's innovation in this field is led by industry, which is not too dissimilar to how PRIs work, but probably with less resource allocated for research. It is also noticed that Japan has the highest proportion of industry involvement in academic research at 19.92% (**Table 5.4**). This implies that scientific publications are more inclined towards assessing new products or 'blue sky' research, while industrial firms are more interested in focusing research in product development which is less novel – which increases the difficulty or relevance in publishing in peer-reviewed journals.

Table 5.4: Share of Economy Research Volume based on Entity Type (1993-2016)

Economy	Entity Type (%)			
	Academic	PRI	Hospital	Industry
China	96.99	6.48	10.2	4.14
Hong Kong	96.62	4.41	10.13	3.08
Taiwan	95.50	15.65	34.46	4.28
South Korea	94.99	23.65	2.55	5.75
Japan	91.40	8.47	10.28	19.92
Malaysia	98.65	7.43	6.08	0.00
Singapore	91.04	18.66	14.18	8.21

Figure 5.6 shows the rate of growth for publication capability – publication capability is defined as the research volume over the population (in million) of the specific economy in this case – over time. This figure represents the rate at which capability is developed over time in the particular economy. In this case, we present three-year averages (the label

being the middle year of the three) to reduce the noise in the Figure due to the volatility of the data. **Figure 5.7** and **Figure 5.8**, on the other hand, show the 10-year average and the standard deviation of the values in the various years.

As mentioned previously, China and Japan maintained a volatile growth rate with China tapering off towards the end of the time period. The other economies demonstrated more volatility in this case, especially Malaysia and Singapore being the most prone to fluctuations in growth rate. This could be due to the substantially lower numbers for both Malaysia and Singapore. The study observed that the peaks in the graph coincide with key policies being introduced as alluded to in **Section 2.2.2** to encourage the growth of research in this sector, after which growth is significantly reduced due to the long research gestation periods as is the nature of the research projects. Nonetheless, a second growth spurt in recent years (2009-2011) can also be observed, which alludes to another round of capital injection into this field of research, to complement the pressing demand for traditional medicine in primary health care. China and Hong Kong still have high production in research volume, although the data show a tapering off in growth rate. The standard deviation in the data is also shrinking over time, which indicates convergence of the various trajectories over time (**Figure 5.8**).

The data points to a strong commitment to scientific endeavour in traditional medicine although the more advanced nations are tapering off their interest. Conversely, economies such as Malaysia and Singapore are catching up in terms of scientific output; which could see these countries emerging as potential new hotspots for the industry in coming years. Although Malaysia and China show a continued commitment to the sector, there is a relative contraction in the other selected economies in this study **(Figure 5.7**).

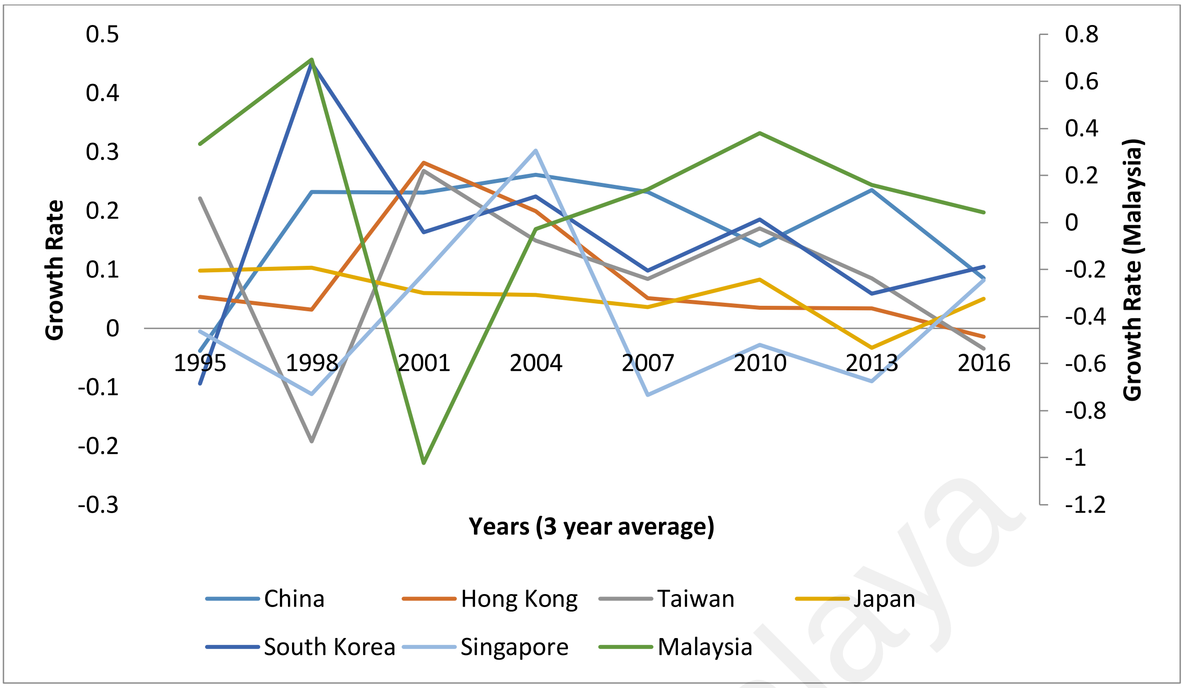


Figure 5.6: Growth Rate of Research Capability[7] (three year average) (1995-2016)

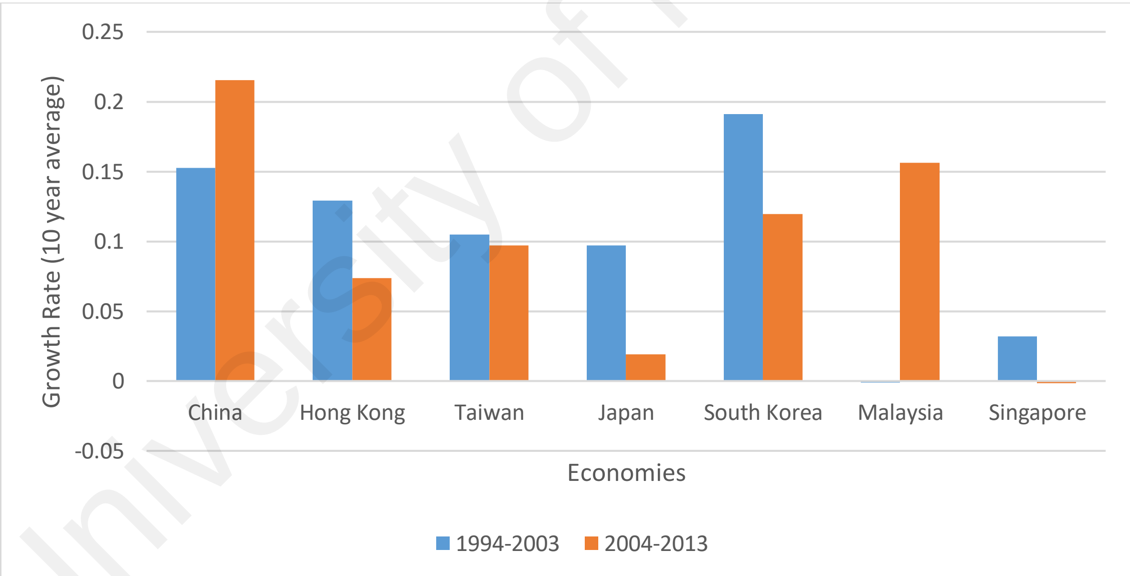


Figure 5.7: Growth Rate of Publication (ten year average) (1994-2013)

[7] Malaysia is plotted on the secondary axis in Figure 5.6.

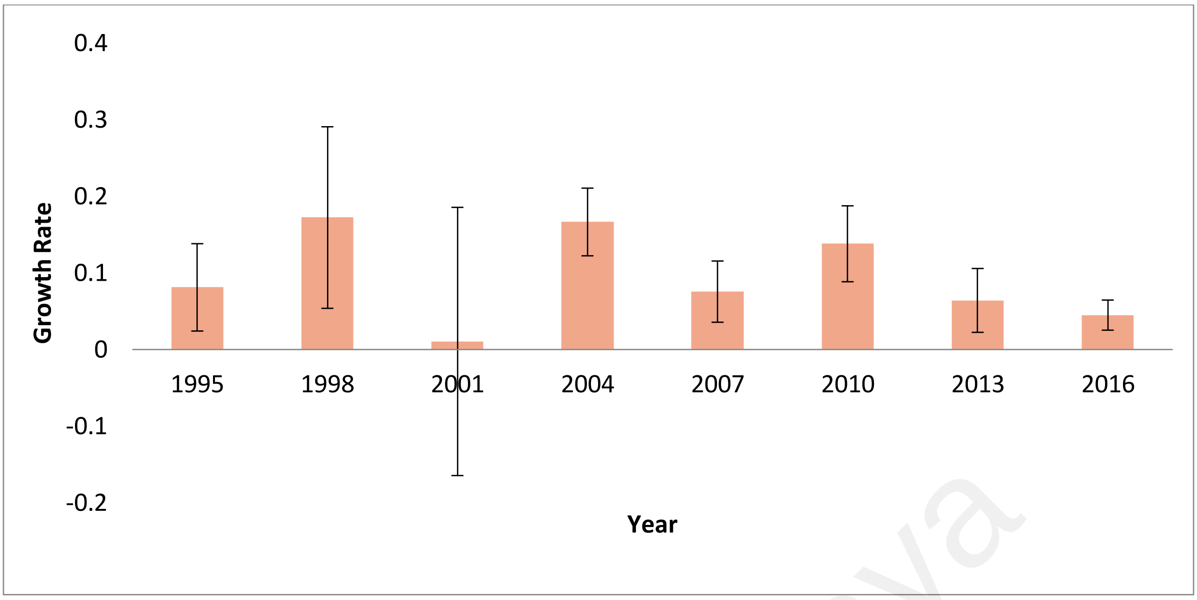


Figure 5.8: Yearly Average of Growth Rate for Selected Economies (1995-2016)

5.3 Comparative Advantage of Selected Countries in Publications in Herbal Medicine

This section presents the comparative advantage of the selected economies through the use of Revealed Scientific Advantage. The scatter plot below shows the position of the economies in relation to two variables, Revealed Scientific Advantage and Publication Share (of the selected economies). The plot is then separated into four quadrants which shows the level of competency against the prominence of the particular research area in relation to the rest of the life sciences. To recap **Section 3.3.1**, the top right quadrant shows an economy that has developed core competency, where the technology is an integral part of the technology profile, the bottom right quadrant shows niche competency where the economy has shown comparative advantage but only in specific areas, the bottom left quadrant shows marginal competency where there is neither priority or distinct advantage, and the top left quadrant shows background competency, where the economy in question is active in the larger technology profile but not in this particular technology.

In the scatter plot below (**Figure 5.9**), four distinct groups of economies clustered according to the classification above can be observed, with China in Quadrant I, South Korea, Malaysia, Taiwan and Hong Kong in Quadrant II; Singapore in Quadrant III and Japan in Quadrant IV. Evidently, China has had the lion's share of publications due to the sheer scale of their research activities backed by their greater critical mass of researchers and resources. However, their comparative advantage is similar to South Korea and Malaysia; lagging behind Taiwan and Hong Kong in that respect.

China is observed to have improved drastically in its share of publications in the last ten years, rapidly consolidating their research activities (Xu et al., 2013); however, they fail to add comparative advantage compared to their counterparts. Thus, this study deduced that the priority of the sector in China has remained fairly unchanged over the past ten-years, although the critical mass of research in this field has scaled up in time.

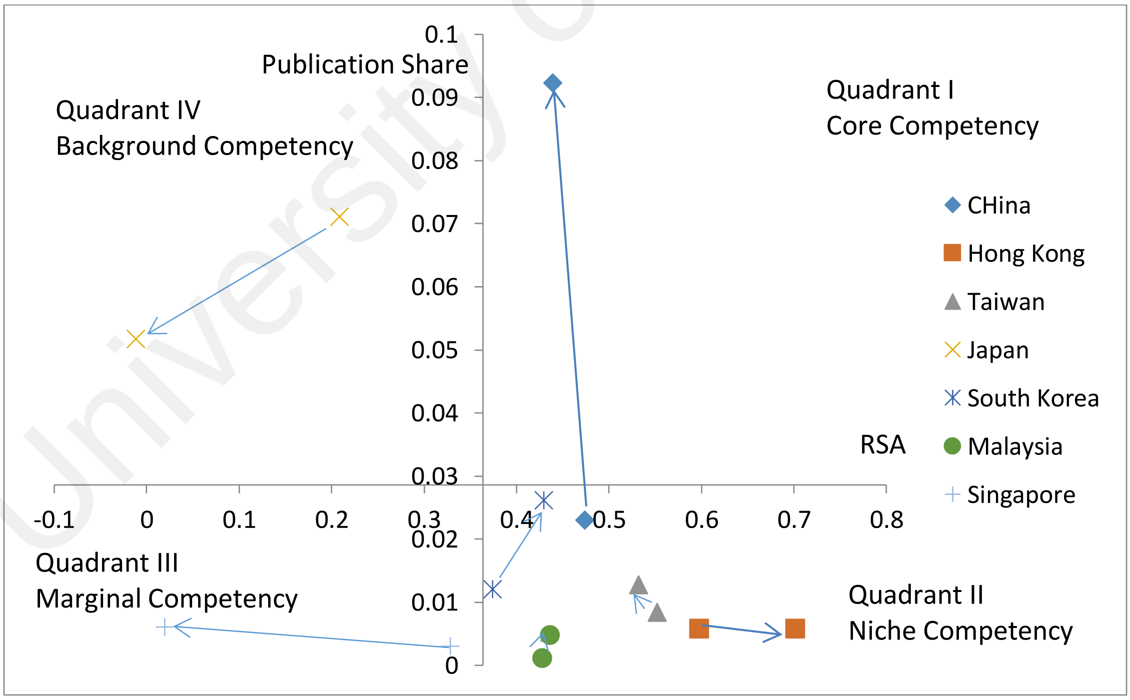


Figure 5.9: Research Profile of Selected Economies (Average of 1998 to 2002; to an average of 2008 to 2012)

In Quadrant II, it is observed that Hong Kong and Taiwan have a greater comparative advantage compared to the other countries, but are focused on niche areas, depicted by the low publication share. This study conjectured that this shows strong political will (which is a major determinant of research priority) with a target-specific research strategy to fully utilise their limited resources. The same can be said (albeit to a lesser extent) of Malaysia and South Korea, although South Korea has a greater share of publication compared to its peers in Quadrant II. Hong Kong has increased their comparative advantage; moving further to the right, thus showing an upgrade in their research activities, while South Korea has shown a growth in terms of share of publications, moving closest to the average values of the selected economies.

Singapore is on its own in Quadrant III showing the low allocation of resources as well as a low comparative advantage. This is consistent with the current rhetoric coming out of Singapore's biomedical research policy in developing competence in Western biomedicine. Though traditional medicine is widely practiced in Singapore, research has only recently been backed by the government which explains the lack of activity during the timeframe studied. There has been a significant regression in terms of RSA in Singapore, showing a sizeable reprioritisation of resources from traditional medicine research. This is consistent with Singapore's positioning as a biomedical hub which saw a greater portion of funding allocated to clinical and biopharmaceutical research, but crucially not for herbal medicine research in past years. Nonetheless, the introduction of the Clinical Research Grant for Traditional Medicine in Singapore shows intention from the government in driving this field forward.

Japan, on the other hand, has shown a high allocation of resources, but a low comparative advantage (Quadrant IV). Japan showed the highest number of publications at the beginning of the time scale with a steady increase year on year, although it was quickly overtaken by the economies from greater China (China, Hong Kong and Taiwan). Also, interestingly, Japanese industrial firms are involved in scientific research; which can mean that the focus has shifted from intensive drug discovery to the development and enhancement of existing products.

It is deduced that Japan has a general policy in terms of scientific policy depending on a general knowledge spill over effect driven by firms as opposed to a 'top down' mandate for research to be done in niche areas. This has led to competence being built in all aspects of biosciences including traditional medicine. However, the selection of environment or local demand for such research ultimately drives the level of interest in this sector which, in this case, is relatively low in terms of comparative advantage. This points to a mature innovation system which is open to market forces as opposed to those in the other economies that are more protected by the State.

5.4 Trends in Innovation Statistics in Herbal Medicine for Selected Economies

Trademarks represent the commercialisation of products and the brand presence of firms entering particular markets. As an innovation indicator, trademarks can be interpreted as a measure of firm activity and internationalisation.

5.4.1 Trademark Statistics

Figure 5.10 shows the distribution of trademarks based on the International Classification of Goods and Services (Nice Agreement), which has been the primary classification for marks at the USPTO since 1973. The chart details the five most common classifications used in marks in herbal and traditional medicine filed between 1993 and 2012. Trademarks can be filed with multiple classifications, allowing companies to hold a diverse number of products using a single trademark.

The most significant classification is the Pharmaceuticals (005) class, followed by the Staple Foods class. This supports the notion of utilising trademark data as a proxy for innovation of traditional medical products, showing that a large proportion of the companies have commercially viable medical products aimed at the US market.

Staple Foods (030) is also quite significant which accounts for products such as coffee, tea, and other edible ingredients. This is justifiable as this study included herbal teas, which is commonly infused with medicinal herbs for preventative health properties, as a part of the definition of traditional medicine presented earlier. It is conjectured that the USPTO data would have a correlation to the landscape in China where public acceptance of traditional medicine is culturally more acceptable.

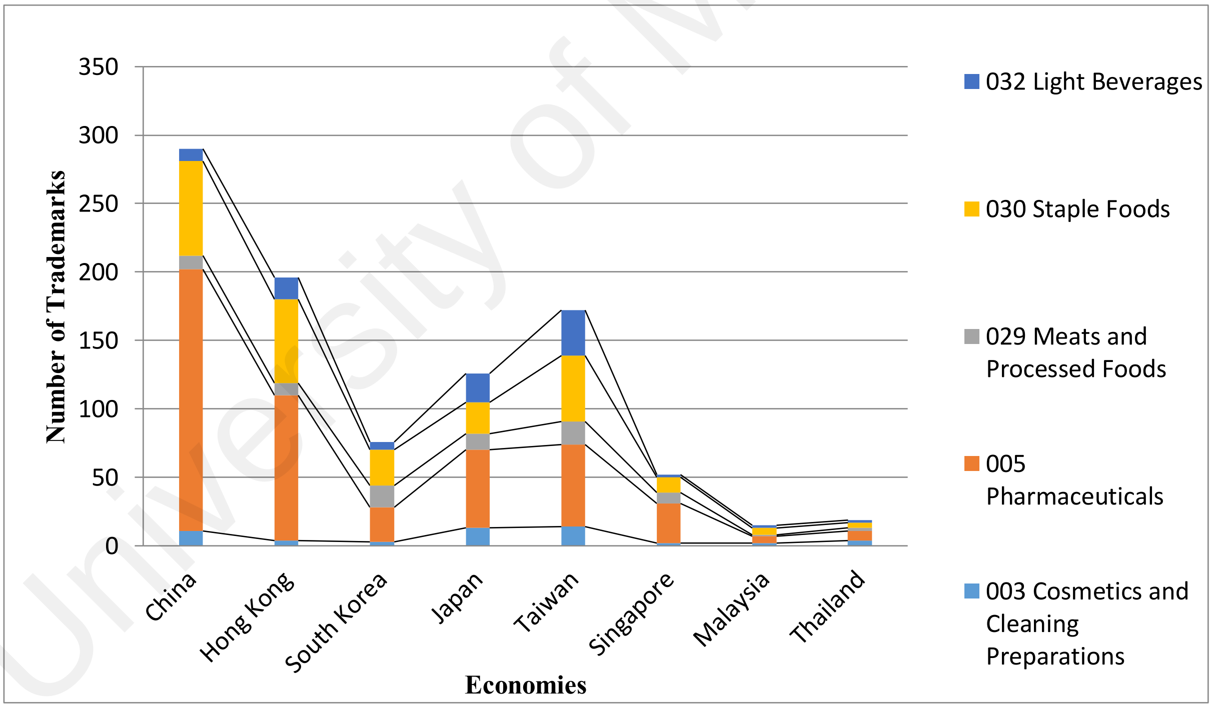


Figure 5.10: Distribution of Trademark Classifications (1993-2016)

The data suggest that China, Hong Kong and Taiwan are the key exporters of traditional medicine products in the US market, which correlates with the findings presented in this section in terms of knowledge production (**Figure 5.11**).

As mentioned in **Section 2.2.2**, China's export volume is well documented and this is another example of the innovative capability of the country, particularly in a field that depends so heavily on indigenous knowledge. Taiwan and Hong Kong have a similar profile though Hong Kong may have peaked earlier than Taiwan. Hong Kong seems to focus more on Pharmaceuticals, compared to Taiwan (**Figure 5.11**), working off their network with the mainland; which could explain why Taiwan seems to have a greater edge as Foods, Beverages and Cosmetics would be less scrutinized compared to Pharmaceuticals in export markets; which would require less time and effort to develop and commercialise.

A point worth mentioning is the fact that Hong Kong has tapered off in terms of trademark registrations after 2009. This loss of momentum could be temporary, pointing to a reprieve due to the economic downturn of 2008. After normalising the data based on population, Hong Kong[8] is clearly the leader in terms of trademarks registered in the US followed by Singapore and Taiwan (**Figure 5.12**). Singapore has shown an upsurge in 2008-2012 in terms of innovation capacity with the presence of several multinational companies operating in the traditional medicine business (such as Eu Yan Sang) (**Figure 5.12**).

South Korea has shown a surge in trademark registrations in 2008-2012, which correlates to the steep increase in papers published in the same period (**Figure 5.2**). This study believes that South Korea is adopting a tried and tested 'fast follower' approach to the traditional medicine industry, mimicking the internationalisation strategy that is pursued by China and Hong Kong. The trend observed can also be the result of bio-based

[8] This study conjectures that the strength of innovation Hong Kong owes significantly to investment and participation from firms in China. The rigorous nature of the Hong Kong innovation system and advanced standard of research and development makes the Special Administrative Region an attractive location to launch TM products for export. Manufacturing in China, although much more cost effective, does carry its own stigma with regard to health products, which is why Hong Kong is used as a conduit to international markets.

industries gaining interest in South Korea in recent years as is the spread of Korean popular culture (food, cosmetics, and beverages).

Japan has shown a steady increase in trademark registrations in this field, similar to Malaysia, which indicates a market developing based primarily on natural market forces with minimal intervention from the public sector. This study has observed that Japan is primarily driven by established firms such as Tsumura & Co., Ichimaru Pharcos Co., Ogawa & Co., and Hisamitsu Pharmaceuticals. The assumption is that firms are driven primarily to develop or build on existing product ranges to consolidate their market share and are not necessarily concerned with spinning off new companies. This is the reason fewer trademarks are observed to be hitting the market as the established firms dominate the product development chain and the environment discourage new start-ups to enter the market.

Singapore and Malaysia, on the other hand, have shown very little trademarks over the years. This can be attributed to a much more academic interest and lack of commercialisation opportunities for the research being conducted there. The mass of research activity (as seen in the previous section) is also much lower than the other economies being studied, which would also explain the lack of commercial potential for the products being researched.

Thus this reinforces the view that China, Hong Kong, Taiwan and South Korea sit firmly in Phase III of the conceptual framework as they have managed to penetrate into the US market much better than the other countries in this study. Singapore has shown greater performance in trademarks than research, but this can be attributed to the presence of multinational Traditional Medicine companies headquartered in Singapore such as Eu Yan Sang, Sindor Healthcare, and the BodyHealth Corporation, who are prolific in trademark registration, thereby exaggerating the strength of the innovation system.

The upward trend (**Figure 5.5**) corresponds with the trend seen in the publication statistics presented previously (**Figure 5.2**), which suggests a 'knowledge spill over' phenomenon from university research into commercial value. However, the linkage between industry and university needs to be explored further in order to support this conjecture.

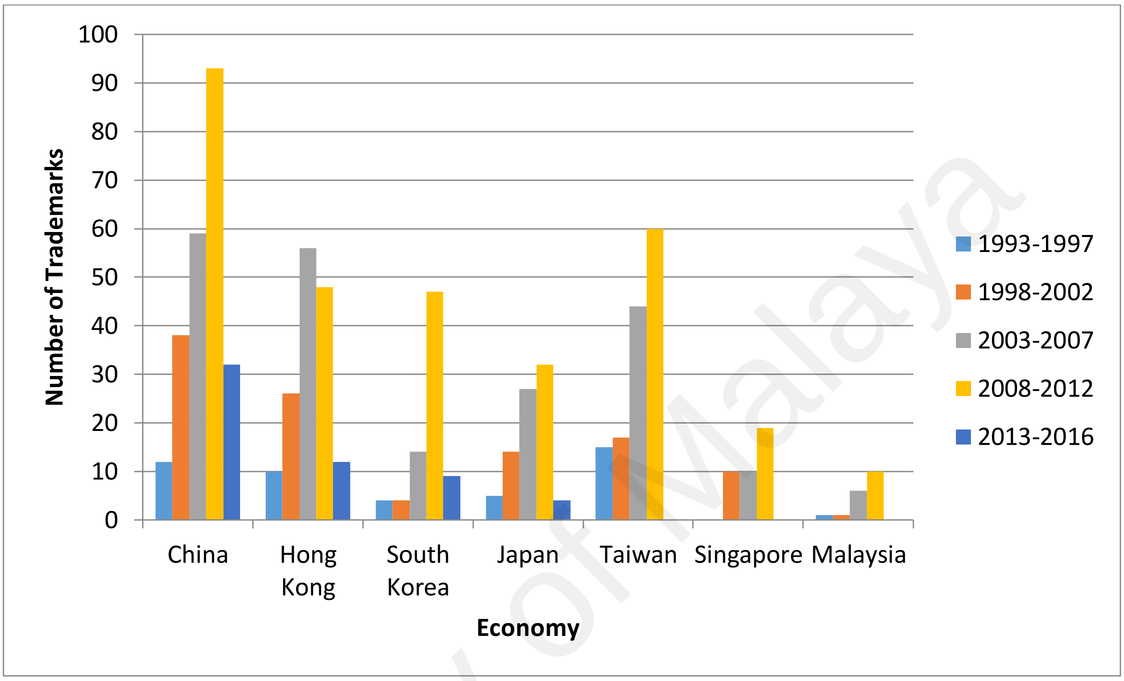


Figure 5.11: Total Trademarks (USPTO 1993-2016)

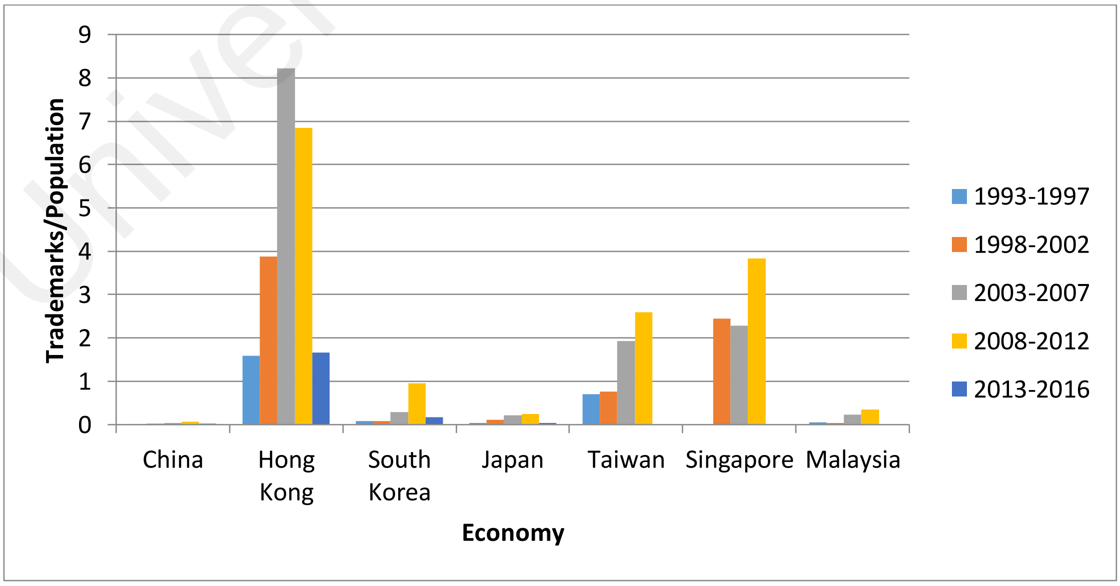


Figure 5.12: Trademark Registrations per Million Population (1993-2016)

Table 5.5: List of Productive Firms in Trademarks (WIPO data) (1993-2016)

Holder	Number
Hong Kong Shen Long Tong Medicine	80
JDB Asset Management Ltd	59
Multi Access Ltd	52
Kusum Pharm LLC	50
Caruso's Natural Health Pty Ltd	40
Delta Medical Promotions AG	39
Vitamin Shoppe Industries	38
Mercury Pharma Group	37
The Pharmaceutical Plant Company	27
Scitec International	24
Oni Global Pte Ltd	21
Vita Green Health	18
Cordlife Group	18
Eu Yan Sang	17
Vitamins Direct Ltd	17
Sigma Company	16
Yunnan Baiyao	16
LKK Health Product Group HK	15
Bioprogress Technology	14
Life Essentials GmBH	14
Hutchison China Meditech	14
Nin Jiom Medicine Manufactory (HK)	13
Purapharm International HK	13

5.4.2 Patent Statistics

In addition to the patent statistics presented in **Chapter 4**, this study noted that patent numbers have gone up considerably from the year 1999 onwards which ties in with the increase in publication numbers as discussed in **Chapter 4**. The rationale for the delay in growth for the number of patents has to do with the lag time required for patents to be applied, filed and granted. This process varies from patent office to patent office.

Figure 5.13 shows the growth of patents over time in the various economies. It is noted that the growth of patents is gradual for South Korea and Taiwan over time, with South Korea having a steeper gradient. However, the trend for China increases dramatically in recent years, particularly due to the release of the TCM Patent Database by the Chinese Patent Office. The database allows for the patenting of medicinal formulations of herbal medicines and is designed specifically for this sector. Therefore, a dramatic increase in patents in China was noticed as the database gained popularity.

On the other hand, Hong Kong, Singapore, Malaysia and Japan have limited patents although they do have some patenting activity. These are attributed to the patenting activities of particular firms that are actively looking to protect their unique manufacturing processes and formulations for their exported products.

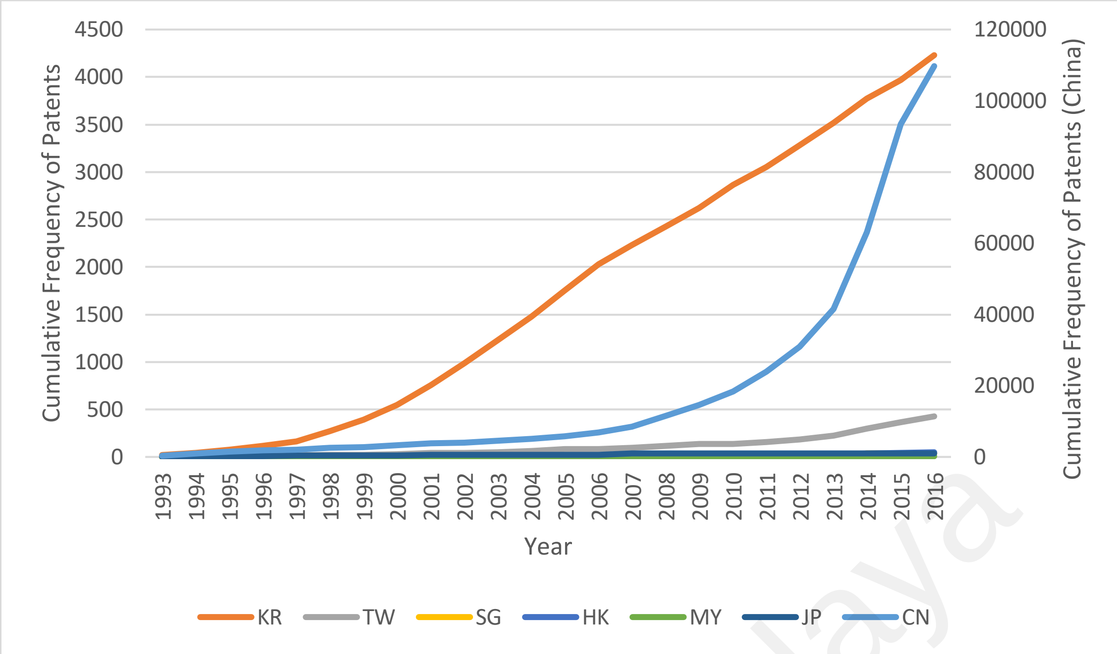


Figure 5.13: Total Patents over Time (1993-2016)

The top patent assignees (organizations) from the selected Economies are shown in **Appendix D**. As revealed in the publication and trademark data, South Korea has a strong research culture and is active in protecting its intellectual property in view of its internationalisation strategy. Interestingly, a large number of these are cosmetic or food companies that utilise their research in herbal medicine to infuse such products with health supplements.

Additionally, a number of universities were also noticed to be actively patenting, primarily as a means to establish the IPR prior to licensing the technology or products to firms. It was noted that universities are also keen to apply for IPR as a way to ensure that their university research receives due recognition for their efforts in developing products or processes with industrial impact. It was also noted that there are a number of firms that have been cited as large firms in this sector that are outside of this list. This study conjectures that such firms are typically reserving their intellectual property as trade secrets and abstaining from patenting in order to avoid divulging their formulations.

5.5 Discussion and Summary

The data presented in this chapter sheds light on the performance of the selected economies in terms of publication, patenting and trademark activities. The results presented here showed that though China has the largest share of publications, patents and trademarks; some of the other economies presented here such as Hong Kong, Taiwan, South Korea and Japan have developed niche competencies in the sector. Malaysia and Singapore, on the other hand, are emerging although there is some promise in terms of the quality of research in Singapore.

Hong Kong showed the highest capacity for innovation in the sector as well as the largest number of firms in the list of productive firms for trademarking (**Figure 5.4**, **Table 5.5**). This acts as evidence towards Hong Kong's position as an international centre of commerce, particularly for this sector. Additionally, Hong Kong also shows the highest niche competency out of the economies in the quadrant (**Figure 5.9**). South Korea also showed substantial activity in publication (**Figure 5.1**) and patenting (**Figure 5.13**). The rest of the selected Economies are more involved in the publication and less in patenting.

Some of these selected economies are at different phases of the technology life cycle. While Singapore and Malaysia are still building momentum in their publication, patenting and trademarking activities, other economies are showing a greater commitment to driving the technology life cycle through building UIG linkages and encouraging interdisciplinary research. Hong Kong and China show signs of being leading edge Economies due to their International strategies and dominance in patenting and publication. Other Economies such as Japan, Taiwan and South Korea are exhibiting modernised characteristics while Malaysia and Singapore are approaching a similar profile. The development of niche competencies is essential in this region as the largest market also has the largest share of research capability (China). As such, other economies leverage on their expertise, influence, as well as indigenous resources in order to entice the dominant market. Thus, we would observe the presence of unique trends stemming from variously selected economies as opposed to the conventional route dictated by China.

The next chapter will look into the research network configuration of the various selected economies and also look at the match between publication and patenting activities. The chapter also delves into the qualitative insights that were gleaned from the interviews conducted in the region.

CHAPTER 6: UIG LINKAGES AND TRANSLATIONAL RESEARCH IN HERBAL MEDICINE

6.1 Chapter Outline

This chapter analyses the research networks of organisations involved in herbal medicine research over the period studied. The previous chapter looked at how the variously selected economies grew during the period. This chapter now looks at the research networks and how the economies organise themselves in order to position themselves strategically in the region. To further understand the niches these economies choose to specialise in, this chapter also assesses the potential of research products emanating from the selected economies. Finally, this chapter also presents some qualitative factors that have been gleaned from semi-structured interviews conducted with various stakeholders from the various economies studied. The purpose of these interviews was to affirm the various findings found in this study as well as to give some context and local case studies to flesh out the analysis.

6.2 Co-publication Network Analysis

This section presents the co-publication networks that was derived from the publication data presented in this study for the selected economies that were outlined in **Chapter 5**. This study avoided plotting the networks for co-patenting data as a lack of discernible patterns for analysis was noticed, as patenting tends to happen between limited assignees and are typically solely owned by organisations. The patterns found in this study were noted to be similar to the network archetypes outlined by Tatarynowicz et al. (2016) with relation to clan or community networks in inter-organisational structures. Thus, this study presents three archetypes and contrast that to the various case studies in the region that are deemed as representative of the network structure in question. In addition, this chapter highlights some key observations that are unique to these case studies as well. **Section 3.3.2** outlined the 3 archetypes of network configurations that were expected to be observed depending on the centrality and prevalence of key actors in the system. This is broken down to university-centric, PRI-centric and firm-centric network structures.

6.2.1 Prevalent university-centric structure: Hong Kong, Malaysia, Singapore and South Korea

The university-centric model depicts a situation whereby universities are the major nodes in the research network in terms of both centrality and volume. In this case, it was noticed that the focus case studies of Hong Kong, Malaysia, Singapore and South Korea are similar in structure in this regard.

The first case study centred on the Hong Kong system which has been dominated by university activity in developing research particularly by the University of Hong Kong (HKU), Chinese University of Hong Kong (CUHK), Hong Kong Baptist University (HKBU) and Hong Kong University of Science and Technology (HKUST). Although they remained fairly different (**Figure 6.1**), a few major universities in Hong Kong showed strong network linkages with institutes in mainland China and overseas, namely Hong Kong Polytech University (124 publications), HKUST (121 publications) and HKBU (172 publications) with ties to both public research institutes and universities. The significance of this is the synergy between research agendas in Hong Kong and China allowing the Hong Kong universities to tap into resources from the mainland in order to advance research in this field.

These findings are relatively consistent with the recent literature on Hong Kong's innovation system, which highlights the increasing integration with mainland China (Sharif, 2006). It is also noted that universities in Hong Kong take up the lion's share of research funding; and is mandated to build and develop the science and technology base of Hong Kong's economy with a focus on basic and some applied research (Sharif, 2006). While CUHK works primarily in a silo, they are the most productive of the Hong Kong universities, given the size of their Institute of Chinese Medicine and the history of the institute (Chinese University of Hong Kong 2014) continuing the advancement of the research area since the 1970s into the 21st century (497 publications).

The variety and differentiation shown by the research network also reflected the competing structure of the network. Although such competing environments do favour the more established universities, such as HKU (247 publications) and CUHK, - leading to the more prominent number of articles published observed in **Figure 6.1** – they have also prompted newer universities to look elsewhere for support. Acting in an environment with selection pressures such as availability of research funding, materials and manpower; universities in Hong Kong have shown ingenuity in circumventing these challenges through strategic linkages with key research institutes in the mainland. This also promotes the development of niches as researchers focus on specific research agendas in order to maximise the use of resources (**Figure 6.1**).

The strong ties with the mainland in this dimension also hints at a flow of research labour from the mainland to Hong Kong, as key executives in the Hong Kong research network, were recruited from research institutes in China. This is a conjecture which warrants exploration in future research. The unique attributes of the Hong Kong research network in traditional medicine, point to certain salient points about the role of universities in advancing the research agenda of the Special Administrative Region and the mainland as well as the academic relationship between both sides of the border. On the one hand, the presence of State Key Labs and the Chinese Academies shows the willingness of the Chinese government to play an active role in research happening in Hong Kong universities, but the level of interaction and dynamics of the relationship needs to be investigated further.

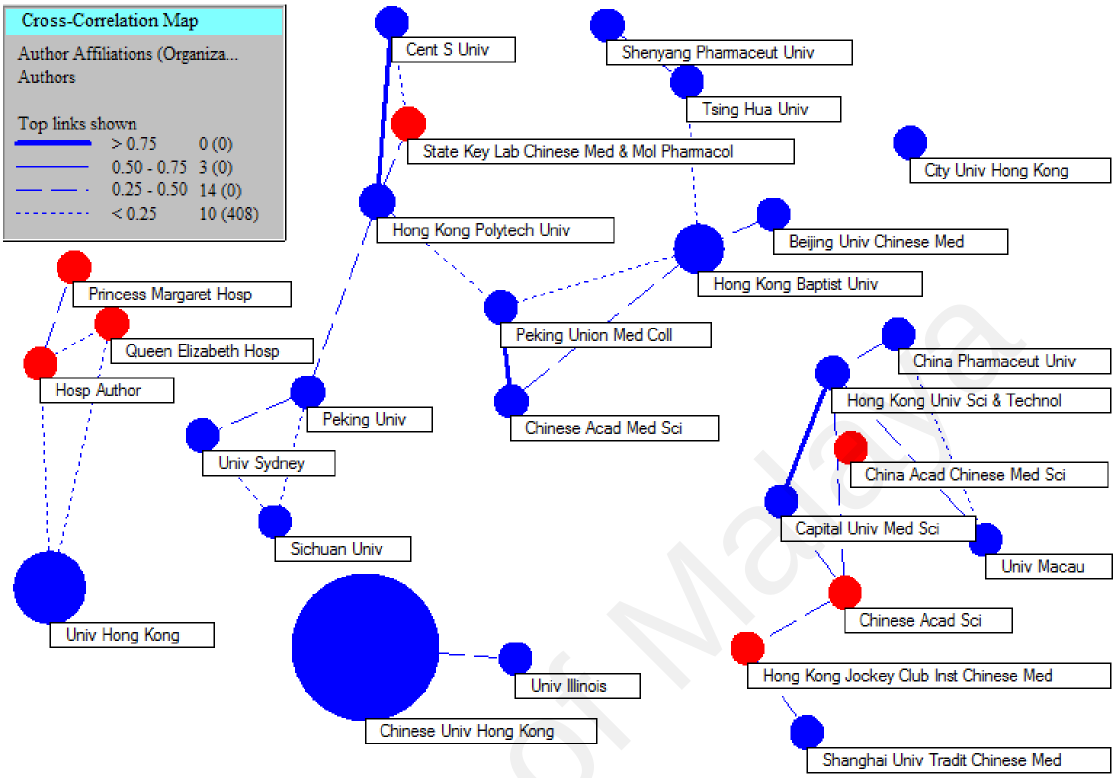


Figure 6.1: Research Landscape in Hong Kong for Herbal Medicine

Similarly, the Malaysian research landscape also shows a heavy reliance on university research with strong network linkages between a few major research universities in Malaysia such as Universiti Sains Malaysia and Universiti Malaya (**Figure 6.2**). This study observed the relatively large node of Universiti Sains Malaysia which is largely due to the activity of several researchers in the School of Pharmaceutical Sciences and the Institute for Herbal Standardisation there. Universiti Malaya also has a relatively large node with work being done in both the Faculty of Medicine and Faculty of Sciences. However, the success of USM in this regard is largely due to their emphasis on collaborations for the purpose of passing clinical trials as seen in their collaboration with the Institute of Medical Research and Penang General Hospital.

There is also evidence of strong research networks in the Northern region of Malaysia as USM ties strongly with AIMST University and Allianze University which as both located in Penang. On the other hand, this study did not see similar collaborations in the central part of Malaysia, with Universiti Malaya, Universiti Kebangsaan Malaysia and Universiti Putra Malaysia being relatively far apart in the research network. To put this situation into context, the Malaysian Government has identified 14 herbs to be targeted for research and identified champion firms to interact with universities and bring these products into the market. There are two major flaws with this endeavour. The first is the budget being set aside for herbal research (RM533 million) which is insufficient for herbal research and clinical development on a national scale. The other is that the focus on these few herbs means that other potential products go understudy, and that this policy does not have space to allow for the screening of a high volume of herbal products.

There are international collaborations with various universities though, as observed, these relationships are relatively sparse compared to the Hong Kong research network. This alludes to the high number of universities in Malaysia participating in herbal medicine, within national boundaries and national standards.

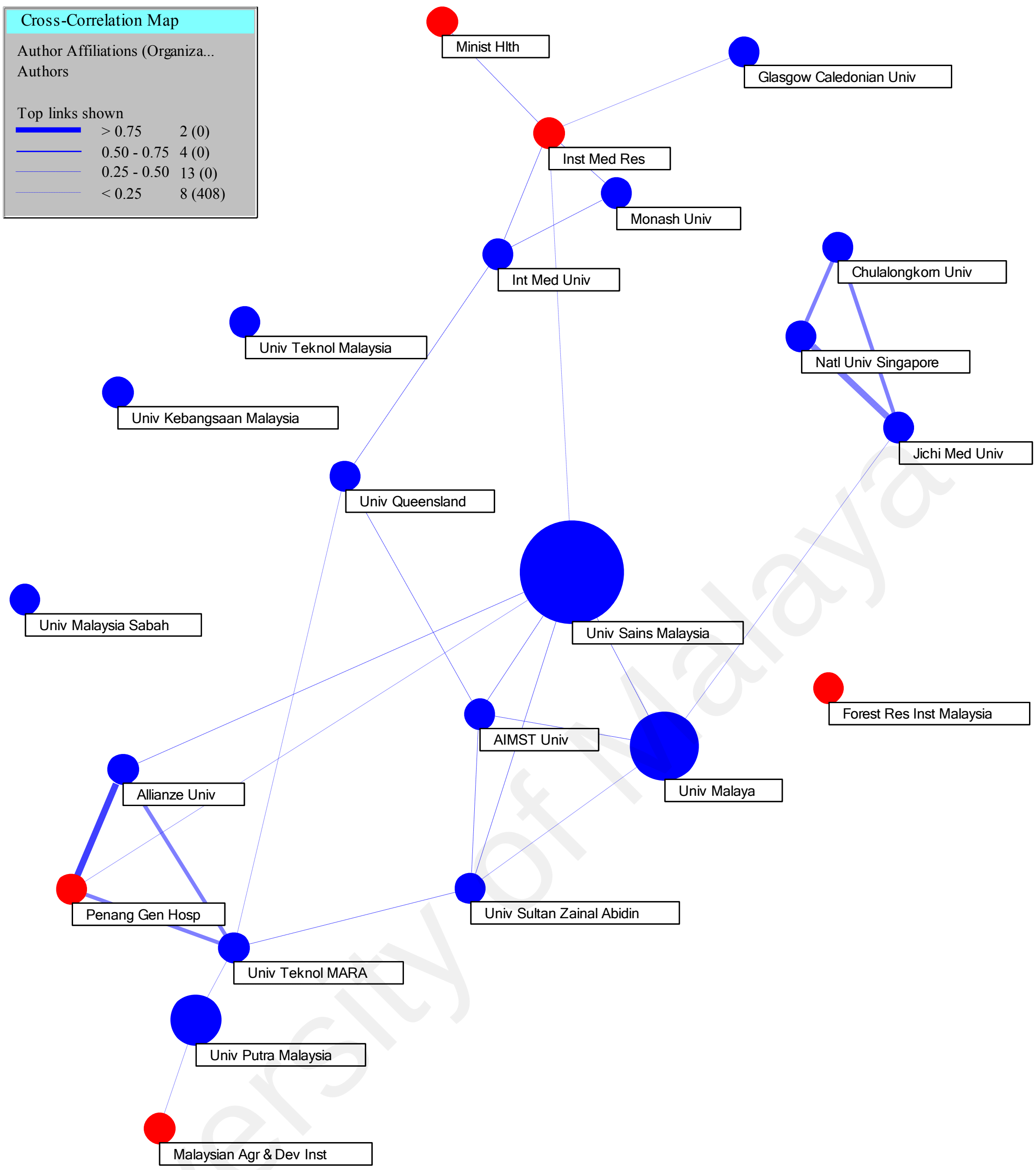


Figure 6.2: Research Landscape in Malaysia for Herbal Medicine

Across the border in Singapore, it is noticed that the landscape is dominated by the National University of Singapore where research in herbal medicine takes place in both the Faculty of Medicine and Faculty of Science (**Figure 6.3**). Considering the fact that there are only two universities in Singapore with Science or Medicine faculties, the majority of the collaboration happens internationally.

There are also no dedicated government research institutes in Singapore that are dedicated to the herbal medicine sector considering that most of the resources are directed towards biomedical and pharmaceutical research, largely through enticing multinational pharmaceutical companies (such as Pfizer, GlaxoSmithKline, and Novartis) to set up research activities in Singapore. However, there are parallels observed in the Hong Kong research landscape in that there are ties to universities and institutions on the Chinese mainland. One explanation for this is the leveraging of ethnic similarities between Singaporean researchers who are mainly overseas Chinese who are able to communicate effectively with their mainland Chinese counterparts in their mother tongue.

The solid lines between the New Zealand Institute of Natural Medicine, Massey University, Sun Yat Sen University, Zhongshan University and Fudan University, indicate that the scholars in each node collaborated on the same papers. This indicates that these sets of papers were a one-off project together with the National University of Singapore. There are a number of nodes with no linkages, which mean that their linkages with the rest of the network were not considered significant enough by the application to be shown (calculated based on the degree of the similarity index in relation to the rest of the linkages).

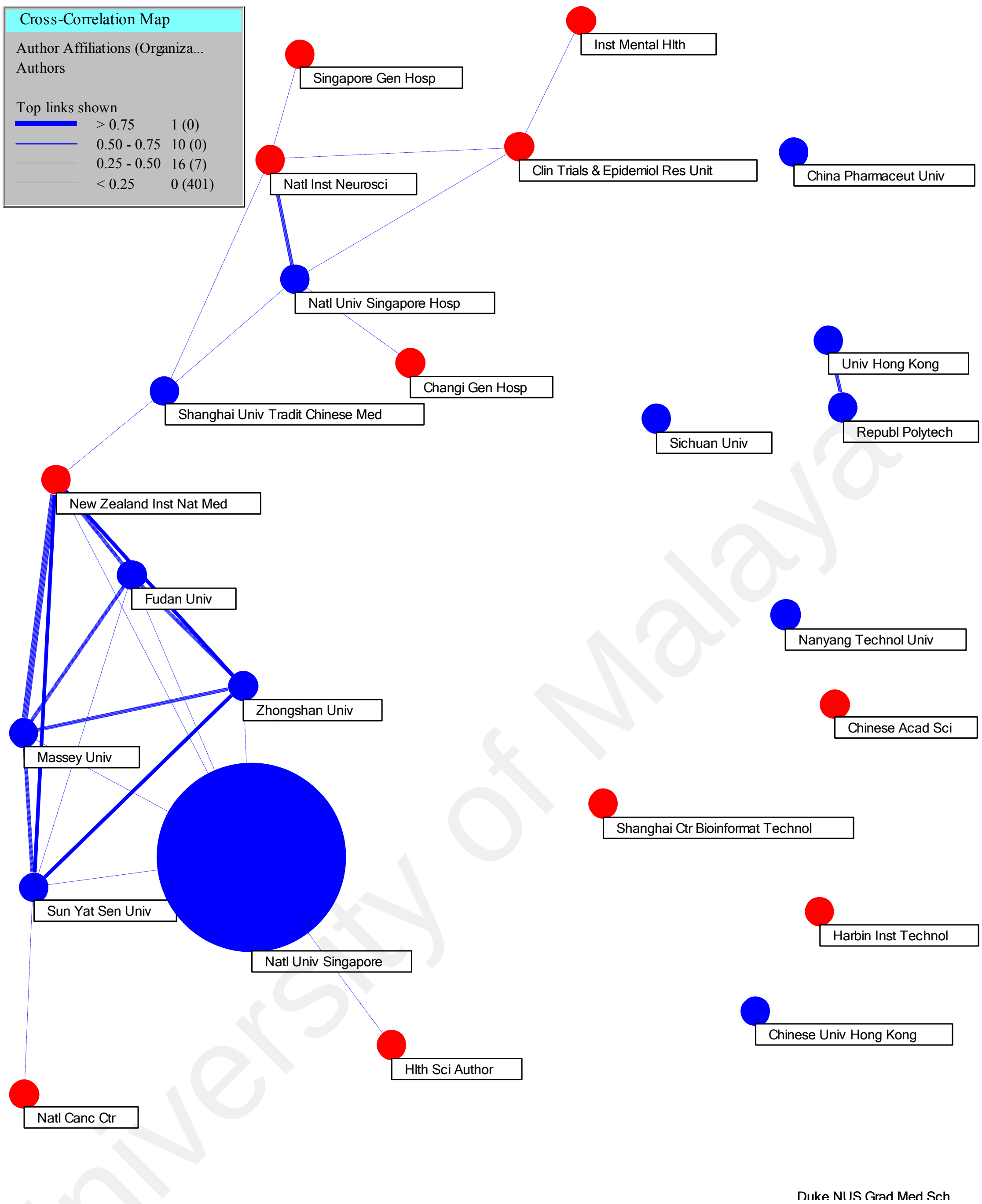


Figure 6.3: Research Landscape in Singapore for Herbal Medicine

Another well-developed network is the one in South Korea (**Figure 6.4**). In this case, the landscape is dominated by universities spread across the country with PRIs working strategically with certain clusters. In this case, the prominence of the clusters are quite uniform with the exception of Kyung Hee University which has the largest node of the universities.

Part of the reason for this is the role of the Kyung Hee University Korean Medicine Hospital which treats patients using Korean Oriental Medicine and acts as a platform for clinical research in Oriental Medicine as well. The presence of the PRIs also strategically stimulates research in the various universities although the action is not seen to be as prominent as the PRI-centric archetype in China.

The patenting data from **Chapter 5** shows that South Korean universities actively patent product and process innovations related to herbal medicine. This spills over to the companies who actively trademark such products and absorbs such innovations. A point of difference in the case of South Korea is that the products that the universities focus on are more towards lifestyle products such as food, beverages and cosmetics as opposed to pharmaceuticals. Based on the interview with a Professor in Kyung Hee University, this strategy emerged from a survey of the Korean Oriental Medicine pharmacopoeia which identified specific herbs which are particularly effective for skincare and overall wellness (Interview with Professor at Kyung Hee University 2014). This trend is also prevalent in the rest of South Korea, where there is an emphasis on products with shorter lead times and less regulation such as cosmetics and foods, as opposed to clinically tested pharmaceuticals which will require stricter testing.

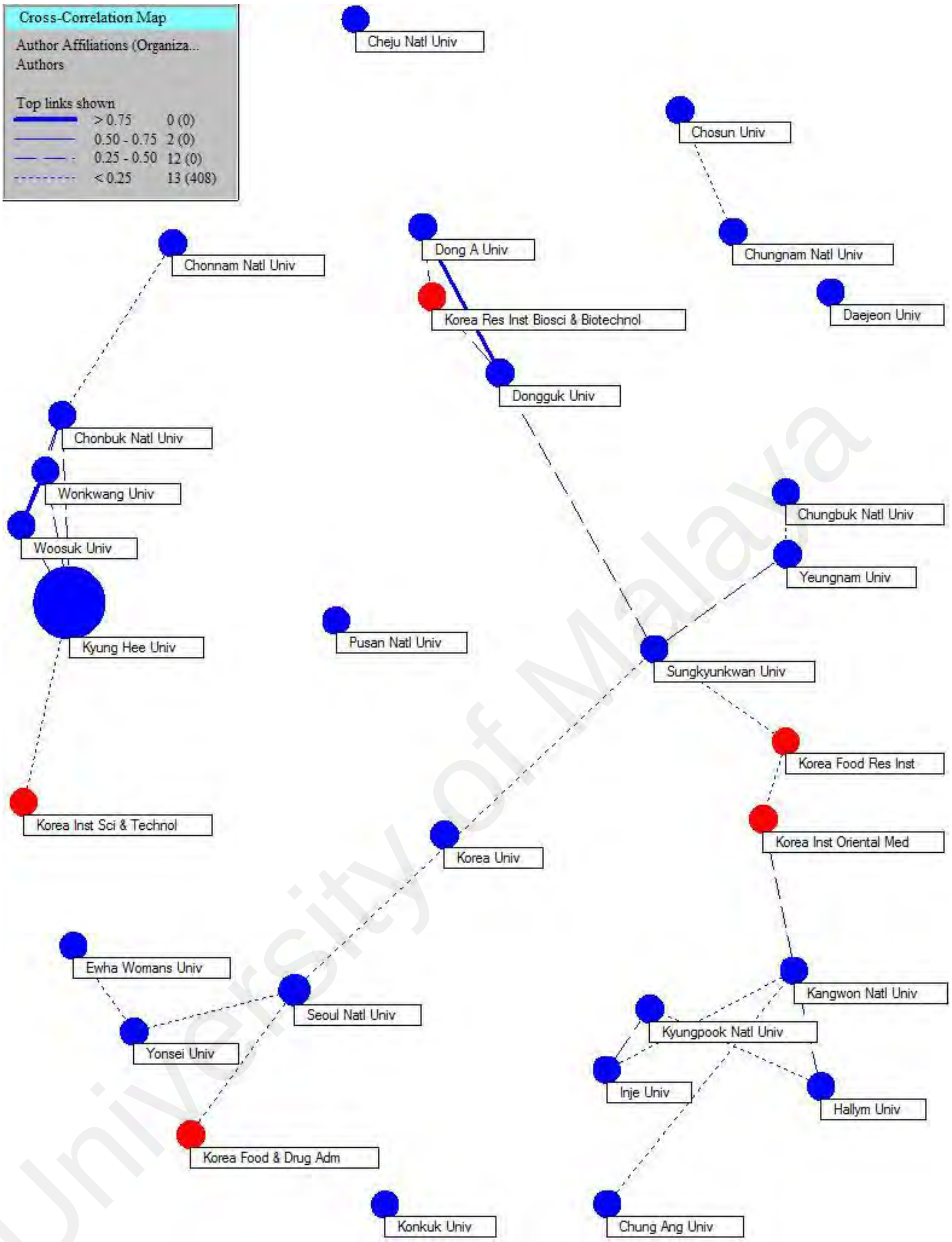


Figure 6.4: Research Landscape in South Korea for Herbal Medicine

6.2.2 PRI-centric structures (China and Taiwan)

In China, this study observed the central role in which the Chinese Academy of Science (731 publications) take in collaboration with the major universities in China (particularly the universities focusing on Traditional Chinese Medicine in Shanghai and Beijing) and conjecture that the central research institute exerts sizeable control over the other universities in the network through the academies (**Figure 6.5**). The top 30 institutes are primarily situated in major eastern China cities in Shanghai and in the north, which interestingly points to a bias in terms of resource allocation for traditional medicine research.

Scholars have noted a transition period for the Chinese innovation system during this period which points to a decentralization of research funding for research institutes and an increase in basic research funding for universities (Liu and White 2001). Publications emerging from China show an evener distribution of researchers (**Figure 5.4**), and points to an even distribution of resources across the universities. As research allocation is non-competitive and state-driven, there is less competition and pressure on institutions to perform for more funding.

This study also observed the lack of collaboration with international universities of any significance, which points to a potential 'lock in' scenario where researchers are largely working within their own communities. Although this protects the network from potential industrial espionage, this could alienate Chinese research from the international academic fraternity. A lack of significant international collaboration corroborates China's position as the country with the highest publication share; meaning that local institutions are highly active in producing papers dealing with 'normal science' without international collaboration. China has arguably the oldest institution focusing on herbal medicine, with the Institute of Materia Medica in Shanghai being active for the past 80 years. There are a total of seven WHO collaborative centres studying herbal medicine in China in major cities. Also, each province has their own university focusing on traditional medicine, thus the research capacity and human capital development are very high. However, China could benefit from increased collaboration with other nations to enhance competencies in niche areas. China's negative growth in comparative advantage can be attributed to the 'lock in' phenomena, caused by the localisation of their research network. Though extensive, a lack of international collaboration means that research in China may be suffering from 'myopia', set in their methodology and standards. Nonetheless, the presence of a strong PRI network means that there is a stronger commitment to the advancement of herbal medicine research and development of novel products for commercialisation. PRIs tend to be less bogged down by the academic restraints of the university, thus they are able to focus on applied research and maintaining close relationships with the industry. There is also a greater emphasis on commercialisation; therefore the agenda is more aligned to that of the industry. It is also noted that the much longer history of research in China means that the evolution of policy and research networks are much more mature in China as opposed to other countries.

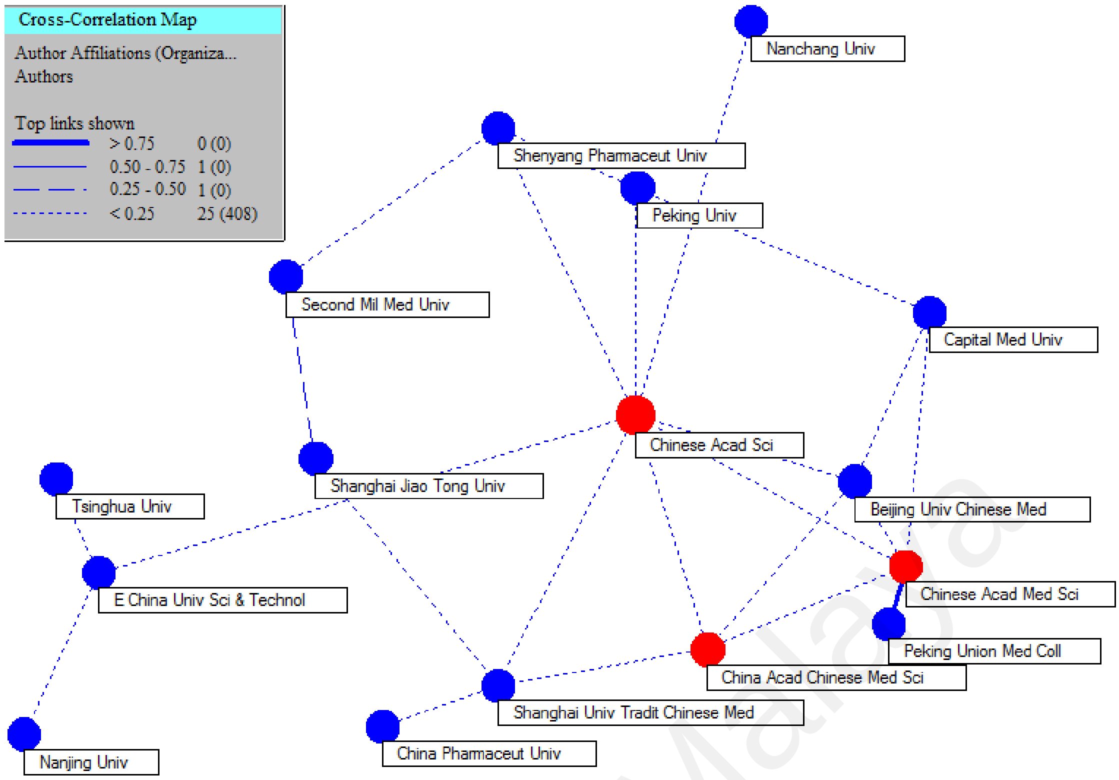


Figure 6.5: Research Landscape in China for Herbal Medicine

What this study noticed in Taiwan is the stronger collaboration with a number of hospitals, which relates to clinical research, which are classified as PRIs in this case (**Figure 6.6**). The structure of academic medical research, hospital clinical research and PRI research working together is evidenced in this landscape with Academica Sinica providing the PRI support to the various universities and their affiliated hospitals.

An interviewee indicated that the management of the herbal medicine sector in Taiwan is heavily influenced by Japan but remains one step later than Japan with the lack of strong firms (Interview conducted with Professor at Hong Kong Baptist University, 2015). Therefore, the research and development are very much confined between universities and hospitals with limited large scale commercialisation.

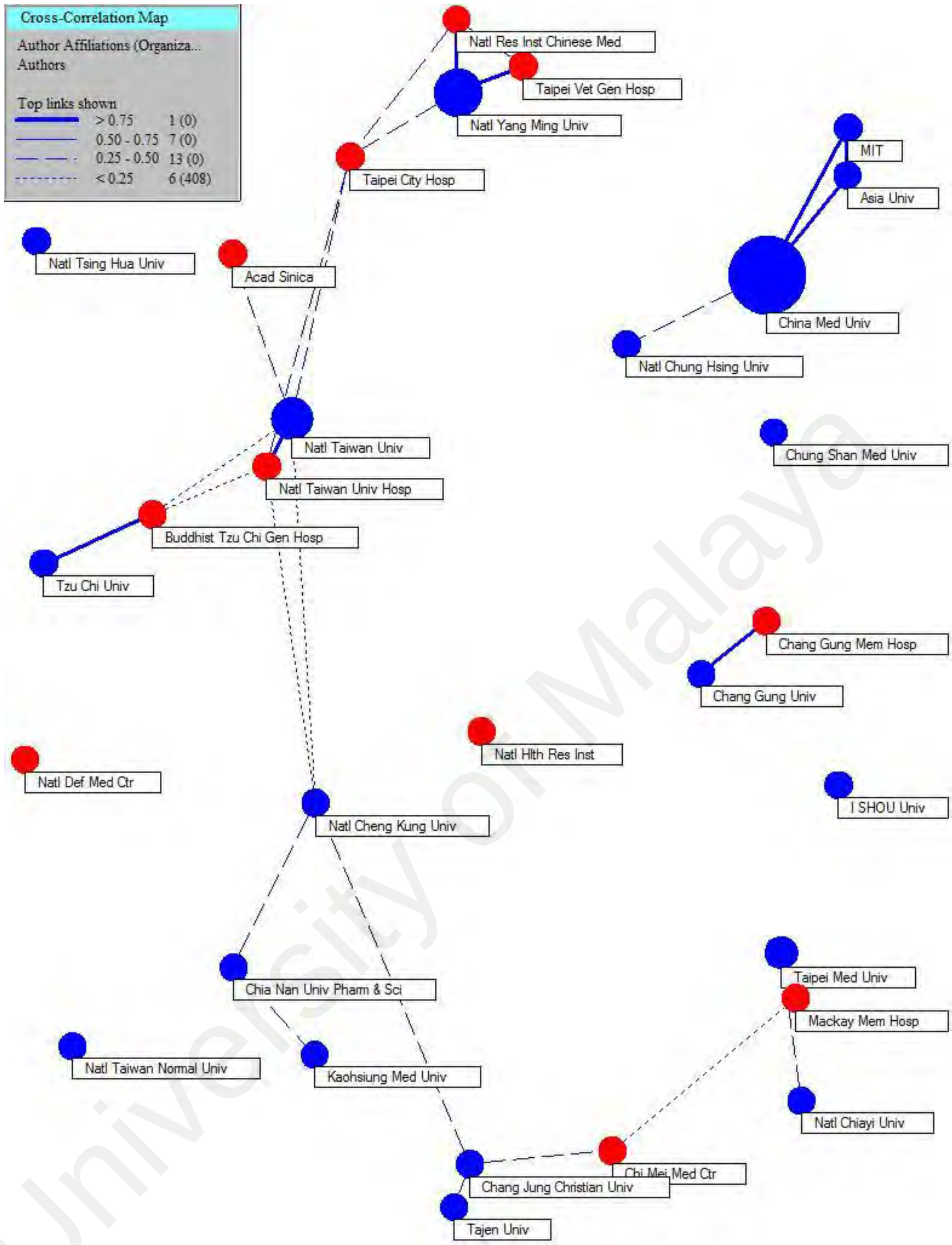


Figure 6.6: Research Landscape in Taiwan for Herbal Medicine

6.2.3 Firm-centric structure (Japan)

In Japan, it is observed that the research landscape has Tsumura & Co (162 publications) in a central position relative to a number of universities, which translates to a high co-authorship of papers between the company and the universities in question (**Figure 6.7**). This is unique among the economies studied and points to a very different approach to innovation where firms are actively collaborating with universities and driving research and innovation in the field of traditional medicine.

This is echoed to some degree by Umemura (2014) who discussed the changes in the innovation system for the Japanese pharmaceutical industry between 1990 and 2010. Noting the rising cost of research in the research and development and the lack of biotechnology research capability in traditional Japanese pharmaceutical firms, Umemura (2014) observed a shift to a more open, networked model which focused on university-industry collaboration to surmount these challenges (Motahashi, 2005). Although the field of traditional medicine was not explicitly discussed, Umemura (2014) did note that these landscape changes were not just reserved for the pharmaceutical industry, but also permeated the life sciences in general.

This supports the notion that the firm leads research and innovation in traditional medicine as Tsumura & Co. sits in a central position in traditional medicine research. This study observed a very even distribution in terms of the number of publications, with a relatively low number of publications. In a previous section, it was discussed that the relative maturity of the technology sector in Japan where publications are supporting the development and enhancement of existing products, which would have more commercial value but less novelty – reduces the prospects of research publications being produced.

Interestingly, Tsumura & Co. have adopted a comprehensive approach to champion the use of Kampo (Japanese traditional medicine based on Traditional Chinese Medicine) in primary healthcare, striving to combine or complement Kampo with Western medicine. The ambition of this project would account for how extensive their research network is and how prominent the company is on the map below (**Figure 5.5**). Tsumura and Co. account for more than 80% of the Kampo market share for the past 8 years which grew to JPY 136.1 billion (USD 1.343 billion) in the past year (Tsumura & Co., 2014). Their operations tie closely with the Japanese Drug Industry Vision 2013 that classifies Kampo companies as 'basic drug companies' together with other pharmaceutical companies, with products in healthcare, essential drugs and traditional medicine products.

One can draw parallels between the position of Tsumura & Co. and the Chinese Academy of Sciences, due to their similarities in terms of centrality and network characteristics. However, a crucial divergence is the fact that Tsumura & Co. is a commercial firm which would prioritize the advancement of science for commercial purposes more urgently compared to a PRI-centric approach, which seeks to develop solutions for the public good or for state interests.

Despite this, Tsumura & Co. still have a very heavy social responsibility angle considering their role as a healthcare product provider. The even distribution of research with the various universities point to a willingness to share and collaborate with academic circles – allowing the innovation system to be built around their commercial activities while leveraging on the research expertise and resources found in universities to lend credence to the quality of their products. An interviewee claimed that Japan is particularly well known for their research expertise in plant chemistry, pharmacology and toxicity (Interview with Professor at Hong Kong Baptist University, 2015). However, the prevalence of Western medicine as opposed to traditional medicine means that the products that do hit the market only serve the local population and are rarely invested for international markets. The exception to this is Tsumura and Co. which plays the role of a flagship enterprise for Kampo medicine. Interestingly, Tsumura and Co. also taps into the

Hong Kong innovation system for research support, having a relationship with Hong Kong Baptist University in several projects.

However, it is conjectured that a Firm-centric approach would discourage international knowledge exchange to protect the intellectual property and trade secrets that are developed by firms. This study projects that the situation in Japan will stay fairly stable and poised to exploit any significant breakthroughs in the application of Kampo. But, their research progress will be slow and exposed to market forces, unless the State supports research in this field more actively through PRIs or research grants.

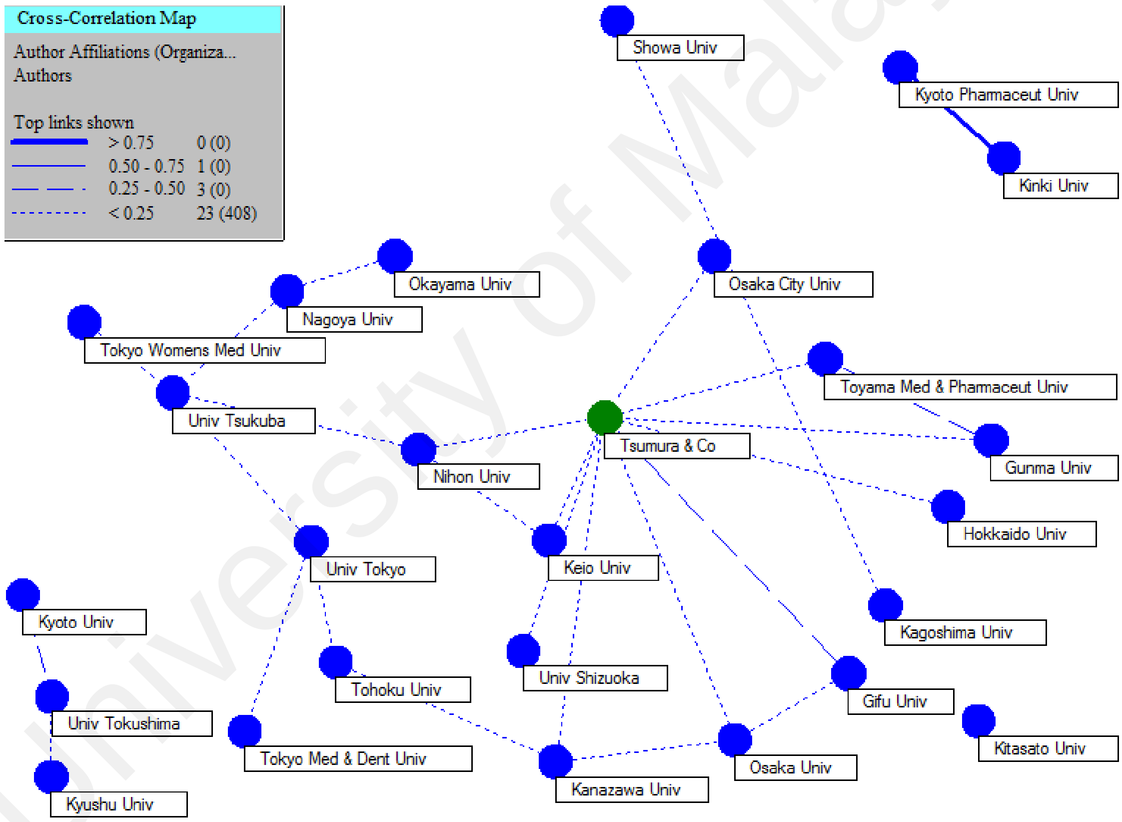


Figure 6.7: Research Landscape in Japan for Traditional Medicine

6.3 Translation of Correlative Indicators for the Selected Economies

In this section, the results in the previous section are linked to the translation results of scientific publications and patents through the findings below. The configuration of research networks should impact the productivity of patents and the level of research and development intensity over time.

The following set of Tables (**Table 6.1-6.3**) compare the spread and intensity of research areas (represented by either WoS categories or IPC classifications) to the World. The purpose of this comparison is to identify the breadth and depth of research in specific niches of the herbal medicine sector. **Table 6.1** compares the translation (concordance) results of scientific publications in Traditional Medicine (TM) for the World and the Selected Economies. The concordance results correspond to technologies classified under IPC patent codes. These publications and patents are mapped into coarse technological classes based on the concordance by Grupp (1998) which were updated in this study (please refer to **Appendix B**). This exercise allows for the comparison between publication and patent data, which indicates evidence of translation between science and innovation.

The World performance informs the study that "Pharmaceutical" is the most anticipated emerging technology for those who perform in academic publishing activities. This is followed by "Basic Material Chemistry", "Food Chemistry", "Biotechnology" and "Medical Technology" being among the emerging few for TM research. Other possible derived biochemistry-related technologies include "Analysis of Biological Materials", "Organic Fine Chemistry", "Macromolecular Chemistry, Polymer", "Environmental Technology", "Materials, Metallurgy" and "Nuclear". It is observed that several ICT/machinery oriented applications for herbal medicine research including "Computer Technology", "Engine, Pump and Turbines", "Audio-visual Technology", "Electrical Machinery", "Thermal Processes and Apparatus", "Civil Engineering" and "Basic

Communication Processes". Hong Kong, a small economy seems to have targeted at similar areas to that of the World. The World common anticipated technologies seem to be consistent with perceived comparative edges of Hong Kong. The same goes for Japan, Malaysia, Singapore and Taiwan where there is an emphasis on niches in the anticipated technologies. However, South Korea and China seem to have a more broad-based approach to the search for new technologies in herbal medicine.

Table 6.2 compares the patents performed by the World to that of the selected economies. Hong Kong seems to have targeted much fewer fields compared to that of the World. This is largely confined to active patenting of Hong Kong in "Preparation for Medical, Dental and Toilet Purposes" (A61K) and "Specific Therapeutic Activity of Chemical Compounds or Medicinal Preparations" (A61P) for respective potential products development. Malaysia, Singapore and Japan also seem to have focused their attention on "Pharmaceuticals" for patenting. Whereas, Taiwan has a broader scope for patenting with regard to "Medical Technology", "Basic Materials Chemistry" and "Measurement". China and South Korea are very consistent with the World patenting activities in terms of breadth and depth.

Table 6.3 compares the anticipated technologies from translation results of science and patents performed by World Pasteur scientists who are targeting certain innovative products for TM market. To reiterate assumptions from the Literature Review (**Section 2.8**), this study defined Pasteur scientists as those who carry out research that have high socio or market value and also have the potential to contribute significantly to the academic literature, while Bohr scientists are more keen to engage in fundamental research, and Edison scientists are more involved in developing practical applications for societal use.

There are a number of identical fields (labeled as red) being targeted by both type of Pasteur scientists (those who produce scientific publications and those who produce patents); however for the case of Hong Kong, Malaysia, Japan, and Singapore (see **Table 6.3**), it is observed that narrower fields were being targeted by scientists producing publications ("Biotechnology", "Basic Materials Chemistry", "Computer Technology" and "Pharmaceutical" being the priorities) and patents ("Pharmaceutical", "Organic Fine Chemistry", "Medical Technology", "Computer Technology" and Basic Materials Chemistry"). This indicated a prevalence of non-"Pasteur scientists" who are more involved in fundamental research or industrial application as opposed to translational research that lead to product innovations. On the other hand, Taiwan and South Korea show several instances where matching between publication and patenting activity is observed ("Basic Materials Chemistry", "Pharmaceutical", "Medical Technology", "Biotechnology" and "Food Chemistry") which indicate a higher prevalence of "Pasteur scientists" or knowledge transfer between "Bohr scientists" and "Edison scientists" in developing research that has commercialisation potential. At the other end of the spectrum is China which has a matching with between all the fields between patenting and publication, but with emphasis on the fields above. This indicates a prevalence of Pasteur scientists or integrated science and technology policies in China.

Table 6.1: Natural Log of Selected Economies in WoS Categories (1993-2016)

WoS Categories	World	HK	MY	SG	KR	TW	CN	JP
Pharmaceuticals	10.21	6.86	5.27	5.43	8.05	7.17	8.95	7.60
Not specified	9.18	5.72	4.04	4.06	6.29	5.92	7.75	5.87
Basic Materials Chemistry	8.46	5.32	3.33	4.11	5.00	5.24	8.03	5.05
Biotechnology	8.34	5.10	3.18	3.87	5.89	5.19	7.58	5.21
Food Chemistry	7.97	4.11	3.56	3.22	5.68	5.39	6.46	4.90
Medical Technology	7.39	3.58	1.10	1.79	3.64	3.56	5.38	4.44
Analysis of Biological Materials	6.54	3.50	0.69	2.48	2.08	2.08	6.27	2.30
Organic Fine Chemistry	6.35	3.04	3.14	1.39	3.47	3.76	5.50	4.14
Computer Technology	6.17	3.22	-	1.79	1.39	3.26	5.25	2.20
Environmental Technology	6.14	1.95	1.79	0.69	3.26	3.09	4.79	0.69
Materials, Metallurgy	5.76	1.10	-	0.69	1.10	3.40	4.90	2.19
Engines, Pumps, Turbines	4.88	1.61	0.69	1.10	0.69	2.08	-	1.39
Macromolecular Chemistry, Polymers	4.74	1.39	-	-	1.10	2.40	4.38	1.09
Audio-visual Technology	4.55	1.79	-	-	1.61	-	3.56	-
Electrical Machinery	4.08	2.30	-	1.10	0.69	2.08	2.94	-

Table 6.2: Natural Log of Selected Economies in Technology Specialisations (1993-2016)

Technology Specializations	World	HK	MY	SG	KR	TW	CN	JP
Pharmaceuticals	9.73	2.40	1.39	1.79	4.61	3.53	9.63	2.64
Food Chemistry	7.86			0.69	5.06	0.69	7.59	
Medical Technology	6.17	1.10			3.33	2.20	5.77	1.38
Basic Materials Chemistry	5.98	0.69			2.56	1.09	5.70	
Measurement	5.93				0.69	1.09	5.78	
Organic Fine Chemistry	5.71	1.61		0.69	2.30		5.46	1.10
Other Special Machines	5.53				2.08		5.32	
Biotechnology	5.24				1.61	0.69	4.93	
Furniture, Games	5.15				3.29		4.08	
Chemical Engineering	4.79				1.38		4.54	
Other Consumer Goods	4.79				1.94		4.39	
Handling	3.91				1.61		3.17	
Computer Technology	3.71	1.10					3.33	
Macromolecular Chemistry, Polymers	3.58				0.69		3.26	
Textile and Paper Machines	3.53						3.04	

Table 6.3: Selected Anticipated Technologies based Translation (1993-2016)

	World		HK		MY		SG	
Technology Specializations	S-T	Patents	S-T	Patents	S-T	Patents	S-T	Patents
Basic Materials Chemistry	8.46	5.98	5.32	0.69	3.33		4.11	0.69
Biotechnology	8.34	5.24	5.10		3.18		3.87	
Computer Technology	6.17	3.71	3.22	1.10			1.79	
Environmental Technology	6.14	3.43	1.95		1.79		0.69	
Food Chemistry	7.97	7.86	4.11		3.56		3.22	
Macromolecular Chemistry, Polymers	4.74	3.58	1.39					
Materials, Metallurgy	5.76	3.18	1.10				0.69	
Medical Technology	7.39	6.17	3.58	1.10	1.10		1.79	
Organic Fine Chemistry	6.35	5.71	3.04	1.61	3.14		1.39	0.69
Pharmaceuticals	10.21	9.73	6.86	2.40	5.27	1.39	5.43	1.79
	KR		TW		CN		JP	
Technology Specializations	S-T	Patents	S-T	Patents	S-T	Patents	S-T	Patents
Basic Materials Chemistry	5.00	2.56	5.24	1.09	8.03	5.70	5.06	
Biotechnology	5.89	1.61	5.19	0.69	7.58	4.93	5.21	
Computer Technology	1.39		3.26		5.25	3.33	2.20	
Environmental Technology	3.26		3.09		4.79	3.18	0.69	
Food Chemistry	5.68	5.06	5.39	0.69	6.46	7.59	4.91	
Macromolecular Chemistry, Polymers	1.10	0.69	2.40		4.38	3.26	1.10	
Materials, Metallurgy	1.10		3.40		4.90	2.30	2.20	
Medical Technology	3.64	3.33	3.56	2.20	5.38	5.77	4.44	
Organic Fine Chemistry	3,46	2.30	3.76		5.50	5.46	4.14	1.10
Pharmaceuticals	8.04	4.61	7.60	3.53	8.95	9.63	7.60	

6.4 Qualitative Insight into the Herbal Medicine Sector

The notion of three separate network models in this study has been exemplified in China (PRI-centric), Hong Kong (university-centric) and Japan (firm-centric) with each showing different characteristics in terms of resource allocation and contribution to research volume and capability. Of the various case studies highlighted, the university-led model (Hong Kong, Singapore and Malaysia) has shown the highest exposure to international collaboration, particularly with key actors in mainland China for Singapore and Hong Kong. However, their knowledge production activities are still heavily driven by their flagship universities, such as CUHK, HKU and NUS respectively, who essentially work in their own networks.

In this section, the findings from several interviews done in some of the selected Economies are presented (Malaysia, Singapore, Hong Kong, China, and South Korea), highlighting various factors deemed crucial to the development of the herbal medicine sector across the region (Please see **Appendix E** for a summary of the interviewees and their profiles). The purpose of this section is to delve into the meaning and experience of key individuals who have witnessed the growth of this sector in the region as well as to elicit their comments about the future directions of the sector. Several themes emerged from the interviews regarding the role of science in the modernization of the herbal medicine sector, namely institutions, intellectual property rights, regulation, and market.

6.4.1 Technology Life Cycle and Intellectual Property Rights in the Herbal Medicine Sector

According to a senior scholar Professor in the Shanghai Institute of Materia Medica a member of the Chinese Academy of Sciences, patenting is a major activity for the herbal drug development process as it is a major determinant for technology transfer to potential private investors.

> *"Patents are important. If you have no patents, the company does not like it as the product is exposed to copying. But in China, there is some protection. Nonetheless, the knowledge and the compounds are not new so it's very difficult to obtain patents. However, we can still find a way to obtain a process or formulation patent."* – Professor, Shanghai Institute of Materia Medica.

This remark relates to the **Figure 4.2** where, in 1998, the regulatory and intellectual property framework was still taking shape in a lot of these countries thereby hampering technology transfer into the market through universities. Additionally, at that time university research is in its infancy; requiring incubation, development as well as the continued support of the government before any significant results.

Scholars from Southeast Asian countries agreed that there is a large gap between East Asia and the ASEAN region as far as herbal medicine research is concerned, but are optimistic that herbal medicine research in the region has a lot to offer considering the rich biodiversity found in the tropics. However, some choose to market their products as health food and beverages which lowers the bar in terms of requisite research. Though the lead time to revenue generation may be shortened considerably, this diminishes the commercial value of the product. However, in this case, the major use of intellectual property is in the protection of unique processes that go into standardising herbal extracts. As one Professor from Universiti Sains Malaysia puts it,

> "*Herbs are consistently inconsistent."* – Professor, Universiti Sains Malaysia

This makes standardisation and proving efficacy a daunting task. Hence, scientists in the university focus on ensuring the stability and consistency of the herbal extracts in order to ensure that the product is effective and reliable.

Polytechnic University in Hong Kong has extensive experience working as an analytical laboratory through their strong industry linkages as well as linkages with the Hospital Authority in Hong Kong. They are also involved in mainland China through the establishment of the State Key Laboratory in Shenzhen. An interviewee (Research Manager at Polytechnic University) mentioned that the patenting activity at Polytechnic University is normally for the modification of particular extracts which are then licensed to their industry partners for commercialisation. In the case of Polytechnic University, they are very clear regarding their role as a support to industry and the motivation for patenting is to ensure that their clients are receiving protected innovations that have market value.

There is also a consensus that accesses to advanced machinery, skilled human capital and funding are major factors in determining the rate at which research in herbal medicine progresses. For example, the work being done in Kyung Hee University depends heavily on their established pool of human capital in research as well as the funding available through their university grants. In Universiti Sains Malaysia, the researchers benefited from returning scholars from overseas who gained knowledge in studying medicinal plants in Indonesia as well as Australia before starting up their own research facility in USM. Nonetheless, there also needs to be the substantial investment made by the institution into the research facilities and machinery available as this translates into credible research findings for the satisfaction of regulatory requirements for such products to go into the market. Such implications can also be deduced from the domination of Chinese firms seen since 2008.

Therefore, the transition from Traditional to Modernization to Leading Edge economies in the Herbal Medicine sector is driven by the Economies' ability to generate research that can be translated into market worthy innovations. To do so, economies' have been shown to prioritize the development of multi-disciplinary institutions to stimulate convergence and in turn, 'windows of opportunity' for new niches to be exploited.

6.4.2 Research, Commercialisation and External Market Factors in the Herbal Medicine Sector

Various interviewees alluded to the size of the market as a major factor for the growth of the herbal medicine industry, which impacts the investment on research and development of new herbal medicine products (Interview with Professor in Hong Kong Baptist University). Particularly in China where the herbal medicine industry is significantly large (estimated at RMB116 billion in 2014; Financial Times, 2015) (Interview with Professor from Chinese University of Hong Kong, 2015). It is similar in Taiwan and Japan where the herbal medicine market is largely geared towards the local market. In that sense, the various firms involved in herbal medicine appeal to the cultural knowledge in the consumer base to boost their product sales.

An interviewee from the Shanghai Institute of Materia Medica mentioned that:

> "*Traditional medicine is still a very interesting field because it has a long history. In China maybe before 1949, we do not know so much about Western medicine. So TCM is the main health care system. Therefore herbal medicine has a very strong market here. We do prioritize internationalization. My drug is going to be exported to Europe. But in my opinion, internationalization is not that important because of the size of the local market. It's meaningful but costly.*"- Professor, Shanghai Institute of Materia Medica.

Some interviewees also alluded to insurance coverage in the various economies. In China, Japan, and Taiwan, granular herbal medicine (modernised herbs made soluble in water) is covered under insurance. In China, there are about 2600 hospitals that operate in traditional medicine. Therefore, the potential market for prescriptions in herbal medicine is very large. This is a situation that is not new to firms in Hong Kong. The migration of firms to Southern China from Hong Kong has been happening ever since China opened its doors in the 1990s. Initially, this was driven by the demand for low cost manufacturing, but this has evolved into a much more high tech approach recently due to the upgrading in social welfare particularly in the province of Guangdong which neighbours Hong Kong (Interview with Professor, City University Hong Kong). Thus, the herbal medicine firms in Hong Kong are well-positioned to capitalise on the mainland Chinese market due to the strength of the innovation system in Hong Kong as well as the perceived superiority of Hong Kong regulatory standards over that in mainland China.

However, in Southeast Asia, the market size is not as big. This is partially due to the size of the populations in the various economies studied, and the other is due to the underdeveloped traditional medicine system as opposed to the conventional Western medicine system. In Malaysia, the prevalence of herbal medicine in primary care is still very limited to several examples such as in Tung Shin Hospital where there is a separate building for Traditional Medicine. In Singapore, some hospitals do have particular wings for traditional medicine but these are typically reserved for pain management and other such ailments. It is also noted that the firms in Southeast Asia are focusing on herbal medicine as a form of functional food as opposed to prescription drugs. This difference in approach could be attributed to the different regulatory standards required for functional foods as opposed to pharmaceuticals. The size of the market would reduce the interest of firms in the market, which is reflected in the number of trademarks in Malaysia and Singapore for this case. Due to the lack of complexity in the product and processes, the motivation to patent is limited particularly for firms as it would be more cost effective to keep the information as a trade secret as opposed to filing for patents.

According to a representative of one of the more successful Malaysian firms in this sector:

> "*We sell ingredients and active products as well as extracts and functional foods. This is mainly because it is a quicker path to market and there is less regulations to adhere to. We are registered in international markets apart from Malaysia such as US, Japan, Hong Kong, China and Russia. We have seen some interest in our international road shows and the response has been encouraging*," Research Manager, Biotropics Malaysia.

The findings from **Chapter 5** are supported by the remarks that were recorded in this subsection, showing the complexity of juggling scientific discovery and product innovation which may not necessarily go hand in hand. Though some of the interviewees are quick to point out their success stories, they are also keen to stress that the road to successful commercialization is long, difficult and better left to industrial players who are better equipped to handle commercial activities.

6.4.3 Development through Institutions and Research Linkages in the Herbal Medicine Sector

Though most of the interviewees cited the influence of personal experience with herbal medicines as the inspiration for their scientific investigation of herbal plants and their effectiveness in mitigating diseases and promoting well-being, the role of institutions in this sector is crucial in driving the innovation engine towards the development of useful products. Such an endeavour has been scaled up to a much larger degree in the East Asian nations where governments seek to capitalise on a well-established traditional medicine system as a means to promote public health and drive the economy. A noteworthy point is the number of resources that have been dedicated to herbal medicine research particularly in East Asia; not just in terms of expenditure on research and development, but also the variety of actors working within the ecosystem to create the dynamic and competitiveness that drives the innovation system forward. An example of this would be the commitment the Chinese Academy of Sciences has on the herbal medicine sector. The significant resources that the Chinese government has allocated for this research during the period of study has meant that the Chinese innovation system for herbal medicine is significantly developed compared to the other economies.

Collaboration between the universities in Hong Kong and China government entities remain a crucial element in the development of the traditional medicine sector in Hong Kong, particularly for universities such as Hong Kong Polytechnic University and Hong Kong Baptist University. The knowledge exchange there is unique as they leverage heavily on networks with the mainland for the advancement of science, through the sharing of resources and expertise. The variety in network linkages and complementarities would account for their growth in RSA.

Since the Hong Kong Jockey Club, a private funding body that was actively supporting research in herbal medicine during the 2000s, shifted its focus from funding herbal medicine research (around 2012), there was a trend whereby universities in Hong Kong were actively developing State Key Labs (SKLs) across the border in mainland China in tandem with local universities in Shenzhen and Kunming. This move opened up access to funding support from the Chinese Government through the Chinese Academy of Sciences and the dedicated SKL funding stream. It also opened up the talent pool, allowing universities in Hong Kong to recruit bright Chinese scholars in the mainland. For Polytechnic University, this means that the bulk of the research happens in Shenzhen, while the teaching happens in their campus in Hong Kong. In some cases, like that of the Chinese University of Hong Kong, it opens up access to raw materials. As they collaborate with the Kunming Institute of Botany, they will have access to raw herbs from the Good Agriculture Practice farm for their research subjects.

This is compounded by the high scientific capability in this field in Hong Kong (**Figure 5.4**). For example, Chinese University of Hong Kong has developed a highly robust research platform for quality control and an internationally recognised research protocol for testing efficacy and safety of herbs through in vitro, animal models and clinical trials; which are all done through a highly trained team at the Institute of Chinese Medicine. This study observed that the selection environment and competitiveness in the Hong Kong technical innovation system give rise to a conducive environment for innovation and growth in traditional medicine in Hong Kong. This is supported by one of the interviewee:

> *"The situation in Hong Kong is promising. We have six universities with different disciplines and the rating for research quality is very high."* – Professor, Hong Kong Baptist University.

In Singapore, the active researchers in this field claim that collaboration happens based on personal networks. Considering the close knit community of researchers, collaboration happens on an ad hoc basis, which is reflected in the lack of volume in publication and patents, as well as the lack of targeted government policy in the area. Most researchers claim that the government has been less interested in herbal medicine research as opposed to biopharmaceutical research which takes up the bulk of the research grant. However, things are getting better with the Traditional Medicine Clinical Research Grant which was introduced in 2014. However, there is still a gap in the research funding which requires them to rely on alternative sources of funding, particularly from the industry or international collaboration. In this case, Singapore was very much left behind as the government focused on developing the biomedical agenda with a greater emphasis on blockbuster pharmaceuticals – which drew the resources and human capital away from traditional medicine research. The consensus from the interviewees in Singapore was that the academics were left to do so in their own time with limited resources and institutional backing.

An established senior scholar working for a university in Singapore maintained:

> *"The government has not done enough to support research in traditional medicine. If it wasn't for our own university funding, we would not have the resources to produce the kind of results we have."*
> – Professor, Nanyang Technological University.

In Malaysia, it is noted that collaboration tends to happen between local universities, however there tends to be a difference in agendas for different universities. As the various universities compete with one another for research funding, there tends to be a duplication of research capacity. Malaysia has identified industrial champions in their Economic Transformation Programme but the industry players find it difficult to collaborate with universities.

Some of the hindrances to this particular configuration is that labs in the universities do not meet international accreditation standards, thus requiring the firms to redo certain tests that do not meet the regulatory standards. On top of this, the research being done in universities tend to skew towards basic or fundamental research which does not sync with the applied research direction required by the firms. There's also the mismatch in terms of desired research output. Typically, the firms require their university collaborators to maintain a level of secrecy in order to protect their intellectual property from being copied during development. However, university researchers are under pressure to publish their research in order to meet their key performance indicators. This does not incentivize industry-university collaboration but rather acts as an obstacle to continued collaboration.

Nonetheless, there are success stories. There is the incidence of universities and industry collaborating closely in Malaysia such as in USM where a research group researching anti-cancer properties in a local herb have spun off their own company and is working on building a pilot plant to develop products for commercialisation. Though the company is still in its infancy, the CEO has reported encouraging response from academic conferences and international trade shows. On the other hand, in South Korea, the foremost university in herbal medicine research. Kyung Hee University, set up a multidisciplinary team of researchers (toxicologists, pharmacologists, chemists, plant biologists and traditional medicine historians) in order to modernise specific Korean herbs for use as cosmetic products.

All countries in this section adhere to the international standards for regulation as put forward by WHO in the regulation of herbal medicine. Thus, products entering any of the markets need to be tested and approved by the individual authorities prior to the license being granted. Therefore, the regulation of the products restricts the flow of products entering the market as it imposes a standard for the safety, and efficacy of drugs or health products before it can be marketed.

For the cases of Hong Kong and Singapore, it was noted that universities do collaborate with the authorities to handle the testing of proprietary drugs in university labs. The practice was established to leverage on the expertise and facilities of university researchers and research labs in order to handle the burden of testing for the various compounds and active ingredients in the drugs. In a way, this also translates into a diffusion of knowledge. As researchers are exposed to the standards required for regulatory approval, they are thus able to incorporate it into their own research in order to ensure that their drugs are approved. However, this study noticed that this diffusion is more apparent in smaller economies such as Hong Kong and Singapore where the community is relatively smaller and thus more closely knit. In cases such as China, Japan and Malaysia, this auxiliary testing typically happens in PRIs that are tasked to do so as part of their mandate. Thus, universities are only exposed to such standards through seminars and workshops. This reduces the learning experience as they are not as involved as compared to that of the smaller economies.

In the selected economies, registration of practitioners and firms and routine checking is common practice. However, universities may not necessarily have accredited labs. As mentioned by an interviewee:

> "*Polytechnic University is not an accredited lab. We assist with certain analytical protocols but are not fully accredited to certify products for safety and efficacy. In China, most major cities have accredited laboratories. "* – Research Manager, Polytechnic University Hong Kong.

The stringent standards for herbal medical products act as a substantial barrier before they enter the market. An interview with a Professor from Hong Kong Baptist University, who has substantial experience working with the sector in China, Japan and Hong Kong, as well as insight into the sector in the region revealed that:

> *"Policy for herbal medicine is just beginning in many countries product registration is a big challenge for regulators, particularly in Hong Kong. In Japan, priority is still given to Western medicine, and then only traditional medicine after that. This is very different from China, where the government is very positive about this industry [sector] and gives very special treatment to local firms."*
> – Professor, Hong Kong Baptist University.

6.4.4 Summary of Qualitative Findings

The key findings from the qualitative interviews covered in this study can be summarised in the table below (**Table 6.4**).

Table 6.4: Summary of Qualitative Findings

No.	Themes	Key Findings
1.	Effect of Innovation Policy on Landscape	The introduction of specific policy mechanisms and political will was instrumental in developing the strength of economies such as Hong Kong, China, and South Korea. Access to human capital was also considered a crucial element to the development of the capacity for herbal medicine research. For the case of Hong Kong, attracting researchers from outside Hong Kong was a key factor in ensuring that the economy remained competitive in the field. Commercialisation is considered a rare occurrence and key institutes are more comfortable licensing and selling ideas and processes and maintaining their core focus on research.
2.	Development of New Products and Innovation Process	A multidisciplinary approach was a key factor in developing the research protocols that were considered industry standards. Though there are some key success stories, lack of access to accredited labs and funding still presents a challenge for the sector in Malaysia and Singapore. The size of the Chinese market means that most researchers focused on developing products and therapies for the local market. Thus, internationalisation is a secondary goal for most researchers active in Greater China.
3.	Formation of UIG Network Linkages	Collaboration between Hong Kong and China is very common due to the presence of research funding from Hong Kong in the early part of the timeline and then China as time wore on. Otherwise, collaboration tends to happen based on personal linkages in less driven settings such as Malaysia and Singapore. There are also active links with government regulatory agencies to provide consultancy and testing services for incoming products.

6.5 Summary

This section looks at the configurations of the research landscape in the selected economies as well as the matched categories for the publications and patents based on the concordance methodology. This section also presented qualitative findings after consulting with various actors in the region regarding how science play a role in the development of the sector.

Based on the findings outlined in this chapter, three major archetypes of research network configurations: university-centric, PRI-centric and firm-centric were outlined, which is evident in the selected Economies. Based on the findings, it is observed that a mixture of university research, government funding and industrial scaling provide the necessary ingredients for a thriving ecosystem. A university-centric model would require significant input from PRIs and regulatory bodies to harness the capability developed and maintain focus in strategic research niches. However, a firm-centric approach is very uncommon and is only prevalent in the case of Japan where a lead firm plays an integral role in the research and development of the sector. It is also observed that the PRI-centric approach is favoured by the more active countries in China and South Korea. Nonetheless, it should be noted that the mapping of such networks using publication data has its limitations as the participation of firms in the publication is fairly low

This is further evidenced in **Section 6.3** where it is observed that China and South Korea has a more diverse patent and publication landscape with a more apparent translation between science and innovation; whereas for the other economies, there is limited match between the niches apart from the common niches like "Pharmaceuticals" or "Food Chemistry".

This is further evidenced in the interviews, where interviewees from Malaysia and Singapore mentioned that the motivation for doing such research is largely self-driven whereas, in the case of Hong Kong, the Hong Kong Jockey Club and government played a major role in empowering universities to do aggressive research. The case of South Korea is similar, however, they managed to get more government support with the presence of several PRIs though the landscape is still very much driven by universities. However, for the case of China, interviewees mentioned that the strength and acceptance within the local market serve as a significant motivation for research and commercialisation in this sector. Various economies also cited the Chinese market as a major target market for the products that would stem from their research.

Based on the criteria in **Chapter 3** (**Table 3.1**) it is observed that China and Hong Kong are leading edge economies due to their dominance in developing research competence, as well as market strength. The symbiotic relationship between the two economies would set the standard for other economies to follow. Taiwan, Japan and South Korea are fast catching up from the "Modernised" phase, looking to exploit niches and gaps in the Chinese market. However, Malaysia and Singapore are attempting to recreate the same conditions in Southeast Asia by modernising their herbal medicine sector through science, which has had mixed results thus far.

The next chapter would summarise the entire study and draw policy implications from the results presented.

CHAPTER 7: CONCLUSION

7.1 Introduction

This study mapped the herbal medicine sector with reference to scientific networks and capabilities based on indicators in publications, patents and trademarks. The study investigated the co-evolution of convergence and the technology life cycle, which is characterised by the growth in the indicators above. This is followed by an insight at the various measures for the selected economies; and then finished with a description of the UIG network linkages, potential translation between publications and patents as well as the qualitative insight into some of the cases emerging from some of the selected Economies.

7.2 Co-evolution of Technological Convergence and Technology Life Cycle

This study demonstrated the sequential emergence of science, followed by the invention, and then by the science-based invention in a highly scientific sector. The takeaway for policymakers in this regard is that a focus on measuring science and technology indicators is best supplemented with a measure of patents citing non-patent literature – to represent the spill over of science into technology. Particularly for sectors with a heavy scientific base, the inclusion of such metrics will be beneficial in demonstrating the utility of scientific advancement within the country. This study found a particular use of this analysis in informing policymakers regarding the different phases of development, with regard to the development of herbal medicine technology. It also provided a guide to which entities are leaders in particular technology or products, and this allows the policymaker to identify champions and clusters from past research activities that can be exploited for future products.

This analysis also sheds light on the demographics of entities during each phase of development – whether individuals, universities or firms. Thus, policymakers can craft interventions that cater to the upgrading and empowering of each type of entity – be it more funding for university research, financial incentives for university-industry collaboration, or to encourage the flow of human capital to the various entities. The life cycle demonstrated in this study with regard to herbal medicine also showed that different related technology converge and phase out over time and eventually blend into a dominant cluster of technology over time. This study posited that the exploration of various niches within the sector is a necessary step in the discovery of the dominant cluster over time.

In **Chapter 2**, Schmoch's (2007) argument that technological innovation follows a 'double boom' cycle was presented; the first attributed to a 'science push' based on curiosity and experimentation, which is followed by a second boom fuelled by 'market pull' that is mainly focused in applied research for commercial gain. Also in **Chapter 2**, a survey of how scholars argued that science-driven markets are accompanied at all stages by high scientific activity was presented. This is highly influenced by institutions within the innovation system that translates scientific research into technological innovation (Malerba, 2002). The analysis provides empirical evidence that herbal medicine follows a similar trajectory, which is then followed by a boom in science-based patents.

On the other hand, this study also delved into the concept of technological convergence which has also been linked with the concept of technological advancement in biomedicine; with scholars arguing that many of the rate-limiting steps in biomedical research rests in the interstices between biomedical sciences and classical scientific disciplines such as physics, chemistry, engineering and mathematics (Balser and Baruchin, 2008; Bröring et al.; 2006; Steinmueller, 1996). This can be observed in the analysis of patent keyword clusters that indicate the presence of multiple niches that fuse into a dominant subsector in the field of herbal medicine.

7.3 Scientific Capabilities in the Herbal Medicine Sector of the Selected Economies

The herbal medicine sector has proven to be a strong emerging industry for the selected economies in the Asia Pacific. TCM-related products showed the greatest promise considering the sizeable research and development activity surrounding it in key knowledge producing economies such as China, South Korea, Hong Kong and Taiwan. Similar systems in Japan, Singapore, and Malaysia are also gaining momentum. Scientific research in herbal medicine is focused on drug discovery focusing on pharmacology, chemistry and molecular biology. This supports the notion that herbal medicine systems provide a roadmap for chemists and pharmacologists to develop new and improved medical products.

Hong Kong has shown to have the greatest capacity in terms of knowledge production and innovation, despite their small population. Nonetheless, China remains the largest producer of knowledge and trademarks followed by Taiwan. A symbiotic relationship between Hong Kong and China can be observed in the development of this sector as several key executives and academics in the Hong Kong innovation system are from China while the commercialisation activity from both economies is very high. Taiwan has shown to have the greatest impact by way of citations, which not only shows greater quality in publications but also greater collaboration within the innovation system and with external parties. In terms of innovation of new products, China leads as well and followed by Hong Kong and Taiwan; with South Korea and Japan catching up. Singapore, Malaysia and Thailand are currently lagging. This study concludes that the findings corresponded to the framework outlined in **Table 3.1** – Hong Kong, China and Taiwan are sitting in Phase III (Internationalisation) primed to push into while the rest of the economies are firmly in Phase II (Modernization) looking to kick-start their herbal medicine sectors to catch-up with the frontrunners. Based on the empirical evaluation conducted, this study implied that herbal medicine serves as a lucrative niche for Asian economies that have gained sizeable investment in developed/rapidly developing Asian economies. Considering the elaborate biotechnology policies in effect in most of these economies, greater emphasis needed to be placed on the potential of other indigenous knowledge centres that could have the opportunity to flourish under the right market conditions. This study concluded from this analysis that the integration of traditional and conventional medicine in economies like China, Hong Kong and Taiwan, together with the presence of active research institutes contributed greatly to the systematic modernization of the herbal medicine sector.

This study alluded to the lack of studies comparing different economies in the herbal medicine sector. Nonetheless, the literature has shown the potential insight that assessing the impact (through statistics on publications, patents and citations) of particular scientific findings or inventions can have when it comes to understanding emerging technology (Fagerberg, et al., 2012; Leydesdorff & Gauthier, 1996, Porter et al., 2005; Tijssen & Leeuwen, 2006). The findings leverage this notion and provided evidence as to the state of the selected economies in relation to one another. Such an approach provides important information to policymakers, particularly those from developed countries to target and mobilise resources to support the development of emerging technologies. This study paints the knowledge production landscape in selected Asian economies, providing a snapshot of the productivity of research and innovation activities.

7.4 Research Networks and Core Competencies from the Selected Economies

The research networks of the various economies presented in **Chapter 6** shed light on the dynamics of how research is being driven in the various economies. Collaboration between the Hong Kong universities and mainland government entities remain as a crucial element in the development of the herbal medicine sector in Hong Kong. The same can be said in the Singapore and Malaysia networks where universities play a major role in the scientific development in this sector with limited involvement from PRIs. South Korea has a similar structure but with more PRIs dotting the landscape. In the PRI-centric research landscape map for China, a more evenly distributed landscape with PRIs playing a central role in collaboration between the universities was observed. Taiwan has a similar structure with a number of hospitals involved in research together with research institutes and universities. Japan has a unique structure where Tsumura and Co. play a central role in the development of herbal medicine. However, it is conjectured that the PRI- and Firm-centric approach would discourage international knowledge exchange to protect the intellectual property and trade secrets that are developed by PRIs and firms. It is believed that universities, with clear direction and financial support from the state, are in the best position to grow the innovation system; circumventing potential network failures due to lock in and lack of capability, provided that the environment promotes competition and international collaboration. It is also noticed in similar structures in Malaysia, Singapore, South Korea and Taiwan; which points to a general adoption of this format. However, a University-centric model on its own may not yield the desired outcome. PRIs and regulatory bodies still have a part to play in harnessing the capability developed and maintain focus in strategic research niches.

In the Literature Review (**Section 2.6**), it is shown how the interactions between university, industry and government and the presence of hierarchy in East Asian innovation systems has been covered in great detail by various scholars (Foray, 2004;

Kim, 1997; Leydesdorff & Etzkowitz, 1998; Mowery & Sampat, 2005; Wong, 2011; Wong & Salmin, 2016). The results illustrated such interactions in research and shed light on the centrality of key actors in the sectoral innovation system of the particular economy.

The translation results seem to imply that China, South Korea and Taiwan have mobilised its resources to obtain a productive routine for developing core competence in herbal medicine scientific research, while Malaysia, Singapore, Hong Kong and Japan are more focused on niche areas. This has led to scientific publications and patents that denoted to broadly anticipated technologies for China, South Korea and to some extent Taiwan. Whereas Hong Kong, Malaysia, Singapore and Japan may have broad competencies in science but limited translation to patents. The targeted markets can be attributed to its advanced science-based research that can develop state-of-the-art pharmaceutical related technology in high tech segment and its lucrative market for food or herbal related innovations (such as packaging, branding etc.) for the low tech segment.

The approach carried out in this study with regard to translation is related to similar studies that seek to inform policymakers regarding core competence of a system and potential for commercialisation of an interested technology through correlative indicators (Gao, et al., 2013; Newman, et al., 2005; Porter et al., 2007; Porter & Rafols, 2009; Robinson, et al., 2013). The approach proposed a routine to compare patents and publications based on updated balancing units initially put forward by Grupp (1998).

7.5 Qualitative Insight from Case Studies of the Selected Economies

The collection of interviews confirmed several key themes arising from the study. Several themes emerged from the interviews regarding the role of science in the modernization of the herbal medicine sector, namely the effect of innovation policy on the herbal medicine landscape, development of new products and innovation process, and the formation of UIG network linkages. The interviewees concurred that specific policy mechanisms and political will were instrumental in developing the strength of economies such as Hong Kong, China, and South Korea. There was also consensus that human capital was a major driving factor, particularly for the case of Hong Kong, where attracting researchers from outside Hong Kong was a key factor in ensuring that the economy remained competitive in the field. Nevertheless, commercialization is considered a rare occurrences and key institutes are more comfortable licensing and selling ideas and processes and maintaining their core focus on research. On that note, intellectual property rights played a major role as it provides an insurance for licensers and firms looking to acquire technology. The interviewees cited this as a prominent exit strategy for their inventions as they understand their role is not as entrepreneurs, but as support to the industry. As far as the development of new products and processes, interviewees cited the effectiveness of a multidisciplinary approach in developing the research protocols that were considered industry standards. In this sense, high standards in lab practice were a major factor as lack of access to accredited labs and funding still presents a challenge for the sector in Malaysia and Singapore. Interviewees were generally positive about market response to herbal medicine products from the selected economies, particularly in the market of greater China.

Collaboration is identified as a major driving factor in this study and is highly cited from interviewees from Hong Kong and China. Joint publications between Hong Kong and China is very common due to the presence of research funding from Hong Kong in the early part of the timeline and then China as time wore on. Otherwise, collaboration tends to happen based on personal linkages in less driven settings such as Malaysia and Singapore. The regulation is also a major factor and also where science played a major role in controlling the entry of new products in the market.

7.6 Policy Implications

The various analyses covered in this thesis have been designed to derive the policy implications for the continued development of scientific activity in this sector. To achieve the transition from a traditional to modernised phase as defined in the evolutionary framework (**Table 3.1**), this study recommends:

- *Promoting Innovation through Horizontal Policies and Multidisciplinary Strategies* – The development of technological niches requires a generalised policy mechanism encouraging the overall development of technology within a particular sector. In that sense, economies are recommended to allow for the development of radical niches and to avoid specific targeting in order for innovative firms of all forms to participate in the innovation ecosystem. Hong Kong had a liberal approach to supporting research and innovation in herbal medicine, backing research in various potential usages which allowed for a wide technological search. Policy makers of emerging countries with interest in such sectors can consider a more horizontal approach to supporting innovation within a specific sector – in order to maximise the possibility of discovering multiple windows of opportunity and capitalising on the next wave in such sectors. On the other hand, policy makers from advanced countries can consider more targeted interventions to supplement the growth, and grow future niches that will sustain the cycles of convergence and innovation in this sector. Nonetheless, some restraint should be practiced in later years to reduce inefficiencies. A conscious effort to reward multidisciplinary activity is also recommended as convergence is noted to take place at the interstices of technologies (Steinmueller, 1996). Thus, there has to be sufficient dialogue between different disciplinary streams to facilitate such convergence.

- *Establishing bridging and research institutions* - Notably, there is a bottleneck in translating science into technologies that may lead to product development. The government can establish bridging and research institutions to perform the following: a) applied science research that can empower the abilities of Pasteur scientists in performing patenting and commercialisation activities, b) creating spin-off companies from public research laboratories or start-up companies based on commercially viable patents and c) routine to allow frequent mobilisation of talents within industries and manpower dissemination to the herbal medicine job market to achieve high technology spill over effect to the economy. China has achieved much success through its PRI, the Chinese Academy of Sciences, which is one example of how an effective bridging institution can act as a positive influence on the innovation system. The state can create policy mechanism that coordinates science and technological activities in a systematic way to attain a multiplier effect to the economic structure and achieve an overarching goal collectively. Systematic support for Pasteur scientists to venture in either technological research that leads to fundamental understanding, or basic research that lead to practical knowledge is essential for the advanced development.
- *Creating University-Industry linkages* - While the selected economies anticipated technologies are consistent to that of the World, there is a learning gap between those performing scientific activities and those producing patents intended for commercialisation in the cases of Hong Kong, Japan, Malaysia and Singapore. It

is important for the State to match the interest of both in order to create the dynamism between science push and technology pull for medium-term technological development. The government can create matching grants to support those who are able to collaborate in areas that would create co-evolution trajectory for science and technology. Nonetheless, some resources should be mobilised to support those who venture in wide applications and innovations from technologies that have the potential to have significant impact on the herbal medicine sector in the respective Economies. Japan has the highest involvement of industry in research activities, nonetheless, the lack of PRIs means that the research remains private and lacks the spill over effect necessary to generate market-wide economic growth. Thus, there needs to be a balanced synergy between the various actors to create a productive structure for advancement.

- *Setting up of accredited labs in various universities* – A gripe of an interviewee is the lack of readiness of the university laboratories in their ability to provide testing services as well as non-compliance with international accreditation bodies. Thus, the government can support the setting up of such facilities to promote better access to such services and reduce the obstacles for products to enter the market.

To transition from modernised to leading edge, the study recommends:

- *Stimulating innovation and commercialisation of convergent technology* – Following the introduction of horizontal policies, the state can play a role in focusing on convergent technology that emerges as a competitive niches to accelerate the technology life cycle. Such niches are characterised by strong translational potential and concentration of science-based patents. These niches need to be supported by a suite of commercialisation funding opportunities to bridge the gap between the lab bench and the market. The PRIs in China, Hong Kong and South Korea practice this approach, housing various disciplines under one roof and having multiple teams working on projects which have been identified as high potential, to speed up the development of products. Malaysia has a host of pre-commercialisation funds to support such endeavours, focusing on developing prototypes. On the other hand, Singapore released Grants for Clinical Research which hopes to bridge the gap specifically for traditional medicine.

- *Utilising innovation metrics as a means to gauge market potential and opportunities*- This study proposes that the methodology presented in this thesis have credence to be utilised as a means to measure convergence of patent clusters over time, as well as scientific capabilities and comparative advantage of economies. The findings and the subsequent policy implications will enable policy makers to understand core competencies and its potential for development. It is nonetheless important to corroborate the findings with the outlooks of the industrial stakeholders. The process would enable eventual consensus on the approach to achieve a desirable outcome that would develop and upgrade the herbal medicine sector.
- *Establishing bilateral linkages for the purposes of sectoral development* - This study observed a lack of international linkages among the various economies with the exception of Hong Kong and China which has a symbiotic relationship in scientific development and product development. Hence, this study proposed that other economies develop similar inter-organisational linkages across borders to promote learning and also develop market opportunities in overseas markets. This requires a matching of core competencies to market niches and stimulating catching up processes in order to transition further. ASEAN has a strong potential for developing such links due to proximity and the existing relationships that is already in place through current diplomatic channels. There is also opportunity

for consolidation of intellectual property protection which would make patenting cheaper for local innovators to have their inventions protected.

- *Investing in disruptive technologies* – The governments can also consider identifying and investing in technologies that sit outside of the dominant design with the potential to enhance or replace existing processes. Such alternative technologies may have certain properties that can be leveraged on and provide a comparative advantage in the future.
- *Focusing in research services and protocols as a viable market* – The development of niche competencies in research and development could be spun off as research services particularly to developing economies looking to develop their own products but lack the quality and resources to do so.

7.7 Limitations

The initial motivation for studying these economies was to provide a landscape regards to the herbal medicine sector based on available resources (patents, publications and trademarks). This study supplemented these findings with qualitative interviews to lend meaning to these case studies. However, though the profile of the interviewees in this study does give them the required credibility as authorities in the subject matter, this thesis could be improved with the inclusion of a larger sample of interviewees to achieve a more rounded consensus.

The lack of an official patent or publication classification for herbal medicine has required reliance on a heuristic search string for the purposes of this study. Although the data has been screened and cleaned, this study concedes that analysing bibliometric data based on keyword searching has room for error both in terms of capturing data with tenuous links to the case study as well as failing to capture data that may not be represented by the keywords used. Despite this, this study argues that this is the best way to derive a consistent set of results for trend analysis and comparisons.

Additionally, this study also concedes that the use of the SCIE database may not capture a comprehensive dataset for herbal medicine globally. The database is noted for its exclusivity as well as its orientation towards English medium journals, while the qualitative discussions with notable researchers in the field have argued that many publications in the field of herbal medicine are in indigenous languages which are poorly represented in the SCIE database. However, this study believes that the SCIE database gives a representation of papers published in highly-cited journals catering for an international audience – which represents internationally accessible codified knowledge in the same way as patents published in the patent offices covered in this study.

The interviews conducted were done as part of a larger study into the modernization of herbal medicine in East Asia and South East Asia and are skewed to the few countries mentioned above as these were done with whatever resources were available for such excursions.

7.8 Further Research

This study proposes to further its interest in the herbal medicine sector by extending the methodology over a longer period of time and a larger variety of economies, most notably the South Asian economy which may have experienced a similar modernization trajectory, to observe trends and potential barriers to development in the sector. South Asia would also be an interesting set of economies to add to this analysis, however the intention was to focus the analysis on the region of East Asia, including selected economies in Southeast Asia, due to regional proximity and cultural similarities.

With further development of this methodology, this study argued that it would provide a useful means for benchmarking economies, sectors, and institutions based on available datasets. A possible avenue would be to utilise this methodology to conduct panel investigations into the evolution of specific sectors or institutions over time – studying the maturation of the research institute or economy into various fields or levels of technology. This could be a means to study research and development strategy at national or sectoral levels.

From the perspective of the bibliometric data, a possible avenue for further research is to analyse the position of universities and industry in the sequence for authorship in publications and patents in the sector. This would shed light on the position of such actors in the research landscape and whether they play an active role in the execution of the research project, assuming that a higher position would denote greater activity. The UIG linkages derived from this study can also be studied in depth by looking at what causes the different patterns and how it evolves over time based on the influence of political and economic landscapes.

There is also an interest in conducting deep interviews with the herbal medicine industry players in Japan to understand the reasons behind the deep industry connections with universities in scientific research. This phenomena is unique to Japan and warrants a deeper analysis of the dynamics of such linkages.

The translation exercise (**Section 6.3**) serves as a means to consider the profile of researchers in these economies. In the case of more University-centric or Firm-centric economies, this study noticed more "Bohr scientists" who are keen on fundamental research, whereas PRI-centric Economies have more application through "Pasteur scientists" who are working on research with potential applications for the market (**Table 6.3**).

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