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Developing a Strategic Policy Choice Framework for Technological Innovation: Case of Chinese Pharmaceuticals

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by

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Abstract

With the growing trend of globalization and rapid development of high technologies, emerging economies face more challenges in technology development because they are chasing a fast-moving frontier. They need to identify global technology trends and adapt to local needs and capabilities. Strategies for technology development differ among countries at different developmental stages.

In this research, a technology policy choice framework is developed to link prospective high-tech areas, technology development strategies, and various innovative resources. The research approach is to develop a hierarchical decision model (HDM) and apply the analytic hierarchical process (AHP). Experts are invited from diverse sources to provide a balanced perspective representing different stakeholders. This research focuses on the fast developing Chinese biopharmaceutical industry as a case study.

The results of this research have identified thirteen prospective biotech areas that China should invest more resources for development. These technology areas include: recombinant therapeutic proteins, recombinant vaccines, monoclonal antibody technology, cell and tissue engineering, gene therapy, antisense therapy, RNAi, nanobiotechnology, synthetic biology, bioinformatics, pharmacogenetics, gene sequencing, and biotechnology diagnostics. For most of these technology areas, the results have indicated an imitative innovation strategy should be taken as a better strategy under current technological conditions in China. The research has further found that high-tech small-to-medium companies and multinational corporations are major innovation contributors in the Chinese biopharmaceutical sector.

The research outcomes can serve as guidelines in resource allocation and policy making for technology development. Based on the overall research findings, policy-makers can apply more specific policy instruments to support innovation activities. Appropriate policy measures may help the country to construct an innovative ecosystem that can serve as the driving force for future technology development.

Dedication

This dissertation is fully dedicated to

my mother Liwen Jin

and

my sister Cathleen Ming Chan

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List of Abbreviations

AHP	Analytic Hierarchical Process
CMO	Contract Manufacture Organizations
CRO	Contract Research Organizations
EFA	Exon-Florio Amendment
EJV	Equity Joint Ventures
FDI	Foreign Direct Investment
FR&D	Foreign Research and Development Centers
HDM	Hierarchical Decision Model
ICT	Information and Communications Technologies
IPR	Intellectual Property Rights
MCDA	Multi-Criteria Decision Analysis
MNC	Multinational Corporations or Companies
MOH	Ministry of Health
MOST	Ministry of Science and Technology
NEDL	National Essential Drug List
NIS	National Innovation System
OECD	Organization for Economic Cooperation and Development
OBM	Original Brand-name Manufacturing
ODM	Original Design Manufacturing
OEM	Original Equipment Manufacturing
PRI	Public Research Institutes

R&D	Research and Development
RIS	Regional Innovation System
RNAi	Ribonucleic Acid Interference
SIS	Sectoral Innovation System
SME	Small-to-Medium Enterprises
SOE	State-Owned Enterprises
SFDA	State Food and Drug Administration
TIS	Technological Innovation System
TRIPS	Trade-Related Aspects of Intellectual Property Rights
URP	University Research Programs
WTO	World Trade Organization

Chapter 1 – Introduction

1.1 Problem Statement

"No nation can afford to be without its own independent Science and Technology capacity." [1] --- Kofi Annan

Innovations in science and technology (S&T) constitute the core of national competitiveness [2]. Nations across the world invest heavily in high technology innovations, but they are facing different challenges due to different developmental contexts. Western developed countries need to maintain their technological competitiveness and sustain their innovative leadership [3] [4]. Emerging economies aim to improve technological competitiveness through catching up and leapfrogging [5] [6]. Strategic innovation policy for effective technology development has become a key issue for all countries. The fundamental and common problem is how nations achieve and sustain S&T competitiveness.

With the growing trend of globalization and rapid development of high technologies, emerging economies face more challenges because they are chasing a fast-moving technological frontier. They need to identify global technology trends and adapt them according to local needs and capabilities. Even though technology programs such as foresight studies generally provide broad pictures about the future, implementation of various high technologies remains a common challenge. The development of high-tech industries suggests that it is necessary but difficult to find balance between local and global, internal and external innovation. How much an industry can benefit from external alliances largely depends on the effectiveness and efficiency of the national innovation

system [7]. Emerging economies may rely more on learning advanced technologies from advanced countries, but they face the "make or buy" dilemma in technology development. International technology transfer can be a major channel to obtain state-of-the-art technologies from advanced countries. However, it is also a high-risk process since there is no guarantee that technology transfer would result in future innovation for the host country. A comprehensive technology development framework at the strategic level becomes necessary in the present environment of global competition.

Strategies for technology development differ among countries because of huge gaps in terms of social values, economic status, and political environments. Technology policy issues vary significantly due to the diversified conditions between developed and developing countries. While many Western developed countries strictly control high-tech export, China adopted a countermeasure policy of "Trading of Domestic Market for Technology." This policy deliberately trades market access for technologies, obliging foreign investors to share technologies if they want to sell to the Chinese market. German scholars found that the strategy is unique because only large economies with high potential markets (China and India) can apply it [8]. However, many scholars cast doubts on this policy, questioning whether this unique catch-up process can foster innovation. Literature suggests that such a policy is not successful in many high-tech sectors [9] [10]. Scholars suggest that a multi-level perspective is necessary for technology policy to consider the complex factors of various levels including macro-, meso-, and micro-scale issues [11]. Further research is needed on policy making to strengthen technological competitiveness and innovative capability in the long run.

1.2 Research Objective and Questions

The objective of this research is to develop a hierarchical decision model to assist technology policy decision makers in leveraging various technologies, strategies, and resources for sustainable innovation. Make or buy has long been a strategic problem for technology development in emerging economies. For instance, international technology transfer has been viewed as a direct contributor toward technology advancement, but it can also stifle domestic innovation when treated improperly. There are no current models to arrive at effective policy design that can align development strategies and resources allocation toward long-term technological innovation. This study develops such a research framework that can assist decision makers in emerging economies to develop guidelines for investments toward the goal of technological innovation. This research will explore different strategies in technological development, and find efficient pathways to allocate various input resources for innovation. This research will be achieved through exploring prospective technology areas, strategic factors, innovation resources, and measuring related judgments from expert panels.

Through literature review, five research questions have been formulated to deal with current problems and support the research objective. These research questions (RQ) are summarized as: RQ1 - What technologies to develop and acquire for emerging economies? RQ2 - What strategies are more efficient in technological development and innovation? RQ3 - What innovation inputs can promote and accelerate the development process? RQ4 - How should technologies, strategies, and resources be prioritized to strengthen competitiveness and support innovation? RQ5 - Where are the areas of disagreements among stakeholders? What are the related policy implications? The model will be applied

to the fast-growing Chinese pharmaceutical industry as a case study, so the questions will be answered and demonstrated through detailed research in China's context.

1.3 Research Methodology

To cope with the questions and achieve objectives, a hierarchical decision model (HDM) is developed. The model has the purpose of leveraging controllable resources to foster long-term innovation. The methodology to be utilized is Analytic Delphi study. Delphi offers a technique to make assessments over future uncertainties and strategic concerns. AHP will be applied to quantify experts' judgments on identified criteria or issues. Expert panels are formed of diverse sources to provide a balanced perspective representing industry and government.

Figure 1 provides a schematic overview of the research process. It is divided into seven phases. Related and supportive research in each phase is briefly discussed. In Table 1, these research phases are linked to the above-mentioned research questions.

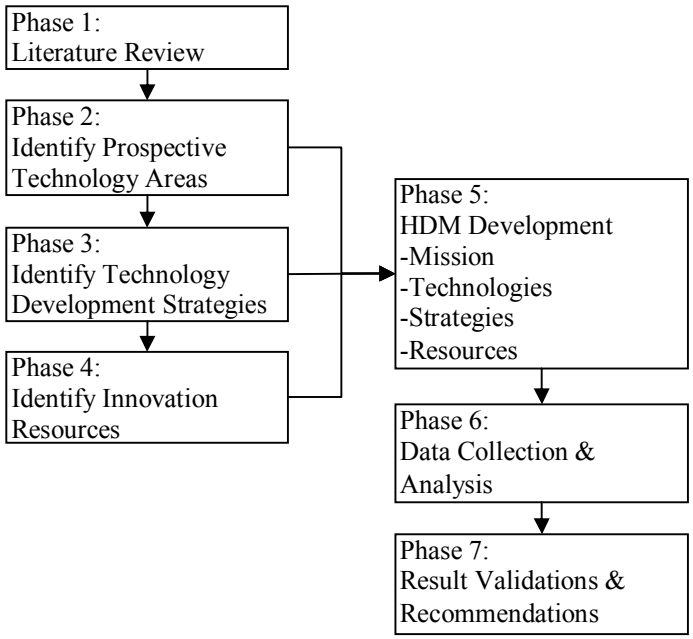


Figure 1: Outline of Research Approach

Phase 1 – Literature Review: The purpose of the review is to develop a solid background and understanding of the research topics. Major aspects include international technology transfer, innovation systems, technology foresight, and technology policies. Research gaps will be identified and highlighted.

Phase 2 – Identification of Technology Areas: The rationale of this phase is to identify global technology trends and adapt them to local needs and capabilities. This means identifying potential high tech areas where competitive advantages can be achieved through catching up and leapfrogging. The related and supportive research includes foresight/forecasting studies, industrial report, market analysis, academic research, expert recommendations, etc. The outcome will be a narrowed list of the technology alternatives. The list will serve as input to the following research phases

where strategic judgment is required. The studies in Phase 2 address the research question of identifying appropriate technologies to be developed by emerging economies.

Phase 3 – Identification of Technology Development Strategies: This part will investigate different strategies in the technological development process. Related studies will compare different conditions in developed countries and emerging economies. The chosen strategies will be based on the host country's developmental context, technology level, and research capabilities. Studies in Phase 3 explore the research question regarding what strategies are more efficient in technology development.

Phase 4 – Identification of Innovation Resources: This part serves to identify effective innovation input to support technological development strategies. Since innovation resources may vary from country to country and from industry to industry, this related study will focus on the innovation systems in emerging economies. Environmental factors such as framework conditions will be considered accordingly. Due to investment constraints, a combination of input resources will be identified and tailored toward the overall innovation objective. Studies in Phase 4 will answer the research question of what input resources can promote and facilitate the technology development process.

Phase 5 – HDM Development: Develop a hierarchy structure to illustrate the multi-level relationships represented in the situation and the judgment process. The research model utilizes information collected in the above phases as alternatives and criteria inputs for the decision process. The hierarchy includes the mission, technology alternatives, development strategies, and innovation resources. The criteria in the hierarchical decision model are presented to the expert panels for further validation.

Phase 6 – Data Collection and Analysis: Pair-wise comparison research instruments will be developed and sent to expert panel members to determine the weights of criteria in the hierarchical structure. According to their expertise fields, the expert panel will quantify the relative weight of importance for the elements in each level. Consistency level and disagreement of the experts will be calculated. Studies in Phase 5 and 6 will answer the research question of how to prioritize various technologies, strategies, and resources for competiveness and innovation.

Phase 7 – Result Validation and Recommendations: The quantification results will be validated and analyzed. The relationship between the elements in different levels will be clarified and explained. Sensitivity analysis will be employed to help improve the understanding of relationships among different levels. The analysis quantifies the range of difference of the optimal set if there are changes in related sub-criteria, and provides the basis to assist policy-makers in modifying the hierarchy for selection of the optimum strategy. Based on result analysis, discussions and recommendations will be given. Studies in Phase 7 explore the research question in the area of disagreement and related implications.

According to the overall research findings, policy-makers can apply more specific policy instruments such as direct and indirect funding, regulation support, and improvement in framework conditions. More detailed public policies will be potential areas for future research.

Research Phases	Research Questions Addressed
Phase 2 – Identification of Prospective Technology Areas	1. What technology to develop and acquire for emerging economies?
Phase 3 – Identification of Technology Development Strategies	2. What strategies are more efficient in technological development and leapfrogging?
Phase 4 – Identification of Innovation Resources	3. What innovation inputs can promote and accelerate the development process?
Phase 5 – Hierarchical Model Development Phase 6 – Data Collection and Analysis	4. How should technologies, strategies, and resources be prioritized to strengthen competitiveness and support innovation?
Phase 7 – Result Validation and Recommendations	5. Where are the areas of disagreements and agreements? What are the related policy implications?

Table 1: Connecting Research Phases and Research Questions

1.4 Research Applications

To demonstrate the model in detail, the research will develop a case application from the perspective of China. Among other developing countries, China is in the critical period of trying to catch up with developed countries and implementing a new path of industrialization. The issue of how to accelerate development and foster technological innovation has aroused great concern from government, industry and academic sectors, at the same time, provided an opportunity for research.

China has been developing fast in terms of economic and social achievements, with a lot of visible improvements but also many underlying weaknesses in technology management. The Chinese innovation system is still at an early stage and its development is always determined by the macro environment. In order to achieve national competitiveness in S&T, the country needs to improve its innovative capacity. One of the most determinative factors is its strength of sustained innovation in a globalized

environment. The core objective of the country is to locate its right position in the global innovation networks, and to construct an innovation infrastructure that can serve as the driving force for future development. Appropriate technology policy measures can integrate domestic innovation efforts along with foreign innovation resources. Such measures may help the country to catch up with the developed world or even leap ahead into the global innovation frontier. The dissertation develops a research model to help in achieving this objective. The research results may also be helpful to other emerging economies for achieving innovation objectives and promoting national competitiveness.

1.5 Outline of Dissertation

Chapter 1 provides an introduction and gives an overview of the dissertation. Research background, objectives, and approaches are briefly presented to give a complete picture of the study.

Chapter 2 constitutes the theoretical foundations supporting the research. It contains a comprehensive search of literature in major areas including international technology transfer, innovation management, technology foresight, technology policy, and related methodologies. Outstanding gaps are identified that motivate the research.

Chapter 3 links the literature gaps with research questions, and further clarifies the research goals. It presents the research methodology, research framework, and research approach. The research process is divided into several phases and discussed in detail.

Chapter 4 develops a case application for the model, which is about the biopharmaceutical industry in China. The customized model criteria, as well as the

structure, are validated by experts. Research instruments are developed to quantify expert judgment. The data collection process is discussed.

Chapter 5 presents the quantification results in charts and tables. The overall contributions of criteria are calculated in matrices. The data are analyzed for inconsistencies, disagreement, and sensitivity.

Chapter 6 discusses the result implications according to various levels in the model. Policy recommendations are included based on research results as well as experts' feedbacks during the validation process.

Chapter 7 concludes the research from the aspects of contributions, assumptions, limitations, and future research areas.

Chapter 2 – Literature Review

The literature reviewed in preparation for this research is focused on several major aspects – international technology transfer, innovation management, technology foresight, technology policies, and related methodologies. The purpose of this chapter is to develop a solid background and understanding of the research topics. In each section, technology policy and strategies are examined in various countries. A special section will focus on technology management issues in China. Literature gaps are highlighted at the end of this chapter.

2.1 International Technology Transfer

International technology transfer is a direct approach to improve the national technology level and strengthen national competence. As many emerging economies face the question of ‘‘make or buy’’ in technology development, introducing new technologies from advanced countries can serve as a fast track to boost the speed of catching up [12]. Through technology import, host countries can often shorten the learning time, enjoy the latecomer advantage, and achieve technology leapfrogging. However, international technology transfer is not an easy process. Barriers exist due to different conditions among countries in terms of social values, economic development, and technology level. There are more complicated issues if technology exporters belong to the developed world, while the technology importers come from the developing world. Scholars suggest that technology transfer needs to be perceived in terms of achieving three core objectives [13]: 1) the introduction of new techniques by means of investment in new plants; 2) the

improvement of existing techniques; and 3) the generation of new knowledge. This section will analyze various issues related to international technology transfer and identify literature gaps for improvement.

2.1.1 Levels of International Technology Transfer

International technology transfer can be studied from different perspectives. One approach is to focus on the entities involved in the process, i.e. technology exporter, technology importer, and technology itself. Another approach is to explore the growing trends of international technology transfer from different perspectives of various levels. A careful examination of the literature reveals that international technology transfer issues can be categorized into several interrelated levels including: national level, enterprise level, and technology level [14] [15]. International technology transfer is a complicated system process that involves not only the activities of market and economy, but also politics, culture, and society. Many obstacles still exist and are unsolved at each of these levels. A good understanding of influential factors provides better insight for policy-making.

At the national level, literature findings show that there are many environmental factors influencing international technology transfer, which include policy, economic growth, and market trend. For example, technology transfer needs appropriate legislation on intellectual property protection. It is also directly influenced by market need and investment. International technology transfer and acquisition should align with national goal in technology development. Macro-level regulations and incentives can have major impacts on the efficiency of the technology transfer process. International technology

transfer, especially high-tech exports and imports, are being strictly controlled by governments at the national level. Western developed countries have issued various regulations regarding cross-border technological transactions. These restrictions have largely deterred international technology transfer activities. For example, the United States has limited technology transfer to China in many high-tech areas, which includes: electronics and communications technologies, ship-building, airplane, satellite, materials, nuclear energy, etc [16]. This policy even inflicts many other EU countries working in high-tech projects with China. As a result, China cannot solely rely on international technology transfer in high-tech industries. Indigenous innovation should be emphasized and promoted at the national level.

At the enterprise level, many actors of international technology transfer have been identified in the literature. In the process of technical transactions, strategies of stakeholders are the determinants for the success of international technology transfer. The technology development process can be accelerated by cooperative interactions among the players. This is closely related to the robustness of technological innovation systems. Multinational companies are important sources for emerging economies to acquire foreign technologies, but there are many factors to consider such as intensified competition, crowding out of domestic enterprises and newcomers. Recent literature showed that international technology transfer can exist in some new channels such as R&D collaboration and cross border M&A. Technology learning has also been enhanced by some non-formal channels which include academic communication, flow of scientists and engineers, etc. These channels are new opportunities for the emerging economies to accelerate their catching up process.

At the technology level, many studies focus on the issues of technology selection and assessment. Characteristics of technology play a significant role in international technology transfer. These features may include availability, maturity, adaptability, and gaps, etc. From the perspective of developing countries, an emerging technology can provide a window of opportunity for technology leapfrogging [17]. Much has been written in the literature about the need to transfer appropriate technologies for developing countries. Therefore, technology adaptability in a foreign market is an important factor for the success of international technology transfer [18]. Technology gaps describe the distance between the domestic technological competency level and international state-of-the-arts technologies. Literature examining institutions and technological development found technology gap may either enhance or deter the efficiency of international technology transfer. Technology management techniques can be applied to international technology transfer for evaluation of technology alternatives, selection and acquisition of appropriate technologies. Emerging high-tech areas bring new challenges for developing countries to catch up and realize the latecomer advantage. Not only do they need to select the right technological direction, but they also need to accumulate technology learning capabilities.

2.1.2 Technology Transfer and Innovation

The intimate connection between technology transfer and innovation has been highlighted in the literature. For example, scholars claim that technology transfer is a key contributor to innovation performance, competitiveness and economic development of a country [19]. Some scholars developed linear growth models to illustrate technology

progress in industrializing economies. The development process was seen as a series of successive upgrading in parallel with a nation's economic environment.

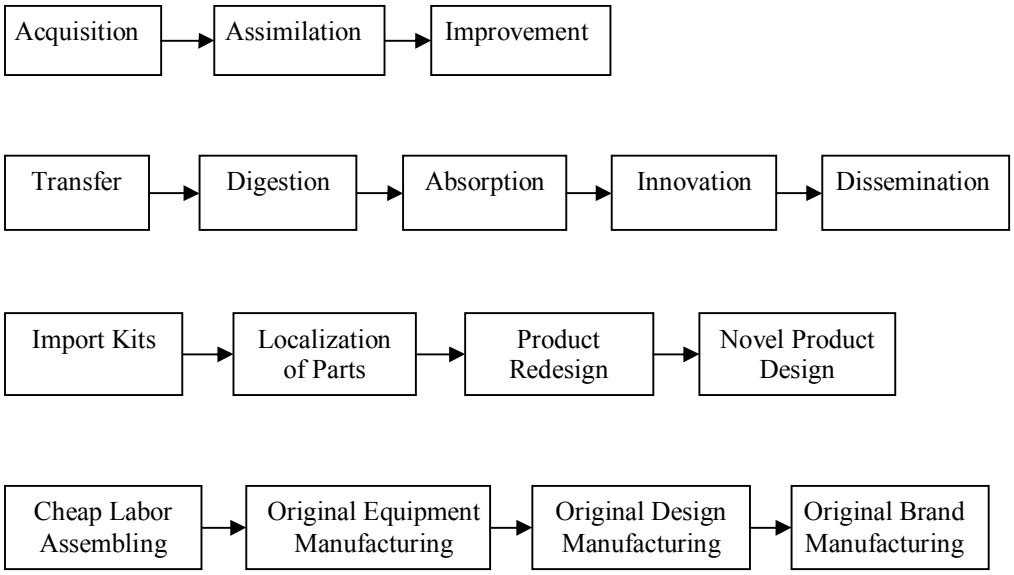


Figure 2: Linear Models of Technology Progress in Industrializing Economies

In Figure 2, Guan et al. (2006) presented a technological progress trajectory for the catching up countries from imitation to innovation which comprises acquisition, assimilation and improvement of technology [19]. Wang and Zhou (1999) considered the role of foreign enterprises and created a model of "transfer-digestion-absorption-innovation-dissemination" from China's perspective of increasing involvement in international production and trade activities [20]. Leonard-Barton (1995) proposed a model to describe import substitution, which starts from import kits, progresses to localization of parts and components, then to product redesign, and finally to novel product design [21]. Hobday (1995) suggested a linear model for newly industrialized countries: from the first stage of cheap labor assembling, through the second stage of original equipment manufacturing (OEM), then to the third stage original design

manufacturing (ODM), and finally to original brand-name manufacturing (OBM). The author emphasized the importance of OEM as a learning platform, calling it "an enduring technological training school for latecomers" [22].

Most of the above models connect international technology transfer with the concept of innovation or improvement in technology. However, implementation in the real world is not as easy as the models have depicted. For example, the literature has conceded that there are many problems, or at least it is still a difficult task for China. Scholars [20] argued that lack of sufficient technological capability is a major inadequacy at the firm level for implementation. The restructuring of the Chinese R&D system from a centrally planned mechanism into a flexible system should be an attempt to solve the problem. The literature has reported that China spent more on technology acquisition—the earliest stage of the technological progress trajectory but much less on the last two stages than Japan and Korea when their economies started booming [19]. Scholars also pointed out that the proportion of hardware transfer is high [23]. Except for some large-sized companies, most importers stay at the level of cooperation in transferring hardware. There is a negative influence on domestic industry in that it is a mature technology which is still largely transferred. Facing incessantly changing technologies and intense global competition, Chinese authors argued that the country should acquire more state-of-the-art technologies that lead to innovation and improvement [24].

Although international technology transfer can be an effective strategy to catch up with the leading countries in many high-tech sectors, it may not necessarily result in future innovation of the receiver. For instance, the literature explored the relationship between technology transfer activities and innovation performance with special reference

to Chinese industrial firms. Based on a nationwide survey covering more than 2000 firms, statistical results showed that technology transfer activities may impede the innovation performance of high-tech firms [19]. Recent research (2011) shows that regarding international R&D spillovers facilitated by FDI, the spillover effect on indigenous technical change is mostly insignificant or negative except in the medium low-technology sectors [25]. These facts mainly result from low absorption capabilities of domestic industries. Therefore, it is critical for policy makers to better utilize technology transfer as a tool to foster innovation and sustain future development. Many scholars from developing countries focus on how latecomers can catch up with advanced countries by leapfrogging or direct innovation at the technological frontier [26-28]. Lee (2005) identified two catch-up modes: Taiwan followed the sequential steps of OEM, ODM and OBM, by learning from foreign countries; Korea jumped from OEM directly to OBM without consolidating design technology. The author suggests that China might be a third model mixing elements of both Korean and Taiwanese models, but more research is needed [29].

2.1.3 Different Motivations and Interests

During the process of technological transactions, there are noticeable differences in strategic objectives among the host government, foreign technology providers, and domestic partners. Their strategies are the determinants for the success of international technology transfer. Scholars argued that research should not only analyze technology strategy in subsidiaries of MNEs, but also examine how such development differs from

that of domestic firms [30]. Their differences decisively affect the implementation of technology transfer.

2.1.3.1 Foreign Interests

The motivations of foreign technology providers have been studied in detail in the literature. Through four cases of Swedish manufacturing firms which have transferred technology to China, the literature generalized some of the Western companies' motivations for transferring technology to China. These include [14]:

1) Access to the Chinese market for China's future development potentials;

2) Achieve Short-term revenues through direct sales of machinery or plants;

3) Utilization of China's low labor costs and improving access to certain resources;

4) Achieve long-term revenue from their equity investment in joint ventures.

The above motivations cannot be easily realized, and major barriers or difficulties for Western companies exist in many aspects. A major threat to foreign companies arises from losing the technological lead to China in high-tech sectors. Most foreign companies are aware of this threat and are sensitive about raising potential Chinese competitors [31]. In the short run, there might be more common interests than conflicts between the foreign companies and their Chinese counterparts, such as growth in local market share and profit. However, in the long run, the Chinese counterparts might emerge as international competitors and capture more market share globally. Considering all the good prospects of the original motivations, this issue might therefore be a "double-edged sword" for the foreign companies. The literature also examined the question of technology transfer from the perspective of techno-economic security and how companies respond to the

possibility of losing competitive advantage through misappropriation or leakage. Techno-economic security raises the issue from a company level to a political level. Since this risk is often exacerbated by insufficient legal protection of Intellectual Property Rights (IPR) in China, the Europe Union officially urged China to strengthen related protection. The issue of techno-economic security relating to technology transfer to China also has a special significance because of uncertainty about, and non-transparency of, the legislation compared to Western systems [31].

2.1.3.2 Local Interests

The motivations of Chinese technology receivers are quite different from their foreign counterparts. Firstly, they focus on the acquisition of advanced technology, reputable trademark, technical and managerial know-how; Secondly, they want to gain access to international markets through export of the product produced by means of the acquired technology and earnings of foreign exchange; Thirdly, they want to become competitive in the local market and secure a technological base for long-term profits; Fourthly, they hope to develop R&D capacity; Last but not least, they may benefit from government's subsidies which encourage technical cooperation with foreign firms [14].

There are many difficulties for the domestic players to implement the above goals. For example, based on a questionnaire survey covering 200 sample companies and factories in mechanical industries in China, the literature provided a detailed analysis on various difficulties perceived by Chinese technology importers [23]. Major difficulties include inappropriate technology, limited access to overseas market information, misunderstanding and lack of mutual trust, steep price of the advanced technology,

unmatched engineering standard, incompatible production management system, training and on-spot service support, difficulties improving the transferred technology, and extra restrictions in the contract articles. Many uncertainty factors may influence the purchase behaviors of foreign technologies by the Chinese companies. Their practical considerations for evaluating foreign technologies can include: domestic market value of the technology, profit return from the technology, foreign advanced level of the technology, market value cited from other exporters, market value of an alternative technology, domestic advanced level of the technology, international market value of the technology, method of payment for purchasing the technology, risk level of the technology import for recipient firms, and supplier's cost for the technology (R&D and transferring cost) [23]

2.1.4 Implications for Emerging Economies

Although international technology transfer is a fast track in technology development, it may not naturally result in long-term innovation, or sustainable innovation [32]. It is widely accepted that the adoption of transferred or purchased technologies has both positive and negative impacts on domestic companies. Technology transfer activities will generally improve production and market performance of many domestic firms, but it might also impede the innovation performance of high-tech firms. Many domestic firms have been relying on costly generation technologies (e.g. key equipment and apparatuses), resulting in negative impacts of technology transfer on cultivating their core competence [19]. Most domestic companies of developing countries stay at the bottom segment of the "smiling curve", where production generates low marginal profit [33]. Although these

companies can receive a certain degree of technology transfer through outsourcing, the high-tech core is always retained by MNCs in the developed countries. Research [34] has shown that many outward-oriented and highly competitive industries, which are based on imported technology and foreign affiliates, seem to have had limited impact on local production and on the diffusion of technology in domestic industry.

From the perspective of emerging economies, there are more issues to consider about the negative effects brought by foreign investment. The entrance of MNCs may deteriorate the industry infrastructure of developing countries. Although the demonstration effect may lead domestic companies to upgrade their technology level, it also intensifies market competition. With a weaker technology edge and limited capital support, domestic competitors are easily ruled out of the market by technology lock-in. The technology absorptive capacity of the domestic company is the primary factor as to whether it can take advantage of spillovers [35, 36]. This will in turn depend on the company's strength of investment in R&D. However, R&D expenditures of domestic firms can rarely parallel those of large MNCs. Moreover, MNCs have different R&D strategies when going abroad, and they tend to minimize spillovers so as to keep competitive advantages [37]. In recent years, MNCs are getting more involved in vertical technology transfer. This new trend has shown that MNCs prefer to establish wholly owned subsidiaries in foreign countries. As a result, knowledge transfers tend to be internalized between the MNC and its wholly owned subsidiaries [38]. This makes domestic companies unlikely to benefit from technology transfer.

To resolve the differences in motivations and interests, the policies of the host country can have a crucial influence on technology transfer and its outcome. Technology

importers should adjust their technology acquisition strategy on the basis of their actual level of economic development, technological accumulation and long-term industrial plans. Scholars have developed an extension of the technology acceptance model (TAM) to study international technology transfer. Several antecedents have significant influence on the success of technology transfer, which include: technological compatibility, ease of adoption, technical and economic benefits to the adopting firm [39]. Therefore, decision makers need to prioritize various factors in technology development. A fairer policy should be considered for both domestic enterprises and foreign technology providers. Mutual understandings are required for both sides. Finding ways of increasing the effectiveness of technology transfer has strategic implications for both the host country and foreign investors.

From a broader perspective, the innovation process is a cooperative interrelation between enterprises and other actors. International technology transfer should be utilized as a supportive strategy to accelerate technology development and promote innovation. The goal of the host government is to achieve long-term social benefits for the host country through the acquisition of advanced technologies. This means localization of high-tech products and improvement of innovation capabilities of domestic industries. However, domestic companies are weaker in terms of technology level and knowledge accumulations. Due to intense market competition, these companies lack enough resources for long-term R&D. With the growing pace of internationalization, domestic enterprises are eager to transfer better technologies from foreign countries to increase market competency in the shortest amount of time. The issues faced by the host government are to adjust related policies and provide an innovative environment, thus

promoting industrial innovation capability. The goal is to leap into the ranks among technology leaders and thus engender a competitive status worldwide.

2.2 Innovation Management

Based on issues identified in international technology transfer, this section aims to further examine innovation and technology policy. Starting from the innovation theory, this section explores various types of innovation systems and related government innovation policies. With such literature reviewed, the analysis will focus on innovation management issues in emerging economies.

2.2.1 Innovation as National Competence

It has been widely accepted that innovation is the engine for development in the Western developed countries. Porter (2002) indicated that innovation has become the most important source of competitive advantage in advanced economies, and building innovative capacity has a strong relationship to a country's overall competitiveness and level of prosperity [40]. Technological competitiveness is often measured by the innovation capability of industries in a country. The innovation concept in Western market economies has gone through several stages. During the 1950s and 1960s, the industrial innovation process, was generally perceived as a linear progression from scientific discovery, through technological development in firms, to the marketplace (Figure 3) [41]. Starting from the 1970s, perceptions of the innovation process began to change with a marked shift towards emphasizing market need (Figure 4) [41]. According to the new model, the market was the source of ideas for directing R&D, which had a

merely reactive role in the process. In the mid-1980s, a new model combining the technology push and market pull emerged, and was widely adopted by both industry and academia (Figure 5) [41].

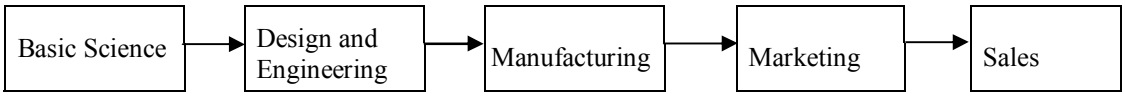


Figure 3: Technology Push Model

Source: Rothwell (1994)

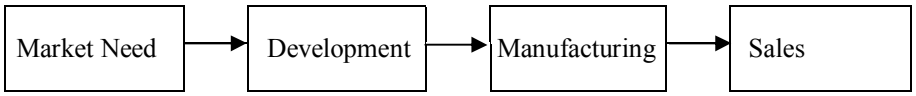


Figure 4: Market Pull Model

Source: Rothwell (1994)

Scholars also developed more complicated models to include various kinds of influencing factors of innovation. The following model (Figure 5) divided the innovation process into a series of functionally distinct but interacting and interdependent stages. In other words the process of innovation represents the confluence of technological capabilities and market-needs [41]. In recent research, Nemet (2009) proposed that the factor "Government Led" should be added to "Technology Push" and "Market Pull" [42]. In developing countries, governments can develop policies to encourage transfer of advanced technologies from developed countries. From different viewpoints, many scholars from emerging economies focus on how latecomer countries can catch up with advanced countries through leapfrogging or disruptive innovation [26-28].

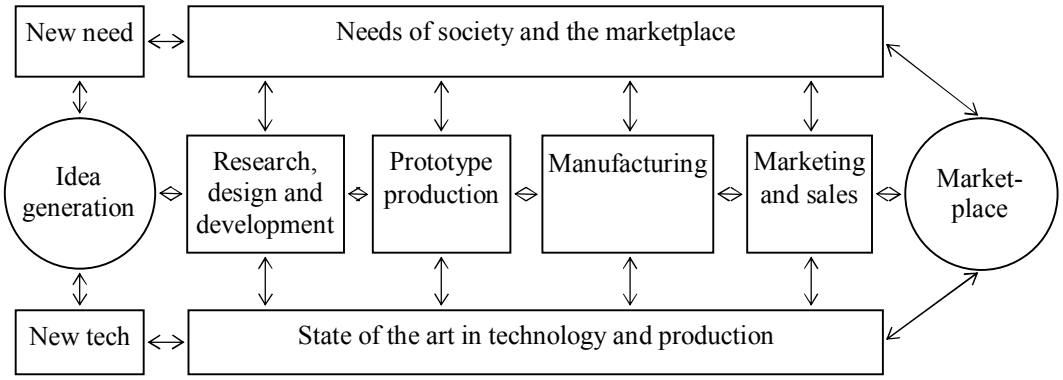


Figure 5: The Coupling Model of Innovation

Source: Rothwell (1994)

2.2.2 The Evolution of Innovation Systems

The linear models of innovation are somehow limited in scope and do not cover the whole picture of complexity. Both industry and academia noticed that innovations were influenced by many environmental factors. Freeman argued that, to realize large techno-economic system transitions, society needs to develop a new model of innovation, combining some features of the much criticized linear model with features of the systemic innovation model [43]. This leads to the emergence of an innovation system as a tool to understand the interactions of innovation activities. An innovation system is a very important determinant of technological change. The emergence of a new system and changes in existing systems co-evolve with the process of technological change [44]. Here we explore how the concept of innovation systems evolved.

Innovation is characterized by complicated feedback mechanisms and mutual interactions involving science, technology, learning, production, policy, and demand [45-47]. Edquist claimed that “firms never innovate in isolation” [45]. In this process, innovators interact with other organizations to develop and exchange various kinds of

knowledge, information, and other resources. These organizations can include other firms (upstream, downstream, or even competitors), universities, research institutes, government agencies etc. Various types of relationships can be established among these innovators during their innovation process. Therefore, innovating firms should not be regarded as isolated or individual decision making units [45, 48]. According to Elzen and Wieczorek, innovations emerge in multiple interrelated societal domains, including technology, economics, politics, and culture [49]. All of these studies indicate that firms operate within Innovation Systems. In recent years, more discussions and research about developing competitiveness and technological advancement have dealt with innovation systems. Mainly, four types of innovation systems are studied, which include National Innovation systems, Regional Innovation Systems, Sectoral Innovation Systems, and Technological Innovation Systems.

Freeman introduced the concept of National Innovation Systems (NIS) in 1987 [2]. It was further developed by Lundvall and Nelson in the early 1990s [50] [51]. NIS includes not only industries and firms, but also various actors and organizations of related fields in science and technology. Freeman defines NIS as a network of public and private institutions that through its activity and interaction creates, brings, modifies and spreads new technologies. Scholars defines NIS as "a system of interacting private and public firms, universities, and government agencies aiming at the production of science and technology within national borders" [52]. Metcalfe defines that a NIS is "a set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provide the framework within which governments form and implement policies to influence the innovation process" [53]. These definitions show that

NIS is a social and dynamic system, characterized by positive feedback and reproduction. The processes of learning and innovation can be promoted by the elements of the Innovation System that reinforce each other, or conversely, that block such processes when they combine into constellations that are unfavorable [50].

The Regional Innovation System (RIS) concept was evolved from the NIS concept. Krugman carried out some related research in regional innovation environments, innovation networks, and innovation clusters [54]. Other scholars further developed the RIS concept from the perspective of system evolution and regional innovative infrastructure [55] [56] [57]. Doloreux focused on the key elements in a RIS, where firms, institutions, knowledge structures and holistic innovation policies played important roles. He emphasizes three aspects of RIS, including interactive learning, milieu and embeddedness [58]. Several conceptual models have been developed for RIS, such as the triple helix model, which illustrates a top-down approach to the RIS focusing on the R&D functions of universities, public and private research institutes and corporations [59]. RIS is characterized by its regional features which can include a whole set of norms, attitudes, and routines that slowly evolve over time. These assets can make it difficult for actors from other regions to imitate similar practices, thereby protect the technological edge of the first mover region [60] [61]. Regional assets can have significant impacts on the innovation behaviors of actors within the region.

Sectoral innovation system (SIS) is another concept evolved from the NIS origin. Breschi and Malerba defined it as “a system (group) of firms developing and making a sector’s products and generating and utilizing a sector’s technologies” [62]. Actors in SIS may share some specific knowledge areas, technologies, needs, and demand. The focus of

SIS lies on agents and firms, which put much emphasis on non-market interactions and on the processes of transformation of the system [63]. Malerba further suggested that the SIS framework has three major dimensions: knowledge and technological domain; actors and networks domain; and institutions domain [64]. SIS reveals the fact that different circumstances and conditions exist among various industrial sectors. For example, each sector operates under different technological regimes, which are characterized by particular combinations of opportunity and conditions, degrees of cumulativeness of technological knowledge and characteristics of the relevant knowledge base [65]. The research of SIS focuses on the relationships among firms through considering the impact of their surviving environment. The boundaries of SIS emerge from the specific conditions of each sector, by focusing on the sources of knowledge and on the role of the environment in the process of knowledge transmission [62].

Technological Innovation System is defined as "a network or networks of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse, and utilize technology"[66]. TIS consists of networks of firms, R&D infrastructure, educational institutions, and policy-making bodies [67]. In comparison to other innovation systems, the TIS approach focuses on specific technology areas. There can be many technological systems in a NIS, but the national borders do not necessarily form the boundaries of the system [65]. TIS may not necessarily be restricted within any sectoral branch. The national boundary may constitute a natural limit of technological systems, or it can further form regional or local subsystems. The boundaries of TIS depend on various circumstances including the technological and market requirements, the capabilities of various agents, and the degree of interdependence among agents [66].

TIS are often used to analyze an emerging system rather than a mature system. As the systems evolve over time, the need for longitudinal studies is justified [65].

The innovation system includes three levels: macro perspective (NIS), meso perspective (RIS and SIS), and micro perspective (TIS). In order to achieve the desired performance of a system, it is necessary to understand the inner mechanism in the system, and it is also important to explore the outer dependencies among different systems. Technological innovation systems play important roles in developing a regional innovation environment, while the sectoral innovation networks and regional innovation systems can be embedded in the national innovation networks. Chung (2002) suggests that a regional innovation system is a good tool to generate an effective national innovation system, as it can effectively create different sectoral innovation systems in different regions [68]. The sectoral system experiences changes in a dynamic evolutionary process, which in turn affects many elements of the system. The TIS are the fundamental elements of various RIS and SIS, which in turn, are embedded in the NIS. From the perspective of a specific technology, TIS cut through both the geographical and the sectoral dimensions [44]. There are several different perspectives of studying innovation systems. Most commonly is to study the interdependency of different innovation systems within a country. Another approach is to compare innovation systems that are different from country to country, i.e. developed countries, developing countries, transitional economies, etc. Still another approach is to study relationships and interdependency of innovation systems among themselves. Owing to the differences in histories and traditions of different nations, and also in their size and development stage, the structure of national innovation systems differs substantially across the globe.

2.2.3 Globalization of Innovation Resources

In the era of globalized competition, the speed of high tech development and the capability of sustained innovation are vital for enterprises' survival. The concept of NIS provided a metric to study actors sharing a common culture, history, language, social and political regime within the national boundaries [45]. However, the trend of globalization and economic liberalization brings new challenges to this limitation. The emergence of global synergic innovations is getting more prevalent and dispersive across the world. The question is whether geographic boundaries are still relevant or not in high tech innovation.

Innovation systems were originally utilized to study the Western developed world. Since innovation has become the most influential factor for technological development and national competitiveness, the Western developed countries have made it a priority in policy-making. These countries have done so by creating and strengthening their NIS to promote technological and economic development [69]. The innovation system framework often links various national innovation resources (education, R&D institutes, and enterprises) to technological outputs (publications, patents, and new products). Fukuda (2008) argues that technology policy should generate innovation with a view to constructing co-evolution among heterogeneous players with different degrees of competitive advantage. Each player is required to recognize and develop its core competence through learning inspired by other players. The agility, adaptability, and alliance among heterogeneous players should be maintained and enhanced [4]. Innovation systems define the ecosystems of related entities, and ensure that potential innovation resources are effectively explored and utilized.

In recent years, an increasing number of geographically dispersed innovation networks have been formed between developing and developed countries. This is partially due to the expansion of multinationals from the developed countries. To fit the challenges of globalization, multinational companies are trying to utilize more dispersive innovation resources through establishing strategic alliances with companies from developing countries. For example, there are many types of international technology transfer activities such as original equipment manufacturers (OEMs), original design manufacturers (ODMs), electronics manufacturing service (EMS), and virtual organization (VO) [70]. Related studies indicate that the more progressive liberalization and deregulation of international trade and investment are, the more rapid the development and diffusion of technology will be, which will fundamentally change the global competitive dynamics in which MNCs operate [28]. Cooperative alliances have become an increasingly important part of the competitive landscape of multinationals [71]. It is a novel domain to deepen the research of systemic innovation based on matching foreign MNCs to SMEs and comprehend the pros and cons of global innovation networks. However, there are relatively few studies linking the innovation resources at both the macro and micro level to how an improvement could result in raising the mutual national Innovation Capacity [72].

2.2.4 National Innovation Strategy

Countries have different innovation strategies due to their differences in social, economic, and technological conditions. Here we explore national innovation strategies in developed countries and emerging economies respectively.

In 2010, the U.S. Federal government asked the National Research Council (NRC) of the National Academy of Sciences to review and analyze the S&T advancement strategies of six competing countries (Brazil, Russia, India, China, Japan, and Singapore) and to judge their likely impact on the U.S. at present and in the future. The result was published in a report titled "S&T Strategies of Six Countries: Implications for the United States." The report argued that multiple factors affect the likelihood of achieving national S&T goals, including the coupling of socioeconomic and cultural drivers, the globalization of R&D, the opaqueness and the resulting unpredictability of programs, and simply countries' available resources, priority setting and execution, disruptions, and so forth [73]. The report provides policy recommendations for the U.S. government based on the findings from other countries' strategies. Key policy implications include: 1) Monitoring the transformation from a national to a global S&T innovation environment portends future prosperity and security for the United States and all countries; 2) The transfer of intellectual property by multinational corporations into domestic companies through S&T activities should be monitored in key countries, particularly India and China. The United States could join with Japan, and possibly the European Union, to establish a united front against such practices; 3) The U.S. should prepare for, and transform to a S&T innovation environment to include global exchanges in education and R&D talent, international as well as national recruitment of R&D talent, multinational corporate collaborations, and public policies that facilitate or restrain the leadership in global S&T innovation; 4) The U.S. should monitor a competing country's capacity to facilitate the cultural changes needed to achieve its global S&T innovation environment, which is especially important for predicting future changes in the S&T innovation

environment; 5) Attracting quality researchers and providing research facilities and research support as important measures for the world's S&T talents; 6) Continue to gauge the efficiency of research, measured by the effective uses of research talent and research facilities, which portends the future of a county's innovation environment; and 7) Seeking mechanisms for sustainable U.S. government collaboration with the international community to uncover and exploit potential S&T breakthroughs [73].

From the perspective of emerging BRIC countries, scholars have also suggested various innovation strategies. Yang and Shu (2005) defined three types of innovation activities in China: indigenous innovation, imitative innovation, and cooperative innovation [74]. The concept of indigenous innovation stresses focus on the system's (country, industry or company) predominant core technologies and core products to improve its competitive ability [75, 76]. Imitative innovation refers to the adaptation based on the advanced innovators' technology, driven by the influences of the leading innovators' demonstration and interest mechanisms [74]. Cheng and Shiu (2008) defined comparable concept of re-innovation as "It is the part of new product development which studies the extension of existing innovations, which can only happen after the first generation of a new product is launched" [77]. Re-innovation is renowned for its potential in creating competitive advantage with reduced cost and time implications. A Japanese scholar suggests that imitation by lagging countries can contribute to the world welfare by making it possible for them to learn the latest technology and to become next-round innovators [78]. Cooperative innovation is a strategy to implement innovative activities with foreign alliances and is dependent on the mutual or multi-facet cooperation among enterprises, research institutes, and universities. The premise of cooperative

innovation is that each side shares the common achievements and develops all together. Accordingly, enterprises with competitive relations and conflicting interest can work hand in hand to gain profits and development momentum [74]. Active cooperation between firms can enable them to achieve outcomes that they could not achieve on their own, while allowing each individual partner enterprise to realize its own strategic goals [79].

An important reason for indigenous innovation is forced by the fact that some developed countries restricted high tech exports to emerging economies including China [80] [81]. Moreover, in some high-tech industries such as biopharmaceuticals, China needs to pay high prices importing foreign products, and this has led the government to develop indigenous technologies. As the latecomer approaches the technological frontier, so its strategies will shift from imitation to innovation [82]. This has been the case for many of the Asian countries. A common question is: Is it likely to stay stuck in catch-up mode as a perpetual imitator, or can it build its absorptive capacity to the point that it can sustain genuine innovation [83]? Indigenous innovation is a strategy with bright prospect for China, but the real question is how to balance it with other innovation strategies [84], i.e., imitative innovation and collaborative innovation, to build up the innovation capacity more efficiently and effectively. Fu and Gong (2011) suggested a "two-leg forward strategy" to maximize the benefits from existing knowledge and accelerate the catch-up process, where both indigenous innovation and acquisition of foreign knowledge are needed, but with the optimal mixture differing among sectors and stages of development. An effective technology policy package may thus be country-, region- and industry-

specific, but well-focused policies to foster the absorptive capacity and innovation capabilities of indigenous firms are always crucial for success [25].

2.2.5 Challenges of Innovation Governance in Emerging Economies

Following the global trend of innovation, emerging economies such as the BRICs are investing more resources to develop their innovation capability. However, the large majority of available studies ignore the fact that the characteristics of technological change of industrializing economies are largely shaped from the outside realms of foreign institutions in industrialized countries [85].

A major challenge for governments is how to construct effective and efficient innovation infrastructure. In many aspects, the BRIC countries, due to their stage of development, have essentially different innovation infrastructures when compared with the advanced economies. There is little evidence that current frameworks of innovation research in developed nations are also workable for countries like the BRICs. Viotti [85] found that that the NIS theoretical and conceptual framework is not appropriate for dealing with the processes of technological change of industrializing economies, which are extremely different from those of industrialized countries. Emerging economies have very different environmental contexts and changing agents. Transition from the traditional institutions towards the innovation model of growth involves formation of better mechanisms for social development based on the balancing of new innovation resources [86]. To such an extent, the construction of an effective and robust innovation structure is extremely necessary. This calls for the need of leveraging and prioritizing various input resources that buildup the innovation capability of the country. Thus

concentrating resources in the areas where the host country's competitive advantages can be achieved helps to boost innovation, which is a key factor that determines the competitive status of the national economy [87].

The inclusion of domestic S&T networks into the global systems of innovation also brings up new challenges. National innovation strategies should be designed and selected according to the developmental context of the host country. Technological innovation is a contextual process whose relevance should be assessed depending on the socio-economic condition it is embedded in [88]. It is a difficult task for transitional economies due to the legacy of inefficient or weaker innovation systems. Sectoral differences also bring challenges in policy making. For example, the private sector dominates biotechnology research in industrialized countries, but there are major market failures in developing countries [89]. The innovation system approach needs to be adapted to the situation in developing countries if it is to be allied to capacity building. Analytical efforts to better understand how more complete innovation and competence building mechanisms may be constructed in the present environment of global competition and networking need to be made [46]. The Global Innovation Index called for the necessity of national innovation strategy, but it did not propose a central operating model for widespread implementation issues [90]. This dissertation will probe into the background, rationale, and impacts of technology policy. Based on such findings, a research framework and methodology are developed for policy decision making.

2.3 Technology Foresight

This section attempts to review technology foresight from the perspective of innovation systems and globalization. It includes several important aspects of technology foresight studies: evolution, policy impact, and implementation issues. Special emphasis will look into recent foresight activities in the BRIC countries. Martin (1995) defines technology foresight as "the process involved in systematically attempting to look into the longer-term future of science, technology, the economy, and society with the aim of identifying the areas of strategic research and the emerging generic technologies likely to yield the greatest economic and social benefits" [91]. This concept and rationale are compliant with the policy needs to deal with the increasingly globalized science & technology development.

2.3.1 Foresight Initiatives in Developed Countries

Nowadays, technology foresight has been adopted on a large scale across the world. However, most available foresight studies are shaped by the practices and methodologies from the developed countries, especially Japan and the United States. Nevertheless, the two countries have totally different attitude toward government-lead foresight activities. Japan is the most enthusiastic country in carrying out national technology foresight studies, but the United States does not have such large-scale foresight activities at the national level.

Major themes for technology foresight in the United States have been examined in the literature: strong contribution to foresight methodology development, important narrowly focused foresight efforts in some federal agencies, and no holistic national

foresight studies [92]. Firstly, most of the widely applied foresight methodologies were developed by US researchers. These tools include: the Delphi methods, scenario planning, Analytic Hierarchical Process (AHP), technology roadmapping, technology assessment, and impact assessment. Secondly, some decentralized foresight studies have been undertaken at the sectoral levels. These foresight initiatives have been lead by agencies such as the US Environmental Protection Agency, the Department of Defense, and the Department of Energy. Thirdly, although there have been some foresight-like efforts in identifying critical technologies during the 1990s [93], there are so far no comprehensive national level foresight studies in the United States, and it is unlikely there will be any in the near future. There is no growing interest for national foresight from the Federal government. The United States relies more on the market mechanism to establish priorities and allocate resources [92].

National technology foresight studies in Japan are typically based on large-scale Delphi surveys addressed to experts in a wide range of fields. The foresight studies have been repeated approximately every five years since 1971. During this long time span, the scope of work and the range of methods applied have also expanded [94]. The first Delphi study took three rounds, but the Delphi studies of following years only took two rounds. The fifth, sixth, and seventh surveys started to address socio-economic needs regarding Japan's future. The eighth Delphi Survey was conducted in 2004. It addressed a 30-year period from 2006 to 2035. Although the study was still based on Delphi, some other methods were added for improvement. These new tools include: Bibliometrics, Scenario analysis, Socio-economic needs analysis, cluster analysis, and AHP. The eighth survey consisted of 13 fields, 130 areas, 858 topics, and about 2300 participant experts,

most of which are researchers, engineers, public and business executives [95]. Some key questions include: the importance of technology, time of realization, leading countries, and necessity of government measures. As a country with extremely scarce resources, Japan continued its foresight activity for forty years and observed that it was an effective tool for future development [94]. Although the Delphi methodology was imported from the United States, it has been adapted and improved to suit Japan's circumstances. Technology foresight is useful in setting stable framework conditions for technology development and improving engagement with policy-making in Japan [94].

2.3.2 Generations of Technology Foresight

The evolution of foresight activities has been significant since the 1990s. It was applied to various environmental settings which included the organizational, industrial, regional, national, or supranational level. Foresight scopes covered everything from limited technical experiments to major government initiatives. The timescale of foresight ranges from the immediate future to the far horizon. The range of actors involved, the process and methods used, and even the status of the activity varies considerably [96].

Scholars developed diverse foresight models to reflect the increasing changes. Johnston proposed five stages in the chronology of foresight, with technology forecasting and futurism leading to technology foresight, from which emerged foresight, with its wider understanding of the economic and social processes that shape technology [97, 98]. The author explored the strong progression within foresight studies towards being embedded within and directed towards planning and decision-making processes at various levels. Georghiou progressively posited a generational model of foresight in the

last few years (Figure 6) [99-101]. The development of the generation models has witnessed the fast evolution of foresight studies to match with the research of innovation. For the first generation foresight the key issues are accuracy of prediction and diffusion of technologies. In the second generation the take-up of priorities and connections of both industrial and academic participants become key issues, while the third generation implies the involvement of more stakeholders and looks for broader social concerns [96]. The fourth generation foresight moves into the distributed roles in innovation systems. To certain extent, the fifth generation will further touch on the complex policy issues of globalized innovation systems.

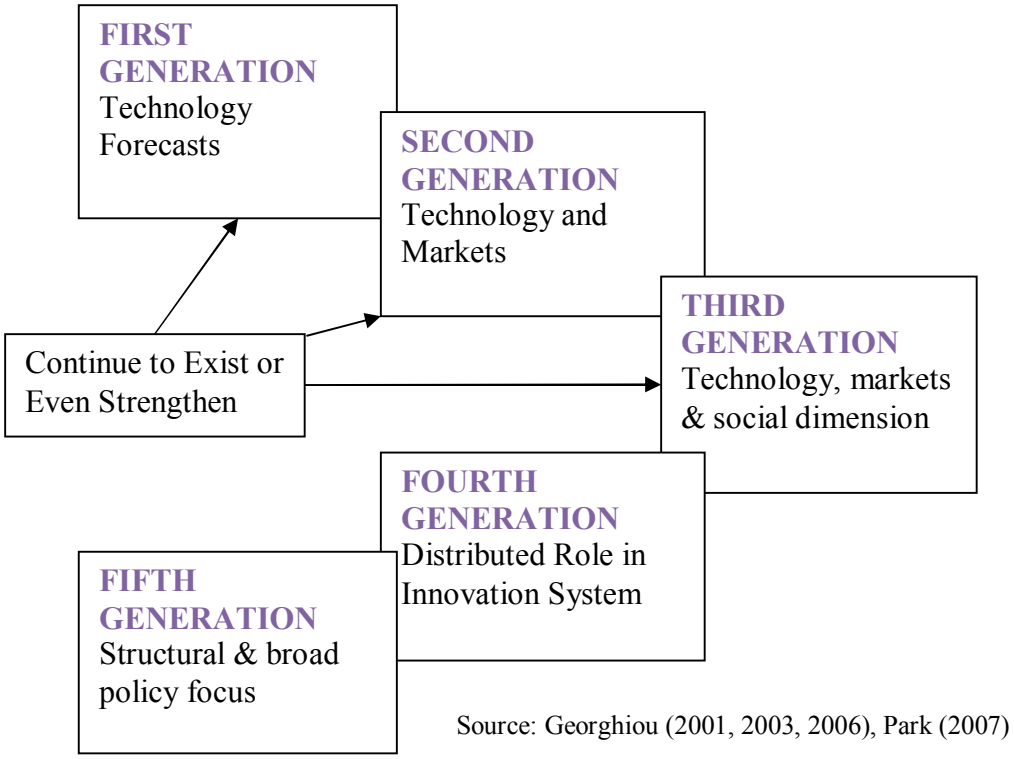


Figure 6: Generations of Technology Foresight

2.3.3 Technology Foresight and Innovation

Martin and Johnston first argued that technology foresight wires up and strengthens the connections within the national innovation system so that knowledge can flow more freely among the constituent actors, and the system as a whole can become more effective at learning and innovating [102]. Technology foresight exercise can be applied at organizational, industrial, regional, and national levels. From a similar perspective, comparable research on innovation systems also has a multilevel structure. Four major types of innovation systems are studied in the literature, including National Innovation Systems (NIS), Regional Innovation Systems (RIS), Sectoral Innovation Systems (SIS), and Technological Innovation Systems (TIS). These innovation systems can be classified into three levels: macro perspective (NIS), meso perspective (RIS and SIS), and micro perspective (TIS). These innovation systems often link various national innovation resources (universities, R&D institutes, and enterprises) toward technological outputs (publications, patents, and new products). Figure 7 shows the connections between technology foresight and innovation systems.

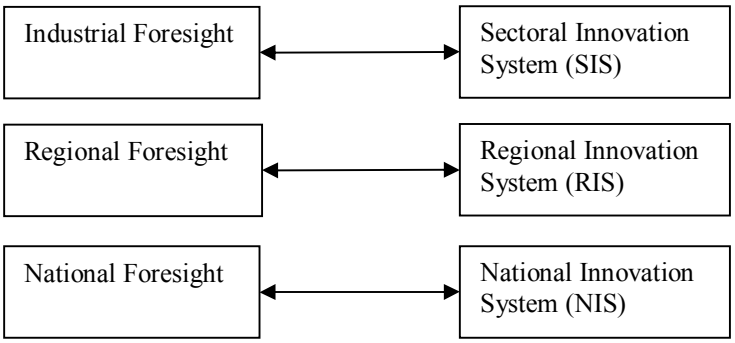


Figure 7: Connections between Technology Foresight and Innovation Systems

Technology foresight and innovation system research should be closely integrated so as to get a comprehensive understanding of emerging technologies and their social impacts. Foresight should be used to build up the new social structures, especially in the context of the more distributed and open innovation systems [96]. When governments carry out technology foresight, they should consider the broader influences from social, economic, and technological development. Related framework conditions have to be evaluated: the engagement of industry, the regulations, public support, the R&D infrastructure, the availability of personnel, etc. [103]. Both foreign and domestic technology development trends should be considered. Various types of technologies should also be distinguished, which include: core technology, key technology, and generic technology. Equilibrium should be achieved for long-term technology development and planning.

Technology foresight activities should adapt to the changes brought by globalization of innovation resources. Environmental differences stem from country specific characteristics such as policy risk, financial instability, and market fluctuations. Countries of different sizes and capacities have different positions in the global innovation networks. The necessity for international cooperation is very different in some countries. For example, Germany has an open S&T system with exchanges of knowledge to and from the neighbor countries, as it is a member country of the European Union benefitting from joint R&D ventures within Europe. On the other hand, Japan's S&T system is traditionally isolated, and not engaged in close joint R&D with other countries [103]. In the era of globalization and internationalization, the speed of technology development and innovation is vital for survival. By using national boundaries, actors sharing a

common culture, history, language, social and political institutions are identified [45]. However, science and technology systems, such as innovation systems, are becoming more integrated across national boundaries, raising questions about how an individual country can best benefit from the changing situations [102]. The speed of globally synergic innovation has been accelerated by economic liberalization. The geographic locations of global innovation cradles are getting more dispersive than ever before. These issues have raised new topics in the research of technology foresight.

2.3.4 Technology Foresight in Emerging Economies

National foresight studies are expanding from the industrialized economies to the developing countries in recent years. However, foresight activities and related social impacts in emerging economies have not been studied much in the literature, especially as a group of countries with similar characteristics. A common feature in these countries is the proliferation of new institutions and innovation systems resulting from transitional economies. This section will focus on the characteristics of national technology foresight activities in the BRICs, exploring the roles of foresight in technology development. Common problems and challenges will be discussed.

2.3.4.1 Foresight in Brazil

Although many Western techniques have been adopted in Brazil's foresight studies, heavy economic and political instability of the 1980s (energy shock and recession) led to seriously faulty (extrapolative) forecasts [104]. Some Brazilian scholars argued that the synergy between Competitive Intelligence, Knowledge Management and Technological

Foresight should be regarded as a new mechanism to support decision-making for sustainable development and innovation [105, 106]. Many recent Brazilian foresight programs have been criticized as follows:

1) The approaches by no means guarantee that the outcomes are easy to be implemented [107].

2) There was no real evidences of the proper use of foresight results, and some programs were discontinued without apparent reasons [108].

3) It is difficult to translate foresight findings into policy recommendations with a long-term vision. There are suggestions that a more systemic view should have been preferred in Brazil's foresight research [109].

Globalization-related impacts impose the need for implementing new strategies in the industrial and technological sectors of Brazil [110]. Foresight practices in Brazil not only need to emphasize issues about catching up with advanced countries, but they also need to consider issues about competing against emerging economies with similar conditions. This pattern has been demonstrated in some recent Brazilian foresight studies [106]. In an increasingly globalized context, the Brazilian market was opened to foreign competition, placing more emphasis on technological innovation, quality, and competition. However, among the many actions and issues with which Brazil needs to deal is how to take advantage of its unique local assets that can provide competitive advantages in the global environment [111]. Despite being the world's eighth largest economy, Brazil's innovative capability is still unsatisfactory. This gap between the generation of science and innovation is also typical of other emergent countries [112]. The country needs to construct a more efficient national innovation system with an

operating structure integrated with the global innovation networks. Technology foresight should play a more important role in such a process. However, as shown in the literature, Brazilian foresight studies experienced difficulties in implementing the foresight results or providing policy recommendations. This should be an area for future improvement.

2.3.4.2 Foresight in Russia

Foresight studies of the Russia Federation have features of a catching up economy. Russian scholars raised the question regarding whether Russia will develop catching-up with modernization or whether it will invent its own approach for exploring the future [113]. The selection of critical technologies in Russia should meet several criteria: Competitiveness, Contribution to economic growth, and overcoming dependence on imports [87]. Russia's development relies heavily on the exploitation of natural resources and raw materials, including energy, agriculture, and natural mineral processing. Although a leader in some high-tech areas, Russia still lags behind the major developed countries. Globalization provides Russia new opportunities in technological collaborations with advanced countries. How to strengthen the global competitive advantages of Russia is an important aspect in Russia's policy making. Foresight reports state that the transition of Russia's economics to innovation development is impossible without the formation of a globally competitive national innovation system and the creation of legal, financial and social institutions that would ensure interactions among the education, science, and business enterprise [86]. Although Russia has most of the elements in its National Innovation System, they are neither efficient nor are they

optimized to foster innovation [114]. The Russian foresight agenda for the future should include the construction of an integrated national innovation system [115].

The "Concept for Long-Term Russian S&T Forecast till 2025" program was developed in association with key ministries, science and business representatives in 2007. The main recommendations made to policy-makers were to develop measures to support spin-offs and start-ups, research teams and institutes, as well as training and education [116]. Among all the leading countries, Russia only leads in about 10% of the technology topics. The United States leads in more than 50% of all technology topics, followed by European Union and Japan, each with more than 30%. The results are comparable with Russia's innovation statistics in the last few years. As shown in Table 2 [117], only about 10% of Russian innovations are really new worldwide (in principle). It also means that about 90% of Russia's developed technologies already exist in other countries.

Year	Total	Including		Ratio
		New for country	New in principle	
2000	688	569	72	12.7%
2001	637	543	44	8.1%
2002	727	606	70	11.6%
2003	821	582	56	9.6%
2004	676	569	52	9.1%
2005	637	538	60	11.2%
2006	735	642	52	8.1%
Average	703	578	58	10.0%

Table 2: New Technologies Developed in Russia

Source: Eliseeva (2010)

2.3.4.3 Foresight in India

The only national foresight program implemented in India is the Technology Vision 2020 foresight program between 1993 and 1996. Although the program was completed more than 15 years ago, no such national level foresight study with comparable scale has been conducted since then. There are some follow-up projects taking place independently, including some regional or sectoral practices, but only in limited scale. The program results highlighted the fact that appropriateness of technology should be the guiding principle in India. It should be noted that what could be a critical technology for India may not be so for other developed countries such as the U.S. [118]. The technology needs of India ranged from strategic emerging technologies to rural development related technologies, all of which should be cost effective to match the domestic socio-economic needs [119]. The Home Grown Technology (HGT) program is an approach of the government to support the development of technologies by indigenous actors. The program supported 77 HGT projects, but was formally closed in the year 2005. Analysis of the programs reveals some shortcomings [120]: lack of funding for large projects, inadequate scale of operation, poor assessment of technology operations, lack of technically skilled manpower, and technology shifts which led to low market potential.

The theme of technology programs in India has strong characteristics of catching-up toward the developed countries. This conforms with government's goal which aims at increasing technological competitiveness and self-reliance, especially in high-tech areas [121]. India has suffered from the technology-control regimes of advanced nations. Developing indigenous capabilities for self-reliance in critical technology areas where denials of technology transfers by advanced countries are India's strategic priorities [122].

However, developing indigenous technologies may encounter enormous difficulties if the domestic innovative capacities are not ready or cannot provide enough support for innovation. Therefore, the country's innovation infrastructure will need to be crafted with due foresight and careful planning. With a new context of globalization and inter-dependence, an integrated approach to strategic technology planning will be essential to developing the requisite capabilities for the future [122]. This calls for a new generation of technology foresight in India.

2.3.4.4 Foresight in China

The technology foresight concept was introduced into China in the 1990s, but there was no formal foresight initiative in China until 2001, when two regional foresight studies were initiated in Beijing and Shanghai respectively. The Technology Foresight Towards 2020 program was a national-level practice led by the Chinese Academy of Sciences (CAS) from 2003 to 2006. The research consisted of two stages, and each stage covered 4 different high-tech fields [123]. A total of 8 fields, 62 sub-fields, and 737 technology topics were studied. The foresight methodology was based on expert panels, scenario analysis, and the Delphi method. Scenarios were designed for achieving a broad-based medium-level wealth society. Expert panel meetings played an important role in the selection of technology topics. During the Delphi survey, more than 1500 experts from selected areas responded to the questionnaires [124]. The methodologies of technology foresight in China are based on adapting practices from developed countries, including Japan, Germany, UK, and Korea. The foresight results showed that resource allocation is the most important issue to be faced by the government. The findings

highlight some potential improvement areas for policy-makers. For instance, under the criteria "Difficulty of Realization", the results reveal some constraints on the technology development: 1) regulation, policy, and standards, 2) human resources, 3) research funding, and 4) basic research infrastructure, etc.

There are some interesting investigations in the survey about China's current technological level compared with leading countries. When comparing the 483 technology topics with advanced countries, China is leading in only one topic, which is the "Chinese character & information processing technology." Since Western developed countries do not use Chinese characters, it is obvious that China can become the absolute leader in this field. For other high-tech areas, China has 20 technologies (less than 5%) on a par with international leading standards. Most technology fields (more than 90%) are lagging behind for 5 years or more (Table 3) [125].

Technology Fields	China Leading	China on a par with Leader	China Lagging 5 Years	China Lagging 6-10 Years
Information and communications	1	5	66	3
Biotech and life science	0	7	76	0
New materials	0	6	49	9
Energy	0	2	81	0
Resources and environment	0	0	99	1
Advanced manufacturing	0	0	52	26
Total	1	20	423	39

Table 3: China's Technological Level Compared with Other Countries

Source: MOST (2004)

Foresight revealed that China's technology level is lagging behind advanced Western countries. Table 4 shows the results of technology leading countries [123]. The USA leads in all technology fields, followed by Japan and the European Union. Russia

ranked fourth, and other countries are barely perceived as technology leaders. One exception is South Africa, which leads in the energy sector for a certain type of coal and petroleum processing technology.

Field	No. of Topics	USA		Japan		EU		Russia		Others	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Information, Communications and Electronics	150	150	0	1	97	0	56	0	0	0	0
Energy Technology	72	50	17	5	17	15	38	2	1	1	0
Materials S&T	86	73	11	12	68	2	6	0	1	0	0
Bio-tech & Medicine	101	94	7	6	23	1	74	0	0	0	0
Advanced Manufacturing	90	79	10	8	48	4	34	0	0	0	0
Resources & Environment	82	64	13	7	17	14	52	1	2	0	0
Chemistry & Chemical Tech	78	72	4	4	24	3	51	0	0	0	0
Space Technology	78	76	2	0	0	0	50	2	26	0	0
Total	737	658	64	43	294	39	361	5	30	1	0

Table 4: Technology Leading Countries

Source: CAS (2006)

2.3.5 Common Challenges of Foresight in Emerging Economies

Catching-up is the main theme of technology development in emerging economies. As we can see from the above comparative analysis, technology levels in BRIC are generally lagging behind world leading standards. Therefore, identifying critical technology areas that are suitable for leapfrogging is a primary concern. Since these countries differ in terms of historic evolution, economic development, technology capacity, and other social factors, technology foresight activities have to consider local needs, capabilities, and social differences. For example, an Indian scholar argued that critical technologies in India may not be that critical for the United States [118].

Appropriate technologies suitable for breakthrough development should be selected and prioritized accordingly. Since no country, however rich, can afford to pursue all the possible opportunities in science and technology, there needs to be better mechanisms for choosing between competing alternatives and resources [102]. They should focus on areas where comparative advantage can be achieved through technology leapfrogging. New models and approaches should be developed to identify and take advantage of opportunity windows, and to underpin areas of strategic research likely to yield the greatest economic and social benefits.

Another common challenge is how to transfer foresight results into effective policy measures and implementation strategies. The BRIC countries faced the problem of how to implement the technology topics identified in their foresight studies. There is evidence that in many emerging economies, after carrying out their foresight studies, the implementation of technologies was disappointing because little effort was dedicated toward strategic innovation management. One important reason for BRIC to rely more on independent innovation is forced by political reasons that major developed countries have strict export control of high technologies. The implication is that successful foresight must include understanding of the interaction of foresight outputs with the strategic behavior of policy and economic actors [126]. Globalization of innovation resources has increasingly changed the culture of technology development as well as the strategic behavior of the implementing bodies. The foresight programs have to cover both the technology status in the world and in host country. Brazilian scholars have used the term "gloCalization" to describe the strategy of "think globally, act locally" [105]. This idea perfectly matches the goal of technology development today. Latecomer countries should

try to avoid “reinventing the wheel” or remaking the mistakes of advanced countries. This may be achieved by learning through foreign experience, and adapting to its own situation but not by just following. Therefore, the decision on innovation strategy is an extremely important topic in an increasingly globalized innovation environment.

2.4 Technology Policy

It is technology that builds the core competence of nations. High technology has become the key factor in promoting regional economies and realizing sustainable development. Strengthening technology competitiveness and enhancing innovative capability have been the principal objectives for all countries. Government interventions in technology development are very common worldwide nowadays. Technology policy has the goal of making the best use of technology to achieve the national goals of improved quality of life for all citizens, continued competitive economic growth, and national security [127]. Through their responsibilities for social welfare and economic development, governments have profoundly shaped the nature of innovation within and across countries. They especially look to innovation in response to the great challenges of the age — in energy, health, and the environment [128]. Based on findings from the literature, this section discusses the political issues and feasible pathways for a government to enact technological policies and for industries to foster innovation. Different framework conditions between developed and developing countries have made the topic more complicated to study. Here we examine government policy related to high-tech industries from the perspectives of both.

2.4.1 Technology Policy in Industrialized Countries

Governments of developed countries are increasingly concerned with the impact of technology on their international competitiveness. The United States and other Western countries are attempting to develop effective technology policies that are in tune with global market realities [129]. Even though developed countries are in the frontier of technology development, they worry greatly about technological competitiveness, and how to maintain their competitive lead over other countries [3]. The United States now faces more challenges from technology competitors around the world. The agencies of the Federal government have conducted series of studies on how to strengthen national S&T competitiveness [3]. Most developed countries invest huge amount of capital in R&D to maintain their technological competitive edge. The U.S. introduced the American Competitiveness Initiative (ACI) in 2006, a major policy initiative to ensure that the United States continues to be the world's leader in S&T [130]. The ACI plans to commit $50 billion to increase funding for R&D and $86 billion for R&D tax incentives in ten years [131]. The target areas for these investments are high-tech industries that are important to the U.S. economy. In the past two decades, America's research-intensive industries: aerospace, chemicals, pharmaceuticals, communications equipment, computers and office equipment, scientific instruments, semiconductors, and software have been growing at about twice the rate of the economy as a whole [132]. The government’s support aims to sustain these achievements through continuous innovation at the technology frontiers.

Technology policy in developed countries focuses on providing various supports for innovations. Through technology and innovation policy, the government can guide the

industry moving it in a preferred direction that caters to social and economic interests. However, market failures have been noticed by economists and politicians in some high tech industries [133]. For instance, President Obama's innovation strategy report (2009) has highlighted the priorities in technology policy as follows: "There are certain sectors of exceptional national importance where the market is unlikely to produce the desirable outcomes on its own. These include developing alternative energy sources, reducing costs and improving lives with health IT, and manufacturing advanced vehicles. In these industries where markets may fail on their own, government can be part of the solution" [134]. In fact, many high-tech sectors need heavy investment and have long development cycles that cannot be supported merely by the market mechanism. Examples of such sectors can include: aerospace, defense, healthcare, energy, and environmental protection. Private companies may not be able to afford long-term R&D investment for 10 to 20 years, or even longer periods. Only the government can guide and subsidize such projects for decent paybacks in the long run. Long-term R&D is an engine for sustainable growth, thus it is important for governmental policy to provide more support for private companies that conduct "challenging" or "future-business oriented" R&D activities [135].

2.4.2 Technology Export Control

Uneven development is a common phenomenon of the world economy, and the technology gap is vast among different countries. Not only do countries invest heavily to develop new technologies, but they also apply various measures to protect their high-tech competitive edge. The transfers of technology, including technology exports and imports, have to strictly conform to a government's regulations. Different countries have issued

numerous legal terms and regulations regarding cross-border technical transactions. These regulations are updated frequently to strengthen a government's control of international technology transactions. Many technology exporting countries, especially Western developed countries, have strict limits on high-tech exports to foreign countries to prevent technology leakage which may potentially damage national competitiveness and other interests.

The United States has very strict and systematic control of technology exports. The Export Administration Act (EAA) and Export Administration Regulations (EAR) build the foundation of America's legislation on commodity and technology exports [136]. Although it expired in 1989, the EAA is still in effect through the President's powers under the International Emergency Economic Powers Act (IEEPA). According to these regulations, technology exports must be approved by the federal government through licensing. The licenses are divided into General License and Validated License. The later has more restrictions that will take longer to process. The Department of Commerce maintains a Commodity Control List [137], which includes all sensitive commodity or technologies that need special censorship. This list of sensitive exports includes telecommunications and advanced electronic equipment, precision machine tools, guidance technology, aerospace and jet engine technology, synthetic materials, specialized manufacturing and testing equipment, and so forth [138]. The list contents are frequently updated by the federal government to include newly developed technologies. Another important aspect is the destination or end user of the export. Foreign countries except Canada are divided into seven categories: Z, S, Y, W, Q, T, and V. Each category represents different controls on exports. For example, countries belonging to Z category

are under a complete embargo. According to various regulations, the United States has restricted technology transfer to China in many high-tech areas, including information and communications technologies (ICT), shipbuilding, aviation, space & satellite, and nuclear power [16]. Moreover, the American Congress passed the Exon-Florio Amendment (EFA) to the 1988 Omnibus Trade and Competitiveness Act [139]. EFA aimed to prohibit any foreign acquisition, merger, or takeover that might impair U.S. national security. It is certain that the concept of national security includes both traditional foreign policy criteria and defense issues. However, it is controversial whether economic considerations should be included. Indeed, there are inherent links among national security, industrial security, free trade, and the free flow of capital across borders. From the applications of EFA in recent years, it can be inferred that the term "national security" be interpreted broadly to include economic considerations. Many cross-border economic and technological activities are restricted by these regulations [140].

2.4.3 Technology Policy in Emerging Economies

While the developed nations try to maintain their technology advantage by tightening export control measures, many industrializing countries are trying to improve technological competitiveness and innovative capability [6]. Examples of these countries include China, India, and Brazil. The trend of globalization has significantly improved the condition for these latecomers' catching-up process. Innovation resources are allocated more diversely around the world. New learning channels are now available for the emerging economies. Technological innovation can be a high risk and expensive economic investment, but the risk and cost of learning from available technologies are far

below that of innovation. Many industrializing countries develop policies to attract FDI and encourage transfer of advanced technologies from abroad. These measures include: investment grants, taxes incentives, reduced tariffs, export subsidy, education and training. These are attractive terms for MNCs to introduce new technologies into latecomer countries.

Rapid development and intense competition of high technology have pushed emerging economies to develop more effective policies. Major policy considerations include national security, economic growth, social improvement, and foreign affairs. The success of the East Asian Tigers brought attention to the fact that most newly industrialized countries had been very interventionist during their early development stages. Examples of such countries include Japan, South Korea, and Taiwan. Their governments had enacted many regulations in trade, FDI, technology transfer and domestic resource allocation [133]. These policies often aimed at improving local competency and weakening the reliance on foreign technologies or products. Many countries require FDI in the form of joint ventures rather than wholly owned subsidiaries of MNCs. In countries like Japan and South Korea, during their developing stages, when policy gave priority to technology acquisition, MNCs were prohibited from establishing wholly owned subsidiaries [141, 142]. Since FDI can either foster or restrain the development of domestic industries, it is the government's role to balance the interests of both local and foreign stakeholders and thus guide and regulate investment. In order to make diffusion and spillover happen, technology policy in host countries should try to improve absorptive capability and innovative capacity.

The concept of technology leapfrogging was brought forward from the research of East Asia's miracle, especially from the experience of Japan and South Korea [143, 144]. Hobday (1994) argued that a developing country may leapfrog some steps and catch up to a developed country directly, bypassing huge investments in technological accumulation [145]. Path dependency in technology development can assist latecomers to achieve technology leapfrogging. The rapid development of new technologies also provided emerging economies with "windows of opportunities" to realize the latecomer advantage. The premise is that not only do they need to accumulate enough technology capabilities, but they also need to select the right technological direction that fits into the global innovation networks. Most of the windows of opportunity will emerge in high technology fields such as nanotechnology, biotechnology, and information technology. However, each of these fields consists of different areas, and adopting a single technology policy is not optimal for all. Accordingly, countries should carefully adopt a set of technology policies so that each policy is aimed at addressing the specific requirements of a specific high-tech category [146]. Technology development can be viewed as a vibrant process where innovations are driven by investment, market, and policies. Since the government has the control of resources, it can provide support to guide development in key technology areas. Macro policies can also impact on the efficiency of innovation systems. The best use of policy instruments can protect the interests of stakeholders, and promote their innovation activities.

2.4.4 Policy Instruments for Innovation

The search for effective policy instruments to foster innovation has long been a task for decision makers and researchers in technology management. Here we review the major types of policy tools. These research findings will provide the foundations for future result analysis and recommendations in policy making.

Innovation policies have been studied from different perspectives, and scholars have established categories that include: direct funding, indirect support, and information and learning [147]. As presented in Table 5 [147], the 3 major areas include 15 policy tools. Firstly, the direct funding part is primarily to identify appropriate actors in the innovation system, and provide them with R&D contracts or funding. Secondly, the indirect support part provides the innovators with more benefits in terms of credits and services. Thirdly, the information and learning part emphasizes the general industrial support measures. In addition to these three major aspects, the author also mentioned that macro conditions may influence innovation. These factors are commonly categorized into framework conditions.

Through studying policy practices applied in 25 member countries of the EU, Reid and Peter (2008) explored the sectoral differences of innovation policies [148]. The authors gathered hundreds of innovation-related policy measures from 11 different sectors. There are clearly sectors with an above average number of innovation policy measures such as biotechnology (129), ICT (128), and energy (117). Some other sectors have fewer measures, such as machinery (94) and textiles (96). An implication from this study is that each sector has a different innovation structure and patterns. Most of these policy instruments are geared to support various actors in each specific sector.

Categories	Policy tools
Direct Funding	• R&D contracts with private firms • R&D contracts and grants with universities. • Intramural R&D conducted in government laboratories. • R&D contracts with consortia that include two or more actors.
Indirect Support	• Patent protection. • R&D tax credits. • Tax credits or production subsidies for firms bringing new technologies to market. • Tax credits or rebates for purchasers of new technologies. • Government procurement. • Demonstration projects.
Information and Learning	• Education and training • Codification and diffusion of technical knowledge • Technical standards-setting. • Technology and/or industrial extension services. • Publicity, persuasion, consumer information

Table 5: Policies for Innovation

Source: Reid and Peter (2008)

As governments' goals and expectations toward technological innovation may vary from country to country and from sector to sector, different sets of policy tools or instruments will be developed to support various actors. It is understandable that each country has a unique framework context due to social, economic, and technological differences. These variations should be considered when developing innovation policies. Since this model will take China as a case study, framework conditions or limitations in China will be discussed in later chapter sections.

2.4.5 Implications for Priority Setting on Technology Policy

The necessity of priority setting in technology policy design cannot be overemphasized. The rapid development of high technology has made stable technology policy a difficult task in every country. The ever changing environment of world politics

and economies has further complicated the uncertainties in policy-making. Like many other public policy measures in society, technology policy is selective in nature. It is not uncommon that various funding and benefits are given to inappropriate innovators that cannot meet the government's original plan as they were expected. Therefore, it is necessary to study the causal factors and intrinsic relationship of policy issues involved. Scholars define national technology strategy as a portfolio of desired related technology areas that receive governmental supports in the form of specialized goals for each branch of technology. This strategy assigns well-defined tasks and responsibilities to the pertinent innovators that are responsible for implementing the goals for each technology areas [146]. The authors argue that prioritization should be emphasized in the policy-making process. Technology policy has the goal of directing technology development and innovation through leveraging limited resources. In both the short-term and long-term, policy should be prioritized so as to guide various innovators in their innovation process and maximize their innovative outputs.

2.5 Technology Development in China

Technology development and policy in China has been a topic of wide concern worldwide. As the largest technology importer in the world, China generates many business opportunities and attracts a lot of investments from developed countries. The lucrative Chinese market is a focal interest globally not only because of its growing rate and size, but also due to its increasing involvement and influence in the world economy. Policy measures in China can typically represent the interests of many other emerging economies such as Brazil and India. It is meaningful for other countries to better

understand similar issues and enact effective technology policies. As a developing country, the establishment of technology policy in China has been lagging behind the developed world. This section identifies some of the challenges and problems in China's innovation systems and related policy issues.

2.5.1 National Technology Programs in China

Since China's political regime still carries many characteristics of a planned economy, technology policies are often implemented along with national level technology programs. This section will summarize some important national technology programs introduced by the central government since the 1980s. Most of these programs served to give direction for S&T research, which focuses on the development of high-tech industries, technology transfer, and acquisition. Through studying the objectives of these technology programs, we can further identify the trends of technology policies in China.

The National Key R&D Program (1982) aimed to modernize traditional industries, upgrade industrial structures, and enhance high-tech industries. The contents of this program were to analyze international trends of S&T development, and carry out research on key S&T issues in China. The Program was fully funded by the central government, and was meant to concentrate the nation's resources to tackle major S&T issues [149].

The 863 High-tech Program (1986) was the most prominent national technology program in the last century. The title of the program means that it was initiated in March 1986. This program was formulated to focus on most high-tech areas for the 21st century. It covered biotechnology, information, automation, energy, advanced materials, space,

laser, and marine technology. The program's objective was to develop high-tech industries for China's mid- and long-term economic and social development.[149] [150] [151]

The Torch Program (1988) was initiated by the Ministry of S&T as a guidance program for technological development. It provided support for establishing research facilities, encouraging foreign high-tech investment, and fostering the development of domestic high-tech companies in special zones throughout China. With this program, the central government selected and funded research programs with high market potential and commercialization prospects [152]. This program highlighted the national policy of reforms and opening to the world.

The S&T Achievements Spreading Program (1990) was an important technology program aimed at bridging the gaps among different regions across China. The purpose was to apply and realize technological achievements to the development of rural areas in China. Technology transfer and diffusion activities from advanced coastal areas to backward inland provinces were written as national strategy [149].

The S&T Innovation Strategic Action Plan (2001) was launched in the new century, and it signifies that the objectives of technology programs are changing to focus on innovation. The program consisted of several subordinate plans, mostly in basic research, including life sciences, biotechnology, alternative energy, and environmental protection. It included many projects that were dedicated to the establishment of infrastructure and supporting facilities in these areas [153].

National Medium- to Long-Term Plan for S&T Development (2006-2020). In January 2006, the Chinese National Council convened the first S&T conference of the

new century in Beijing. During this conference, Chairman Hu, Jintao proposed the strategic objective of constructing China into an innovative country within 15 years (by the year 2020) [154]. The goal was written into the plan as a long-term policy, which implies that China is resolute to boost its technology level to match that of developed countries. The core of this program is to promote China's innovation capability and to rely more on domestic research and development. The plan emphasizes raising innovation capabilities to generate original invention through basic research [153].

2.5.2 Landscape of Innovation in China

By reviewing China's national technology programs, we can identify that the main theme of its policy on technology development has been switching toward innovation, but how can the Chinese NIS operate effectively? It depends on the strengths of various innovators or technology implementers. Technology policies need to consider and address the many issues faced by stakeholders and actors. Through reviewing recent literature, this section examines the unique characteristics of each participant or innovator in the innovation system. The situation in China is more complicated than many other developing countries due to its legacy of a central planned economy. The analysis will focus on issues faced by some key actors in China's evolving innovation systems. The following table presents recent literature (2006-2011) on technology development and innovation in China (Table 6). The stakeholders and innovators being examined in these studies have been identified and listed. Analysis will be followed to discuss major barriers and obstacles faced by each of these identified stakeholders.

Author	Year	Innovators Studied	Brief Summary
J. Wu and N. Pangarkar [155]	2006	MNCs, SMEs, SOEs	Explores how domestic firms in emerging markets can counter the threat posed by the entry of MNCs. Performance levels depend on the strategy adopted by the firm
P. Fan [156]	2006	SOEs	Domestic firms should focus on in-house R&D development to build their innovation capability, supplemented with external alliances.
W. S. Siu et al. [157]	2006	SMEs	Examines the interplay of government intervention, manufacturing systems and business approaches and impacts upon the new product development of SMEs in China.
X. D. Chen and G. Reger [158]	2006	MNCs	The motives for German FDI are long-term based and market-oriented, which can be characterized through seeking new markets and enlarging market shares. Technology transfer is mainly dedicated to production and managerial facilities.
J. Duanmu, F. M. Fai [159]	2007	MNCs, SMEs	Investigates vertical knowledge transfers from inward-invested multinational enterprises to indigenous Chinese suppliers
Xiaohui Liu, Trevor Buck [160]	2007	FR&D, MNCs	Foreign R&D activities by multinational enterprises in a host country significantly affect the innovation performance of domestic firms
Xudong Gao, et al. [32]	2007	MNCs, SMEs, SOEs	Development of strong manufacturing capabilities may not be an effective strategy for domestic firms competing against MNEs. The way to go is developing innovation capabilities and core technologies.
K. Motohashi and X. Yun [161]	2007	SOEs, SMEs, PRIs, University	Chinese manufacturing firms still possess only a low level of technological capability. Collaboration with PRIs and universities needs to be promoted.
G. Hutschenreiter and G. Zhang [154]	2007	SOEs, PRIs	Technology imports, and international technology transfer will continue to play important roles in China's development, but the country needs to continue investing in R&D and education and to overcome the institutional and structural weaknesses
K. Chen and M. Kenney [162]	2007	PRIs, University	Explores the role of URIs in the development of the Chinese economy through the comparison of developments of regional technology clusters
Xiaohui Liu, Huan Zou [163]	2008	FR&D	Foreign R&D activities by MNCs in China significantly affect the innovation in domestic firms and there exist both intra-industry and inter-industry spillovers
K. Fisher-Vanden, G.H. Jefferson [164]	2008	SOEs	Explores different purposes of internal R&D and Technology imports. Chinese firms simultaneously expend resources on disparate forms of technical change that embody different factor biases.
J. Zheng et al. [165]	2008	SOEs	China's reform measures often resulted in one-time level effects on productivity, but further institutional reforms are required to consolidate China's move to a full-fledged market economy
W. Hong [166]	2008	University	Examines university–industry collaborations in China, and shows a decentralizing / localizing trend in knowledge flow.

S. Girma and Y. D. Gong [167]	2008	SOEs, MNCs	Reforming the largely inefficient SOEs presents a major challenge. Limited regional linkages and low level of absorptive capacity are found to be the main reasons for the disappointing performance.
J. Y. Kim and L. Y. Zhang [168]	2008	SOEs, MNCs	This paper investigates the clustering of Chinese electronics manufacturers with foreign producers. It analyzes how MNCs' collaboration with local firms fosters local economic development.
K. Asakawa and A. Som [169]	2008	FR&D, MNCs	Compares the MNCs in managing their R&D in China and India. The paper supports the trend that more innovation is required by firms and managers to strategize their R&D investments in China.
S. Girma and Y. D. Gong [170]	2008	SOEs	Competition from sectoral FDI has a deleterious impact on the growth and survival probability of SOEs.
K. Kiyota et al. [171]	2008	MNCs, CMOs	Examines the determinants of the backward vertical linkages of Japanese foreign affiliates in manufacturing, focusing on the local backward linkages, or local procurement in China.
L. G. Ying [172]	2008	FR&D, CROs	The Chinese R&D productivity growth depends on the simultaneous expansion of the domestic and foreign knowledge stock in China. It largely depends on spillovers of the pioneer R&D.
H. Kroll and I. Liefner [173]	2008	University, SMEs	Spin-offs have been proven to be appropriate solutions for technology transfer at Chinese universities, but many of the companies still suffer from defective incentive structures and lack of performance.
Y. Zhou [174]	2008	MNCs, CMOs	Examines how the synergy between China's domestic market and the international market has affected its most competitive indigenous companies.
G. Bin [175]	2008	FR&D, MNCs	Investigates the contributions of four technology acquisition channels including: in-house R&D, foreign technology transfer, domestic technology transfer, and inter-industry R&D spillover.
S. Girma, et al. [176]	2009	MNCs, SOEs	Inward FDI at the sector level has a negative effect on innovative activity in SOEs on average, but there is a positive effect of FDI on SOEs that export, invest in human capital, or undertake R&D.
Dong Chen, et al. [177]	2009	MNCs	As emerging markets develop, foreign firms are being viewed less and less as providers of capital and/or technology, and more as integral parts of society
K. S. Swan, B. B. Allred [178]	2009	MNCs	The relationship between a perceived influence of China on technology strategy and MNC subsidiary process technology sourcing strategy is moderated by the innovation context
F. Hatani [179]	2009	MNCs	Drawing on the global value chain analysis and institutional views, MNCs inhibit technology spillovers even at the lower tiers of the supply hierarchy within the emerging economy context.
J. C. Guan, et al. [180]	2009	SOEs, SMEs.	Innovation activities of Chinese firms were mainly directed at quality improvement. SMEs that obtain support from the government generally perform better.
J. Fan, et al. [181]	2009	MNCs	China's FDI inflow is inefficiently large because weak institutions deter domestic investment while special initiatives that attract FDI are thus either unsupported or not unique to China.

C. Huang and N. Sharif [182]	2009	SMEs	Foreign-funded companies were less active than Guangdong domestic companies in pursuing research and development (R&D) and innovation activities.
Brandt and Thun [183]	2010	MNCs, SOEs, SMEs.	Industrial upgrading efforts are often domestically driven, intense competition exists between both domestic and foreign firms, which stimulates the upgrading efforts of domestic firms
Kroll and Schiller [184]	2010	PRIs	Domestic firms continue to depend more on foreign technology transfer than domestic technologies. PRIs will depend on improved management and a new funding system.
Lu, Tao, and Yang [185]	2010	SOEs	Local governments can help SOEs gain access to cheaper production inputs, but these enterprises may be used to pursue private benefits for officials
Motohashi and Yuan [186]	2010	MNCs	MNCs have vertical spillovers to Chinese firms. In some industries, only a small amount of vertical spillover effects are found. Horizontal spillovers do not exist in both.
Tian [187]	2010	MNCs	MNCs can manage technology spillovers through selection of entry modes, selection of technologies, and selection of investment priorities in the affiliates they establish in China.
Tang and Hussler [84]	2011	SOEs, SMEs, PRIs, University	The Chinese NIS should be reconsidered and designed to improve the absorption and innovation capability of domestic firms and to strengthen their interactions.
Fu and Gong [25]	2011	FR&D	Although foreign investment appears to contribute to static industry capabilities, foreign R&D activities have exerted a significant negative effect on the technical change of Chinese firms.
Koichiro Kimura [188]	2011	SOEs, SMEs	The Chinese firms need to strategically choose between "make or buy" decisions when they face technology gaps against foreign firms.

Table 6: Journal Articles on Technology Innovation in China

2.5.2.1 Higher Education Institutions

Higher Education Institutions (HEIs) have long been key players in technology development and innovation activities. HEIs were seen as having two tasks — to train high-level qualified personnel with professional skills and to develop science, technology and culture [189]. There are more than 1000 state owned universities in China, of which 200 have been regarded as strong in research (National 211 Program). Some selected premium universities are equipped with good research facilities and laboratories, where students and faculties can carry out scientific research in high-tech areas. Universities

participate in technology development through various channels, including cooperation with industry, collaboration with governmental departments, establishment of high technology spin-offs, and academic communication with other universities.

Although expanding at high speeds, Chinese universities still encounter many obstacles hindering their development in recent years. First of all, the central government is not able to provide enough funding for all. Most Chinese universities suffer from budget constraints, and many of the universities have to seek funding or even try to make a profit by themselves. Secondly, the academic programs are not designed toward long-term national goals. Programs in basic research give way to commercially related streams such as business and computer applications. Thirdly, only a very few Chinese universities have state-of-the-art equipment; therefore, R&D activities in many universities are below standard. Fourthly, Chinese universities experience difficulties in recruiting competent faculties. More graduates choose to work in industry, especially for foreign companies, where the salaries are higher. Most elite graduates seek opportunities to go abroad, either furthering their studies or careers. Last but not least, the performance evaluation system, distribution of benefits, and protection of IPR are also notable issues in Chinese universities [166] [173].

2.5.2.2 Public Research Institutes

Public research institutes (PRIs) are major sources of technological innovation in China. Their mission is mainly to serve the ministerial departments and enterprises within their industry. Due to the legacy of the centrally planned structure, technological R&D activities in these institutes were managed by vertical administration from the

government departments. However, in recent years, research institutes are encouraged to work with the industry, undertake research projects from other sources, and make profits from the outcomes of their research. Research institutes have gained more autonomy or have become completely independent of the government. These institutes decide which research projects to pursue and how to raise funds for projects and salaries [189].

The original purpose of these reforms was to alleviate the funding burden of the central government. However, such technology policies have brought negative impacts to the balanced growth of PRIs. To a certain extent, the S&T system reform is intrinsically prioritized for commercialization, which has weakened the development of basic research and public-benefit-oriented research [162]. Those applied-oriented research institutes have gained the most benefit from the reform, whereas those involved in basic research cannot easily obtain enough funding, neither can they attract or recruit enough top-level researchers. The situation is similar to the problems encountered by the Chinese universities. More importantly, the supply of public-benefit-oriented research has been insufficient to meet the basic demand of the nation. For example, the SARS scare in 2003 exposed the weakness of the public health system to defend the nation against serious diseases [149]. Many challenges remain with regard to how to improve the efficiency of PRIs and, more strategically, as to what role the they should play in China's emerging enterprise-centered innovation system [154].

2.5.2.3 State-owned Enterprises

State-owned enterprises (SOEs) are medium- to large-sized companies left by the centrally planned system, and they are referred as "the eldest sons of China." These

enterprises used to enjoy preferential treatment in terms of policy and resource allocation through government planning [180]. In recent economic reforms, some SOEs have been transformed into other categories of ownership such as shareholding enterprises, limited liability firms, and privatized SOEs. Except for the last category, the privatized SOEs, the government still maintains the majority share control of companies in the other two categories. The corporate governance mechanism in these companies is quite different from other types of companies. Top executives have to be appointed by the government and their experiences in these companies are continual building blocks of their political careers. As a result, these managers tend to focus on short-term economic performance rather than risky long-term strategic investment in R&D [167].

Funding and allocation of resources for thousands of SOEs across the country have long been an important concern for the Chinese government. The above mentioned economic reforms in recent years were to reduce such expenses and to increase revenues. However, SOEs' performances did not improve as much as expected, and they began to face more challenges under new conditions. There is a large spread in returns between the performance of the small number of state firms that do well and the bulk of them that do very poorly [165]. According to OECD (2008) reports, Chinese SOEs still record much lower levels of productivity than other firms, often appear to be less efficient knowledge producers and often lack the basis for R&D [190]. Scholars found that while R&D activities are more concentrated among SOEs, these enterprises are not efficient in knowledge production [191]. More recently, many SOEs have lost their previous monopolistic advantages due to economic reforms. Although SOEs continue to enjoy some priority of access to resources, their statuses are much weakened to a lower level.

Another concern is about the property ownership of SOEs, especially on the issue of infringing state assets caused by privatization. To sustain the transition process, the central government has been forced to pay more attention to developing S&T policy that fits the strategic orientations of different forms of enterprises, particularly those of SOEs [180].

2.5.2.4 Small- to Medium-sized Enterprises

China's economic reform in the last thirty years has resulted in the rapid expansion of the private sector. Small- to Medium-sized Enterprises (SMEs), which mostly consist of new ventures, have played a significant role and have largely contributed to industrial development. The growth of privately-owned SMEs also signaled that the Chinese NIS are transforming to a market-oriented economy. Many high-tech SMEs are emerging firms specializing in niche areas of some sub-sectors. They aim to profit by achieving competitive advantage in these market segments. SMEs usually favor more on market value than advanced level of technology. Therefore, their R&D activities are more likely to be targeted toward problem-solving rather than long-term basic research.

Although growing at high speed, the Chinese SMEs have faced many obstacles in recent years. Waves of SME bankruptcies have trickled out of China during the recent global economic recession. Growing financial troubles among high-tech SMEs pose an immediate challenge to China's technology policy. SMEs have not only encountered difficulties of limited financing channels, but have also experience excessive increases in raw material prices and labor costs. According to OECD (2008) reports, China's financial system does not meet the funding needs of private firms, notably SMEs. The capital

market is underdeveloped and SMEs find it difficult to secure loans since banks favor large companies, particularly SOEs. Smaller, privately owned firms thus largely depend on self-funding [190]. Moreover, some policies focused on SOEs have at the same time crowded out support to non-state owned companies even though they hold a large potential [154]. Export oriented SMEs face a series of problems, including: appreciation of the Yuan, shrinking foreign demands, surging costs of raw materials, and competition looming from other developing countries. Many other factors such as increased interest rates and heavy taxes are adding up to deteriorate the survival environment for SMEs. In order to support the development of SMEs, the government needs to increase financing and resolve the unfavorable conditions.

2.5.2.5 Joint Ventures and MNCs

Equity joint ventures (EJVs) are cooperation between the foreign MNCs and domestic companies. EJVs have been a preferred mode for the Chinese central government to acquire and introduce high technology from abroad. The policy of "trading domestic market for foreign technologies" has been adopted since the 1980s and the government expects foreign investors to transfer technologies when they work together with domestic partners. Many MNCs who invested in China chose to form joint ventures with Chinese partners. Two external factors appeared to be the major determinants of this choice which are environment factors and the market factors. JVs would be preferred for the MNCs when they are not familiar with the environmental of the host country. The domestic partner can provide them the knowledge in dealing with customers and local officials. For many Western firms, China offers the attraction of a

large domestic market for capital goods, intermediate products, and final goods and services. To others China may hold the promise of becoming a low-cost production base from which it could eventually serve not only the domestic market, but also the global market [14].

In recent years, EJVs in China have met bottlenecks for further development. Although China's entry into the WTO has reinforced foreign direct investment (FDI), these FDIs tend to favor low-tech industries that extract more resources from China [155]. The quality of enterprise level cooperation and related international technology transfer is at a relatively low level, and high-tech components are barely transferred. As a result, technological innovation only improved in several limited industries, and S&T achievements in many high-tech areas still grow at very slow rate. Another concern is that the MNCs are switching away from choosing EJVs as an entry mode. The Wholly Foreign Owned Enterprise (WFOE) is a more prevalent set-up among many foreign companies [168]. It is generally accepted that such a governance mode can ensure MNCs to withhold knowledge leakage and protect the technology edge. An additional reason for the phenomenon is that the Chinese government did not provide better policy support for EJVs over WFOEs. In order to sustain MNCs' contribution to domestic innovation, policy design should induce foreign investors toward target high-tech areas, and introduce technologies with internationally accepted quality standards. The government should offer favorable policy measures such as land, subsidy, taxation, and industry-level education and training.

2.5.2.6 Foreign R&D Centers

A growing number of Western and Japanese firms have been launching their R&D operations in China [169]. This has no doubt brought China a new channel of international technology transfer [160]. On the one hand, some companies have established foreign owned in-house R&D facilities in China. On the other hand, many companies have setup virtual R&D networks, building partnerships with domestic companies and research institutes, as well as universities to conduct research. A wholly owned in-house R&D center in China can recruit and train high quality employees. It also helps the foreign side to have better control over the research process, as well as their investment [163]. A virtual network is a good choice for firms to reduce risks and costs. Risk sharing occurs when separate entities invest in a common risky endeavor. Through cooperation with other firms, each entity pays only a fraction of the investment. This allows research to be done more efficiently. It expands a company's capacity, increases flexibility, and reduces fixed infrastructure. R&D contributions are not limited only to China, but are also expandable to other countries, or even globally.

A notable problem is that there are more "D" activities than "R" activities in the foreign R&D centers. In many cases explored by available research, "development" is a dominant part of R&D in China. Part of the reason is that foreign investors tend to focus on the development of technologies that are immediately applicable to the Chinese market, while neglecting long-term basic research. Although many of the investigated foreign investors expressed a wish to expand the "research" part, including knowledge transfer, they have so far been reluctant to do so, because they see serious problems in China [31]. Some of the common issues include lack of quality local researchers, weak

IPR protection, and a lack of policy support. Firstly, many companies try to expand their R&D activities through cooperation with local universities, which can have a strong bearing on recruiting prospective graduates and qualified talents [175]. Secondly, some investors considered the R&D facilities as being very sensitive in terms of maintaining and increasing competitive advantage [169]. As long as the IPR issues still exist in China, foreign companies tend to keep their core R&D in headquarters or split up their R&D activities among various units to reduce risks of losing core knowledge and technology [31]. Thirdly, since different actors are competing for resources, policies are not geared to support foreign R&D centers. For example, many restrictions and regulations apply to foreign research in China, ranging from resource exploration to exploitation. Summarily, if the Chinese government were to better utilize foreign R&D centers as innovation instrument, policy measures need to be enhanced to guide and support their growth.

2.5.3 Framework Conditions for Innovation

Due to the differences in social, economic, and technological development, each country has different framework conditions for innovation. These include various institutional limitations to be considered in policy making. Since this research will take China as a case study, it is necessary to discuss related constraints in China's innovation environment. China is shifting from a central-planned system to a "socialist market economy", and its NIS is undergoing a transitional process. Innovation policy should consider lifting or mitigating various limitations to improve the conditions for innovation.

The legacy of the central-planned economy has left China with a relatively stronger state-owned enterprise system but a weaker private sector. According to a statistical

report in 2010, the revenue of the top 500 private Chinese companies combined cannot win over that of the top two state-owned companies [192]. SOEs are still holding a favored position of technology development in China. Private-owned SMEs are in an inferior position in market competition as well as R&D activities. Due to intense market competition, domestic companies tend to focus on short-term revenue and financial performance. In general, the ratio of R&D investments to sales revenue of domestic enterprises is much lower than that of multinational companies. Domestic companies favor acquiring and transferring technologies that lead to easily replicated fields. This situation may lead to market failure in domestic industries, such as China's automotive sector. After opening up for more than 30 years, China is still heavily relying on imported automobiles and parts. Considering the fact that neighboring countries such as Japan and South Korea had successfully established their automotive industries in only 20 years, the Chinese policy makers should reconsider their strategies in technology development. Government intervention and regulatory changes should be adjusted to promote business R&D and innovation.

The distinctive Chinese R&D system is another critical issue in promoting innovative capability. Universities and research institutes are still under direct control of the government. Ideology issues and bureaucracy are still prevalent and have deterred the improvement of innovation conditions. For example, students are forced to take multiple courses in Socialism and Marxism. All universities and research institutes are required to have a Party Committee, and its members have to be included in the administrative and management levels. Such a management structure deeply interferes with teaching and academic research. Due to a better research environment and less control, as well as

higher pay, many high quality scientists and engineers choose to work for foreign-owned companies. Although increased investment in universities and public research institutes can be a major solution to ease the problem, structural reforms are needed to improve innovative conditions and lift unnecessary political barriers.

At the national level, high-tech export controls over China have to be considered in policy decision. Technology exporting countries have various regulations to maintain their national interests and competitive advantage. These policies prohibit advanced technologies from being transferred across borders. The implications for U.S. foreign policy revealed the fact: "When it comes to advanced technology, national security can no longer be viewed in pure military terms; economic security is also a vital consideration" [129]. Moreover, the U.S. has allied with major developed countries to enact strict limits on technology transactions related to China. So far there are very limited actions that the Chinese government can take, except through formal foreign policy negotiations or lobbying activities. Although China has been isolated from the Western world for many decades, it becomes very necessary for the country to improve international relationships in the background of globalization.

At the enterprise level, multinational companies have common concerns about intellectual capital protection issues, which constrain their willingness to bring new technologies into China. Without appropriate IPR protection, MNCs may take the risk of losing competitive advantages to Chinese counterparts. It is not uncommon to see in a joint venture when the local side learned all core technologies and then the foreign side was kicked away. This is the reason why some MNCs are reluctant to fully transfer their core technologies to developing countries. It is a challenge for them to balance the

collaboration and competition with domestic companies. Much research evidence shows that multinationals will hesitate to make investment in developing countries if their interests are not protected. This will influence their strategies of technology transfer, and lead to the transfer of low-tech products [193]. Research reveals that strong protection of IPRs can promote international technology transfer and bring more FDI for late-comer countries [194, 195]. Therefore, policy makers should consider improving the regulative framework to protect foreign investments.

The above discussions briefly covered major institutional limitations of innovation policy in China. Overall, policy initiatives should be designed to improve institutional environments through better regulation, standardization, intellectual property management, training of workforce, etc. [148]. The innovation efficiency of actors is highly impacted from above by macro-level institutional factors, and from below by micro-level technological issues. It is natural to link these influence factors with the innovation infrastructure in the host country. As a result, it is necessary for policy makers to identify major actors and mitigate related institutional limitations. This may provide the actors a better environment in which to develop new technologies and thus contribute to technological innovation in the long run.

2.5.4 Challenges of Innovation Management in China

Technological innovation in China's high-tech sectors has been deeply influenced by industrial policies implemented by the central government. The country has gone through a long way to catch up with the developed world. China's NIS is still fast evolving and has caused much difficulty in policy-making. Although the central government has taken

initiatives to facilitate interactions among various innovation players through many national technology programs, policy actions concerning innovation system reforms aimed at improving innovation performance and efficiency are still very limited. This is mainly due the complexity of China's innovation infrastructure as a fast transforming economy: Tylecote (2006) argued that dual innovation systems co-exist in transitional China [196]. One is an upper level innovation system which mimics its counterpart in developed economies and focuses on the development of advanced technology. The other is a lower level innovation system which has its roots in locally embedded industries. Li (2009) suggests that during the catch-up or transition process, overall economic and innovation performance depends largely on how China coordinates the two system levels [197].

Despite rapid growth in the last three decades, China is still weak in many high-tech sectors but stronger in some low-tech areas. Most domestic companies rely on over-consumption of natural resources, and specialize in labor intensive sectors. FDI tend to favor low-tech industries that extract more resources from China. Although China's joining the WTO has further reinforced FDI, the market environment did not improve much for the domestic players, as they began to face more intense competitions from all over the world. As a result of globalization, many foreign investors have established localized R&D facilities in China trying to benefit from cheaper resources [198] [199] [169]. These investments have no doubt increased China's research capacity in some low-tech areas, but the question is how China can effectively integrate these resources to achieve sustainable innovation. Scholars suggest that China needs to find ways to better integrate inward FDIs into the emerging Chinese innovation system [154].Generally

speaking, China needs to improve its technology policy through balancing foreign technology learning and indigenous innovation [84].

As an emerging economy with transitional innovation systems, China does not have effective innovation measurement mechanisms that can fully consider its unique macro environmental context. A benchmarking method from the Organization for Economic Co-operation and Development (OECD) has been adopted in the last few years. The Chinese Ministry of Science and Technology (MOST) formally requested OECD to carry out a review of innovation capacity in China. The review process was implemented as a joint OECD-MOST project, which took place from 2005 to 2007 [190]. OECD sent multiple experts and consultants to a station in China, where they guided the local researchers to carry out related studies. From a Western perspective, the report gives comparative analysis of the Chinese national innovation systems. The reports highlighted some key challenges to be faced to achieve China's ambition to base its future economic and social progress on a stronger national innovation system. First, there are downsides to the current growth pattern to rely on basic and large-scale production capabilities. The country should strive to make the transition to a more innovation-driven and sustainable growth model. Second, technology policy should serve to improve the framework conditions for innovation. Third, the government should foster an enterprise-centered NIS. Fourth, policy measures are needed in the repositioning and upgrading of the public R&D system. Fifth, the government should prepare to meet the challenges and opportunities of globalization. Lastly, the report suggested strengthening innovation governance [190]. As we compare these OECD suggestions to literature findings, they align to each other. Although the OECD's report identified many problems in the Chinese NIS, there are still

some noticeable deficiencies. Firstly, it did not give detailed solutions especially when dealing with sector-specific issues. Secondly, the report came up with some suggestions, but how to prioritize limited resources was left open. Thirdly, as a government (MOST) initiative, it did not criticize or evaluate some disputed technology policies, i.e. trading of the domestic market for foreign technology. Furthermore, the analysis on globalization of innovation resources is not enough, and it does not come up with a new implementation methodology.

2.5.5 Implications for Technology Policy in China

As it would be difficult to separate the national strategies of the Chinese government from those of the Chinese enterprise, one must add as motives the economic and industrial aims of the state that consist of foreign exchange earnings, import substitution, creation of new jobs, and improvement of industrial productivity, quality and capacity [14]. Given that the central government continues to exert a leaden impact on industrial innovation, technological policies should be adjusted in a timely manner to match the rapidly changing economic and social context.

Policy measures implemented by the central government were in a predicament in recent years. For example, “Trading of domestic market for foreign technology” has been a major strategy of China's technology policy to attract FDI and promote technology development since the 1980s. In a broader sense, this policy covers all measures that acquire foreign technology through granting foreign companies free access to the domestic market. There have been many disputes on the outcome of this policy in China, and the topic has aroused wide attention in academia. The main argument is, “Can

technology be exchanged for by market share?" The rationale of this strategy assumes that China could use the latecomer advantages to upgrade its industrial structure and technology level. In the mean time, China can save lots of foreign exchange on technology by just giving away some market share. However, in some high-tech industries, the advantage of latecomers has scarcely been realized, domestic innovation capacity makes little improvement, and the technological gap is further widened. In some extreme cases, such as the automobile industry, domestic enterprises have even fallen into the trap of reliance on import of core technologies. In recent years, a similar technology policy has been applied again on technology transfer deals in the high-speed rail industry. China introduced Electric Multiple Units technology from four different countries (Japan, Germany, France, and Canada), but the core technologies are still controlled by the foreign side [10]. A major difficulty is that China lacks the innovation capacity to fully absorb foreign technologies. The government has many things to do in order to improve the country's innovation systems.

The government should strategically allocate both foreign and domestic innovative resources under the new condition of globalization. Technology policies should consider the interests of foreign investors. There are some areas in which policies and initiatives at the national level could protect the interests of foreign firms. These include the protection of intellectual property and trade liberalization. Swedish scholars found many challenging aspects for the foreign companies while negotiating technology transactions with the Chinese side [14]: The legacy of a centralized system, a poor infrastructure, a distinct culture and foreigners' lack of access to adequate information on the Chinese technology. China's entry into the WTO in 2001 marked a new era in technology

development. However, the WTO agreements cannot remove all the preconditions imposed on foreign investors. For example, China did not sign under the article which removes the requirements for transferring technology when establishing joint ventures with domestic partners. It is likely that China will continue to impose many restrictive conditions on foreign companies. Therefore, there is a necessity at the national level to give better transparency in policy-making, especially regulative measures for foreign companies. The construction of a sound regulatory framework for investment and a better enforcement of Chinese regulations on intellectual property rights are prime examples to solve the problems [31].

Since policy is selective in nature, prioritization and optimization of innovation resources are very necessary. The literature has identified that a government's management of resources and related constraints and impetus are most important in policy making. Since the central government has the privilege of resource allocation, it can therefore establish regulations or offer incentives and favorable measures to promote technology development. Scholars have introduced a conceptual framework that addresses major determinants of technology development and transfer in China [189]. The determinants include the ideology, economic system, and constraints and impetus. Although the authors have identified the importance of government's management of resources and related constraints and impetus, no prioritization strategy was made or proposed (Figure 8) [189]. Moreover, little consideration has been given to include the increasing influence of foreign companies, which have been argued by many studies to have extensive impact on technology development and innovation. In order to increase industrial innovative capacity and strengthen China's national innovation system, policy

should be designed to guide and support innovators that can contribute more toward technology development.

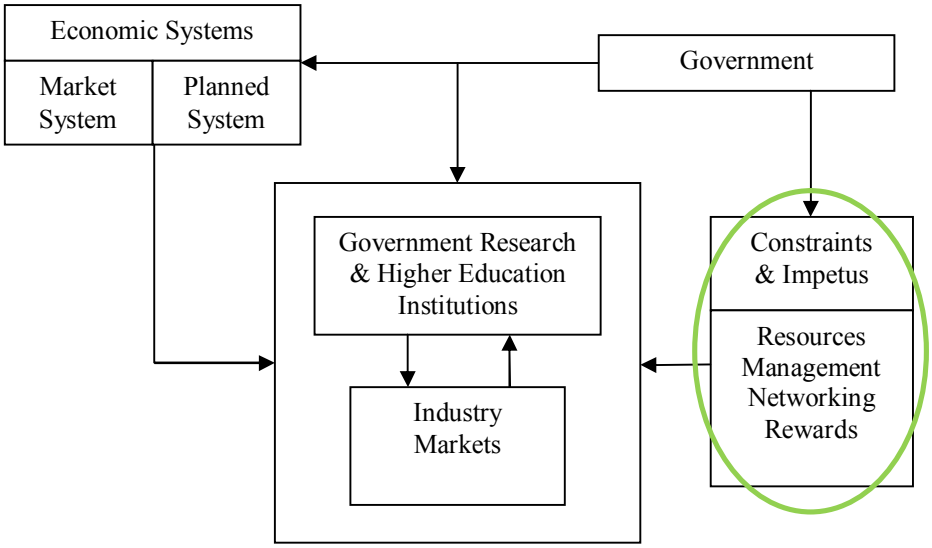


Figure 8: A Framework for Technology Development in China

Source: Liu and Jiang (2001)

Overall, there are still many difficulties in China's macro policy regarding technology development. These include ideology issues (Market System and Planned System) as indicated in Figure 8 [189]. However, such issues will not be included in this research because they are beyond the control of researchers or individuals. Instead, this research will focus on how to transform resource advantage into technology edge; how to better integrate international technology transfer toward long-term innovation. As China gained access into the WTO in the last decade, the country faces both opportunities and challenges resulting from globalization. To overcome various difficulties, the tasks of the

government are to optimize its technology policy, select appropriate strategies, and improve its domestic innovation structure.

2.6 Methodology Review

As discussed in previous sections, the impacts on technology development are complex and multi-leveled. Therefore, methodologies from different perspectives should be employed to carry out related research. Salo and Salmenkaita (2002) suggested that there are synergies between three intelligence tools that serve to inform policy decisions, i.e., technology foresight, technology assessment, and research technological development program evaluation [200]. Methodologies related to these criteria will be reviewed to study technology policy, enterprise strategy, and technology selection.

2.6.1 Foresight Methodology

Foresight and forecasting methodologies have been widely studied during the last few decades. Literature has explored related topics from various perspectives, and provided different threads for further research. Scholars studied technology foresight activities in some Central European countries, and found foresight an effective tool for the development of science and technology policy [103]. Oner and Saritas, (2005) combined the research on national development planning with technology foresight studies, and proposed a new model for systems analysis of technology policy in Turkey's five-year development plans [201]. Some other scholars studied technology foresight activities in Brazil. They focused on methodology analysis, and the results were used to guide government agencies to fund nanotechnology R&D to help raise competitiveness

of the country [106]. Georghiou and Keenan (2006) argued that assessing the effects of foresight requires an understanding of many aspects of public policy. To be effective it needs to be tuned into the strategic behavior and cycles of policy and economic actors [96].

The selection of technology foresight methods involves a broader knowledge of foresight scope, objective, and criteria, all of which may vary with the actors participating in foresight activities. Foresight is a process that involves consultative procedures to ensure feedback to and from relevant actors. The main aspects of this process can be summarized as 'the five Cs' : 1) concentration on the longer term; 2) coordination between the stakeholders' visions, intentions and actions; 3) consensus on research areas that seem particularly promising; 4) communication; and 5) commitment to the implementation of R&D policies [91, 200]. Since many types of methods are available for this complex process, classification of these methods becomes an important issue. Generally, there are three ways to categorize foresight methodologies: 1. Exploratory or Normative methods; 2. Expert-based, Evidence-based, or Assumption-based methods; and 3. Quantitative or Qualitative methods. The third approach is supported by Porter (2004) and many other scholars [202]. Popper (2008) further divided the category into Quantitative, Semi-Quantitative, and Qualitative methods (Figure 9) [203].

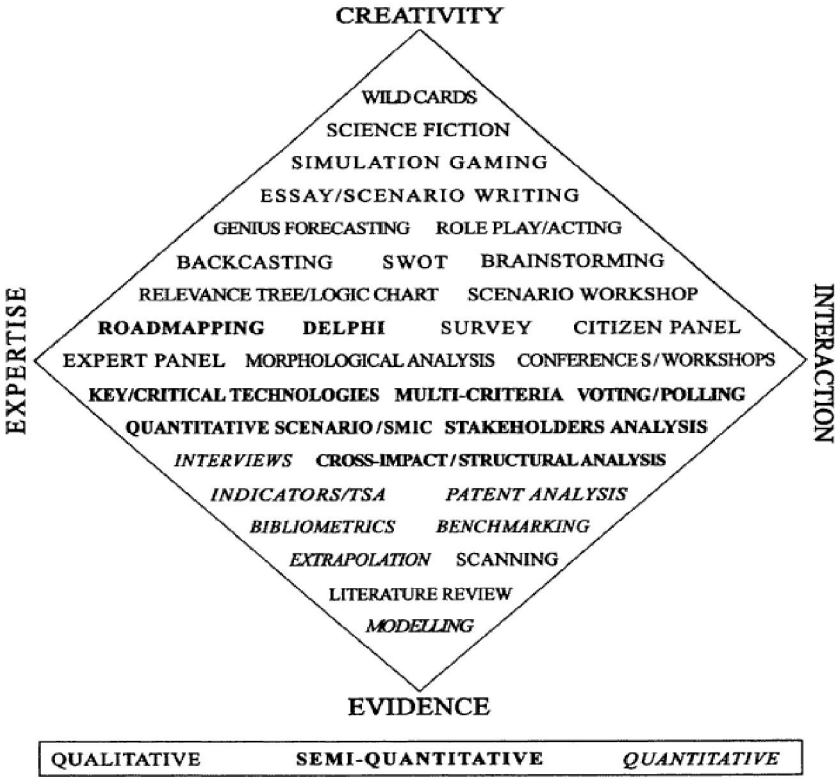


Figure 9: Diamond of Foresight Methodologies

Source: Popper (2008)

Quantitative techniques are used to monitor measurable variables and apply statistical techniques to process and analyze numerical data or indicators. Some frequently used quantitative methods include bibliometrics, modeling and simulation, and trend extrapolation. Qualitative methods are also frequently applied techniques in technology foresight activities. These techniques provide interpretations to development and observations. However, such analyses tend to be subjective and based on particular standpoints, perspectives, and perceptions. Some widely used foresight methods include literature review, expert panels and scenarios, all of which are qualitative. Semi-quantitative methods apply mathematical principles to quantify the opinions of experts.

Such methods include cross-impact analysis; Delphi; critical technologies; multi-criteria analysis; quantitative scenarios; stake-holder mapping; and technology roadmapping [204] [205].

Due to the multifaceted environmental settings and requirements, combination of above methodologies is the trend in foresight and forecasting studies. Methods can be combined in many different ways to create a comprehensive methodology for the complex and lengthy foresight process. It is obvious that any methodological approach should be sensitive to the impacts sought from foresight. Ideally, methods should be selected and combined to achieve certain impacts [206]. In academic literature, scholars develop methodologies through some smaller scale forecasting studies. Banuls and Salmeron (2006) proposed a Scenario-Based Assessment Model (SBAM), which is a combination of the Delphi Method, Analytic Hierarchy Process (AHP), and Cross-Impact Analysis [207]. P. Gerdsri (2009) used AHP and expert judgment quantifications to develop national R&D strategies for agricultural nanotechnology in Thailand [208, 209]. N. Gerdsri and D. Kocaoglu (2004) proposed a systematic approach to strategically identify emerging technologies in order to achieve technological competitiveness. The authors combined the Delphi method and Hierarchical Decision Model to build a technology development envelope (TDE), which serves as inputs for the technology roadmapping process [210, 211]. Some other scholars carried out research on emerging technologies through the integration of bibliometrics with scenario planning, trend curves, and historical analogies. System dynamics is also used to simulate the dynamic ecosystem of the technology development [212]. Bengisu and Nekhili (2006) presented a method of forecasting emerging technologies with the aid of S&T databases, which was

applied to emerging technologies in the Vision 2023 foresight program previously conducted for Turkey [213].

The review of the existing integrated methodologies has shown some room for improvement: (1) the methodologies need to be optimized and adapted to the changes in the fourth and fifth generation of foresights; (2) the restrictions of environmental and social conditions have to be considered across countries or regions; (3) some integrated methodologies have unbalanced integration of quantitative and qualitative tools; (4) some studies relied only on limited members of expert panels, and not all stakeholders were included, the later being crucial for real world technology implementation; and (5) Technology foresight evolved from technology forecasting, covering a broader scope, and it is still evolving fast. Foresight should be used in exploring future opportunities for setting investment priorities in science and innovation activities and building new networks and linkages across fields, sectors and markets, or around problems [96]. These attributes well fit the research requirement of innovation systems.

2.6.2 Technology Assessment

Technology assessment has been widely applied in public policy-making and in business decision-making [214]. It encompasses activities which analyze and evaluate the anticipated impacts of a given technology, examines areas of potential social conflict caused by its deployment, promotes a constructive dialogue between the stakeholders, and produces recommendations for improving the technology and the terms of its application [215]. Technology assessment techniques can be applied at various levels for the evaluation of technology alternatives, selection and acquisition of appropriate

technologies, and strategic technological planning. Many technology assessment approaches and tools have been identified to conduct related research, which include: structural modeling, scenario analysis, impact analysis, risk assessment, decision analysis, cost benefit analysis, Delphi, and evaluation of emerging technologies [214].

The characteristics of technology are the key factors in the process of technology assessment. These features may include technology status, maturity, adaptability, and availability. For example, in the process of international technology transfer, technological characteristics determine the value of specific transfer objects between the provider and receiver. Technological unevenness endures primarily due to the spread of ideas and is contingent on active attempts by firms to learn, imitate, and adapt existing technologies [85, 216]. At the national level, technology gaps exist because countries invest differently in education, R&D, and other inputs [217, 218]. Here we focus the discussion on several important assessment features including: technology trajectory, technology adaptability, technology distance, and other characteristics.

Technology assessment is closely related to both existing technological trajectories and institutionalized regime practices that have inherent advantages in determining the direction of socio-technical change [11]. Technology trajectory can be illustrated by S-curves. Both the process of an emerging technology's evolution and the pattern of its adoption in the market can be illustrated to conform to S-shaped curves. When compared with traditional technologies, emerging technologies may have market uncertainty and unknown impact on industrial development. These new technologies generate potential market opportunities for new investments, thus bringing great challenges to decision makers. From the perspective of developing countries, an emerging technology can

further provide a window of opportunity for technology leapfrogging, which can trigger significant improvements to domestic industrial structure. Technology transfer can take place at any stage of the technology life cycle, but not all technologies have the chance to reach their natural limits on the S-curve. A replacing technology may form another S-curve through establishing a brand new technology trajectory if it satisfies the same market need, and there will be a trend for companies to replace the incumbent technology with new technology. For many MNCs in the developed world, a better choice is to sell or transfer the current technology rather than completely abandon it. This process has been illustrated by the "Flying Geese" model proposed by Japanese scholars [219]. Scholars proposed a reverse product life-cycle model which explores this trend in technology development [220]. For new firms in the industrializing economies, they are more likely to choose the technology at an early stage on the S-curves. However, that may bring challenges for the MNCs since it raises new potential competitors [34].

Technology feasibility and adaptability in an unknown market is a notable criterion for technology assessment. Scholars [221, 222] have argued that, in order to understand the complexity of adaptability, research should deal with all three intertwined dimensions of the construct, which include: technology, market, and organization-related factors. Much has been written in the literature about developing and transferring appropriate technology for developing countries. For example, technology transfer in an international context is subjected to more diversified environmental conditions, such as cultural differences, thus creating greater challenges [223]. There are numerous examples of unsuccessful launches of new products in developing countries. Some are caused simply by marketing failures, while other examples which go beyond such simple failures are

product designs which depart from local custom as regards tastes, habits, and preferences and thus may never be accepted [224]. The adaptation and modification of technology should be viewed from a strategic and organizational perspective, as technical integration of the technology provider's process with the acquirer's system must make allowance for different operating contexts [225]. Literature has pointed out that technological novelty is sometimes far less important than relevance [226]. For instance, in the pharmaceutical industry, appropriate technologies are more important for serving the purpose of direct applications for reducing risk of infection and disease; affordability and cost-effectiveness; saving foreign exchange; satisfying public demand with political benefit to the government; and promotion of social equity. A study has shown that technology policies of developing country comprises more than choosing technology as a means to production. They include the control of a broader selection of technical and non-technical items that link technology to strategy through capabilities of the host country [227].

Many other technology characteristics are identified in the process of technology assessment. Blalock and Gertler (2009) define "technology gap" as the distance from a domestic firm's technical competency level to that of international best practice [228]. Similarly, other scholars developed concepts such as technology distance, technological proximity, technological position, and technological diversification [229-231]. Technology distance between partners can have an impact on their choice of cooperation mode. However, there are some unsolved disputes about the effect of technology distance. From one perspective, firms with a longer distance may be too far away from the best practice, resulting in limited capability to learn, assimilate, and share knowledge, thus causing negative effects on innovation. Firms with a smaller gap should have better

technical competency and could easily catch up with the technology frontier. From another perspective, firms that are further away from the technology frontier will gain higher returns from learning. Firms with a smaller technology gap may have already mastered similar technologies that have lower returns, but making further efforts to alter existing practices are more difficult. Scholars from different countries carried out many empirical studies showing that technology gap can result in either positive [232, 233] or negative [234-236] impacts to the learning process. Some other scholars found that the relationship can be nonlinear and U-shaped [237, 238]. It is clear that technology gaps and distance have significant impacts on technology transfer and diffusion. However, the characteristics such as size and direction of the impact are still unclear. Scholars [238, 239] claimed that absorptive capacity should be crucial for economies that have a sizeable distance from the technological frontier. Therefore, it is necessary to base technology assessment on the technological capabilities of local enterprises.

As a short summary of related literature, research revealed that technology assessment is an important method in technological development and policy planning. Technology policy must consider the nature of technology, market trend, and enterprise level capabilities. Emerging technologies have distinguishing characteristics such as market uncertainty and unknown impact on industrial development. These new technologies offer a rich source for market opportunities that provide incentives for new investments, thus bringing great challenges to decision makers. For late-comers, emerging technology can further provide a window of opportunity for leapfrogging. Developing economies catch up only when they actively learn and adapt from leaders [240]. Their choices about how to invest, as well as the productivity of these investments

should be based on the assessment of economic, social, and technological dimensions [50, 241].

2.6.3 The Delphi Method

The Delphi method was originally developed for the U.S. Air Force as a group decision method [242]. It is a method for structuring group communication so that individual experts can act as a whole in dealing with complex decision problems [243]. The Delphi method has been adopted in many countries and in a wide range of fields. National Delphi has been conducted in Japan every five years to generate informative projections on potential technological advances. Many other countries such as Germany, Korea, and Britain have emulated similar efforts. The technique is applied to fields including project selection, operations management, drug policy, and administration management issues [244, 245].

There are several characteristics that make Delphi an effective method to create consensus among groups of experts: 1) Anonymity; 2) Iteration; 3) Controlled feedback; and 4) Statistical aggregation of group response [246]. The technique uses a panel of experts who are not allowed to interact in order that their judgments will not be influenced by each other. Anonymity provides at least two advantages: firstly, it avoids the possibility for the panel members to be influenced by other experts' social position or reputation; secondly, it allows panel members to change their opinions without feeling intimidated by others. Iterations with controlled feedback may provide the opportunity for panel members to change their previous judgments. Everyone is given the group results after each iteration, showing statistical values such as mean, median, and variation.

Outliers are asked to explain their rationale to the group, which makes it possible for others to modify their earlier judgments.

The Delphi process usually takes several rounds before obtaining consensus from the participants. It requires that experts repeatedly express their opinions through a series of linked questionnaires. The first round focuses on the exploration of the subject, and the participants will contribute additional information through answering open questions. The middle rounds involve the process of reaching a common understanding of how the group views the issues. The final results occur in the last round after all previous information is analyzed [247]. During the consultation process, two types of information will flow among experts through the effort of coordinators: 1) available data previously requested by respondents; and 2) considerations suggested as potentially relevant by other respondents [242]. To save researcher and participants' time and effort, the first round is sometimes substituted by deliberate literature review. The middle rounds could be combined due to time constraints or low response.

The literature summarizes some advantages of Delphi that make it more appropriate than traditional methods like surveys or questionnaires [243]. 1) The problem is not suitable for analytical techniques but could benefit from collective judgments. 2) A relatively large number of experts are needed in order to create more interaction than would occur typically in face-to-face meetings; 3) Experts have no history of previous communication and may represent diverse backgrounds with respect to experience or expertise. 4) Time and cost make frequent group meetings infeasible. 5) The efficiency of face-to-face meetings can be increased by a supplemental group communication process. 6) High disagreement levels among experts so that the communication process must be

refereed and/or anonymity assured. 7) Bandwagon effects or domination by quantity or by strength of personality must be avoided to preserve the validity of results. Although it has many benefits, some research also points out several potential limitations of Delphi, which include [243] [248]: 1) Deception resulting from the data retrieval; 2) Discounting the future and considering the present more important; 3) Illusory expertise resulting from bias; 4) Optimism or pessimism bias; 5) Prediction urge by moderators; and 6) Simplification urge from experts.

2.6.4 Multi-criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA) is a type of research method aimed at helping decision makers to determine overall preferences among alternative options. It is particularly suitable for complex problems where multiple criteria are involved. MCDA is especially useful for policy makers to evaluate a wide range of criteria including social, economic, environmental, and technological factors. The method provides a logical, well-structured decision-making process based on the quantitative analysis through scoring, ranking and weighting of judgmental data.

Among many of the MCDA models, Analytic Hierarchy Process (AHP) is the most widely applied quantitative decision-support method. It is designed for structuring, measuring and synthesizing multiple factors or elements. The working process involves decomposition of a complex and unstructured research problem into an organized set of components [249]. There are several basic steps included in the process, regardless of the nature and scope of the research problem, which include: 1) Construction of a hierarchical model; 2) Prioritization of elements; and 3) Calculation of results. The most

important step in MCDA is that a HDM should be developed to illustrate the problem. Decision elements or criteria are identified and arranged into various levels according to their relationships. In the following step, decision elements at the same level are compared with each other regarding their contributions toward the upper level criteria. Different types of comparison methods have been used in this step. The constant sum method was developed by Comrey [250] and Guilford [251] and refined by Kocaoglu [252], where a total of 100 points are allocated to the comparison values. The eigenvector approach was adopted by Saaty [249], where 1-9 scale measurements are used. The constant sum method gives a more precise measurement of data. In the third step, relative priorities are calculated and synthesized by multiplying the local weights with those of the corresponding upper level elements.

The method has several built-in advantages including simplicity of structure, ease of use, and flexibility. It can be applied to assist complex decision-making when a relatively large number of quantifiable or intangible criteria are involved. The method allows calculating priorities and weights in a hierarchical structure in order to identify the most important elements [249]. A major difficulty in decision making is to reach consensus in a multidisciplinary expert panel. MCDA provides a tool so that the experts do not necessarily need to agree on the relative importance or the rankings of the Criteria. Each expert individually makes his or her judgments, and jointly contributes to a group decision. AHP gives a clearer understanding of the situation and leads to a higher degree of commitment to a chosen alternative [253]. AHP was successfully applied in many research areas including technology selection, evaluation, resource allocation, health care, policy-making and strategic planning [254-257].

2.7 Gap Analysis

The literature review has explored the available knowledge base in the areas of international technology transfer, innovation systems, technology foresight, technology policy, technology development in China, and related research methodologies.

Areas	Research Gaps	Research Opportunities
Technology Policy	1. Latecomers face the dilemma of ‘‘make or buy’’ decisions in high tech development [12] [84] [258] [259].Technology export control at various levels complicates their problems [16] [80] [138].	There is a need to find a proper balance between various technology development strategies. Institutional limitations of the host country should be considered accordingly.
	2. Latecomer countries and emerging economies need to identify the “windows of opportunity” for catching-up and leapfrogging [27] [29].	Technology areas and implementation strategies should be prioritized according to local capabilities and needs.
Technology Innovation	3. International technology transfer activities may not necessarily result in sustained innovation, technology diffusion not efficient and spillover not obvious [23] [25] [34].	Host countries should build up domestic absorption capability and innovation capacity to benefit from technology diffusion and spillovers.
	4. Different attitudes toward appropriate technology. Common concerns exist but different interests and motivations are obvious among the stakeholders [30] [32] [37].	Various stakeholders should be involved in the technology planning process. The disagreements should be considered in the development of technology policies.
	5. Globalization brings new challenges to the research of innovation systems; innovation resources are across boundaries [7] [72] [260].	GloCalization: scholars suggest that it is necessary to find a balance between local and global, internal and external innovation.
	6. Transitional innovation systems: allocation of innovation resources is not effectively linked to national or regional tech development strategies [196] [197].	Restructuring of inefficient R&D system and allocation of limited resource at various levels according to innovation strategies.
Methodology	7. No viable framework has been developed to deal with technology policy problems in latecomer countries. A decision model for the implementation mechanism of selected technologies is needed in such countries [180] [208] [261].	A research framework that incorporates the importance of innovators and their strategic considerations should greatly assist decision makers.

Table 7: Research Gaps and Opportunities

Through summarizing the literature search results, this part of the chapter analyzes various research gaps in the above mentioned areas. Connections of literature findings to the research opportunities are listed in Table 7. Although the research gaps were identified from different areas, they are interrelated and all point to improvements in technology policy design. Successful filling in of these gaps requires a comprehensive look into the issues. To link these gaps with research goals, the following section will critically examine and categorize them in detail.

Gap 1: Technology policy problems in latecomer countries are discussed in literature, but no viable framework has been developed to solve these problems.

Latecomer countries face the dilemma of "make or buy" decisions in high technology development. The literature has examined the problems, but no available models have been developed to tackle them [12] [84] [258] [259]. There are barriers for both "make" and "buy'' approaches. When making the technology by themselves, latecomer countries may not have the technology capability, so it may take huge efforts and many years to catch up. If buying the technology from advanced countries, latecomer countries may need to pay a high price for importing it, and they risk having to continuously buying follow-up technologies. Since no country, however rich, can afford to pursue all the possible opportunities in science and technology, there needs to be better mechanisms for choosing between competing alternatives and resources [102]. Due to limited technology capability, it is unrealistic for any latecomer country to aim at exploring all high-tech areas on their own effort. It is especially meaningful that they should avoid "reinventing the wheel" or remaking the mistakes of advanced countries.

This may be achieved by learning through foreign experience, and adapting to their situations but not by just following. Globalization offers new opportunities in technology learning. Selecting the right strategy in technology development may help in taking the advantage of such opportunities, and accelerate the catching up process.

Technology export control at various levels complicates the problem of high-tech development in latecomer countries. Technology blockades at national and enterprise levels make it difficult for latecomers to learn from advanced countries. Major developed countries have strict export control of high technologies. For example, the US Commerce Department's Bureau of Industry and Security restricted American companies from selling many sensitive high-tech products to China [16] [80]. This policy negatively inflicts other countries working on projects with China. Recently, Brazilian companies working in the Sino-Brazilian satellite project were denied access to American products considered sensitive [80]. Moreover, at the enterprise level, many MNCs hesitate to transfer high technologies to foreign countries for the protection of their competitive advantages. These institutional limitations have pushed many emerging economies to rely on indigenous innovation.

Gap 2: Emerging economies and latecomers need to identify the "windows of opportunity" for technology leapfrogging.

Scholars have argued that in the early phases of a given technology trajectory, late-comer countries may enjoy windows of opportunity which allow them to catch up [17]. However, early-stage technologies are highly risky for investment. Many efforts by the local governments have failed because such technologies are not sustainable in the host

country [18]. Late-comer countries often lack the necessary technological accumulations and innovative capacities. Therefore, it is unrealistic for them to devote everything to uncertain high technology areas. It is better for them to focus on areas where comparative advantage can be achieved through technology leapfrogging. The host country should assess whether the new technologies are suitable for local capability and needs. Therefore, better approaches in technology selection should be developed to underpin strategic research areas where the greatest economic and social benefits can be yielded.

Gap 3: International technology transfer may not necessarily result in sustainable innovation, technology diffusion not efficient and spillover not obvious.

It is generally accepted that technology transfer activities alone may not necessarily result in sustainable innovation. Relying too much on FDI has brought many disadvantages in the domestic industries. Technology acquisition from firms in more advanced countries is obviously important to firms in industrializing countries that are trying to catch up technologically, but technology diffusion and spillover effects may not necessarily happen [19]. Moreover, since technology suppliers are not usually willing to disseminate core technology to other enterprises, developing countries can acquire only some medium- or low-level technology using this source, so a technology gap exists when compared with the latest international technology [20]. Scholars argued that the innovation activities in Chinese manufacturing firms could not be boosted substantially merely through the acquisition of key equipment and apparatus from abroad [19]. The government should formulate viable technology policies for strengthening local absorptive capability and innovative capacity.

Gap 4: The stakeholders have different attitudes toward appropriate technology. Common concerns exist but different interests and motivations are obvious.

It is important for technology policy makers to fully understand the diversified motivations and interests among the players of international technology transfer. Western technology suppliers and local technology receivers have different perceptions and criteria for success. While the foreign side aims to penetrate the domestic market, utilize low labor costs and maximize financial returns, domestic partners aim to acquire advanced technology, a reputable trademark, technical or managerial know-how, R&D capacity, and access to international markets [14]. Different interests also exist between industry and government. Industrial players are commercially motivated for profit and market share, while governments aim for long-term national development, social welfare, and technological competitiveness [31]. Technology policy should consider these different standpoints, and address such needs accordingly.

Gap 5: Globalization brought new challenges in the research of innovation systems, national boundaries are dimmed in the development of high technologies

Globalization has brought both opportunities and challenges to countries. The question has become who can benefit more from resource-sharing resulting from globalization. Globalization of innovation systems has deeply influenced the culture of technology development as well as the strategic behavior of the innovators. Tidd (2007) identified several major issues regarding globalization. Firstly, since technology and innovation are not evenly distributed globally, they are not easily packaged and

transferred across regions or firms. Secondly, different national contexts significantly influence the ability of firms to absorb and exploit such technology and innovation. Thirdly, the position of firms in international value chains can constrain their ability to capture the benefits of their innovation and entrepreneurship [7] [260].

Globalization results in deeper specialization, which may deter latecomer countries from catching up in technological innovation. Due to the fact that latecomers lack innovative capabilities in advanced technologies, they are easily trapped in inferior positions as low-cost resource providers. Domestic companies of these countries can only be specialized in the manufacturing of low-tech, low-value products or services, thus they are unable to achieve sustainable innovation in the long run [262] [34]. This also causes mature or standardized technologies and related production to be transferred to latecomer countries [263, 264]. As a result, the latecomers cannot easily catch up with the leaders in the areas of advanced technologies. This may further establish an endless loop in which technological leaders can always outrun their imitators [265] [266]. Therefore the decision of innovation strategy is an extremely important aspect to support technology development in latecomer countries. Technology planning has to cover the technology trends in the world, but the actual process of development must be supported by local strengths in knowledge and innovation [88]. Brazilian scholars (Humbert 2005, Canongia 2007) have used the term “gloCalization” to describe such a strategy as “think globally, act locally” [105]. So far, few research models have integrated this idea in technology implementation.

Gap 6: Transitional innovation systems - allocation of innovation resources is not effectively linked to national or regional technology development strategies.

Emerging economies such as the BRICs are investing more resources to develop their innovation capability. However, there is little evidence that current frameworks or approaches in developed nations are also workable for these countries. This is because emerging economies have different environmental contexts and changing agents. Viotti (2002) found that the Western NIS theoretical and conceptual framework is not appropriate for dealing with the processes of technological change of industrializing economies, which are extremely different from those of industrialized countries [85]. New studies are necessary since the emerging economy's unique environmental factors should be considered. For example, China is changing from a centrally-planned economy into a market-oriented economy, and its NIS is fast evolving. The legacy of traditional R&D infrastructure is notably inefficient for innovation activities. Longer-term perspectives and strategies call for better use of limited resources. The support and goal-oriented prioritization of resources for certain technologies are very necessary [103]. Allocation of resources for technological innovation is an important but complicated issue for both government and enterprises. Technology policy should play a more important role in the restructuring of inefficient R&D system and allocation of limited resource at various levels to support innovation strategies.

Gap 7: A decision model for the implementation mechanism of selected technologies is needed in latecomer countries

Available studies have developed technology assessment and selection models to address various social, economic, and environmental needs in latecomer countries. For example, Baez (2005) developed a technology assessment model for the ICT industries in Costa Rica [261] [267], and Gerdsri (2009) developed technology selection model for the nanotechnologies in Thailand [208] [209]. However, these models did not consider the realities of limited innovation capabilities in latecomer countries. It is impossible for these host countries to develop and realize some of the identified high technologies merely through their own efforts. These countries should consider learning from or collaborating with leading countries. Many latecomer countries often aim for the best and latest technologies, but they neglect local capabilities and innovation orientations. Bin (2008) has urged that government policies should be combined with commonly followed technological strategies in determining the relationship between domestic in-house R&D and foreign technology transfer [175]. Instead of innovating in the global technology frontiers, latecomer countries should focus on catching up. They should strive to build up innovative capabilities in order to develop those identified high technologies.

Implementation of innovation strategies requires long-term investments in the industrial foundations and renewing innovation activity by both public and private sectors, and resources targeted at broad-based innovation activity should be increased at a pace exceeding that of general economic growth [268]. A framework that incorporates the capabilities of innovators and their strategic considerations should greatly assist decision makers. Therefore, current technology assessment and selection models should be extended to include strategic concerns about how to develop and realize the selected technologies, especially in the developmental context of latecomer countries. Appropriate

models and approaches should be designed to support policy making from a systematic perspective. In traditional models, technology alternatives are usually located at the bottom level of the hierarchical structure. In this research, a new model is implemented by bumping up technology alternatives into higher levels, indicating the prospective areas for technology development or potential areas for breakthrough innovation. This new model links technologies and innovators with corresponding innovation strategies.

2.7.1 Short Summary of Gap Analysis

The above section has explored the available knowledge base in various areas of technology management and identified major research gaps. These gaps are interrelated and will lead to the improvements in new research. Scholars suggest three factors of technological change: demand-pull, technology-push, and government-led [42]. Technology policy should assist to adjust the strategic differences among innovators. Rapid development of high-tech industries makes stable technology policy a difficult task. Strategies of technology development need to be adjusted in a dynamic mode to deal with future uncertainties. By summarizing the above literature gaps, a systematic approach should be developed in organizing and funding research in high technology sectors, guiding the public and private sectors in their investment decisions and directions, coordinating industries and sectors, building an efficient scientific infrastructure, and providing insight for improvements in national technology competency. Such a model is needed in both developed countries [4] [90] and industrializing countries [88] [146].

2.8 Research Scope and Boundaries

By analyzing and summarizing available literature findings, the research scope can be further clarified and defined. In order to make the research process manageable, it is necessary to delineate the scope and boundaries of the research work. This research will focus on crafting a research framework to formulate innovation strategies in dealing with the uncertainties of technology development in emerging economies. It serves as a bridge connecting high technologies and policy decision making (illustrated in Figure 10).

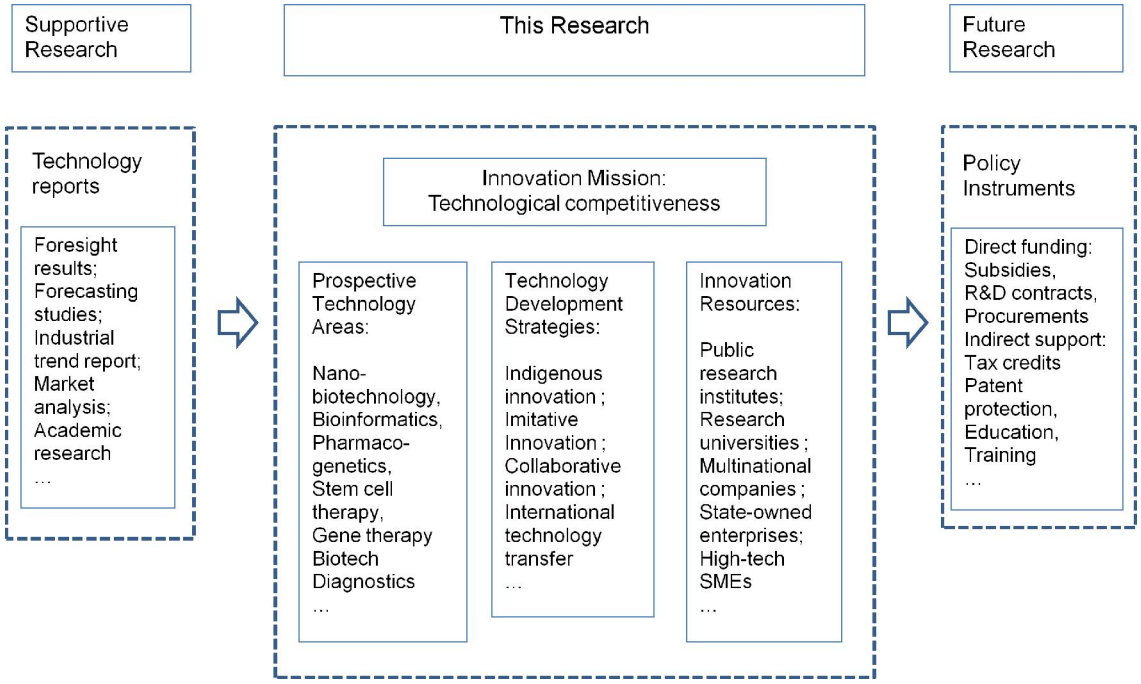


Figure 10: Research Scope and Bounds

On the input side, the supportive studies may include technology-oriented research such as foresight/forecasting studies, industrial reports, product analysis, and technical expert recommendations. On the output side, the research findings will assist decision-makers to develop more specific policy instruments such as direct or indirect funding,

regulation support, and other favorable measures. The design of such detailed policies may be potential areas for future research.

Chapter 3 – Research Methodology and Approach

Through the analysis of research gaps, this chapter clarifies the research objectives, research goals, and research questions. The literature review revealed that many problems coexist in the process of technology policy-making, especially for emerging economies. This chapter will highlight major research questions and use them as a starting point to develop the research methodology and research process.

3.1 Research Objectives, Goals, and Questions

The objective of this research is to provide a systematic framework for promoting national S&T competitiveness and innovation capacities in high-tech sectors. The framework serves to provide insights for both public and private stakeholders as they strategically plan for further technological advancement. The approach of this research is to formulate effective technology development strategies, linking prospective high-tech areas and various innovative resources to assist the decision-making process of technology policy.

From the gap analysis, research goals have been developed and categorized into several major aspects including:

1) Identification of appropriate technology areas for innovation and leapfrogging.
2) Balancing different strategies in technology development.
3) Identification and allocation of limited innovation resources.
4) Prioritize technologies, strategies, and resources to support innovation.
5) Identification of disagreement among stakeholders and related implications.

Referring to Table 7 in Chapter 2, the linkage between research gaps and research goals (RG) is established. Five research questions are proposed as guidelines for this research according to the research goals. The linkage between research goals and research questions (RQ) is illustrated in Figure 11.

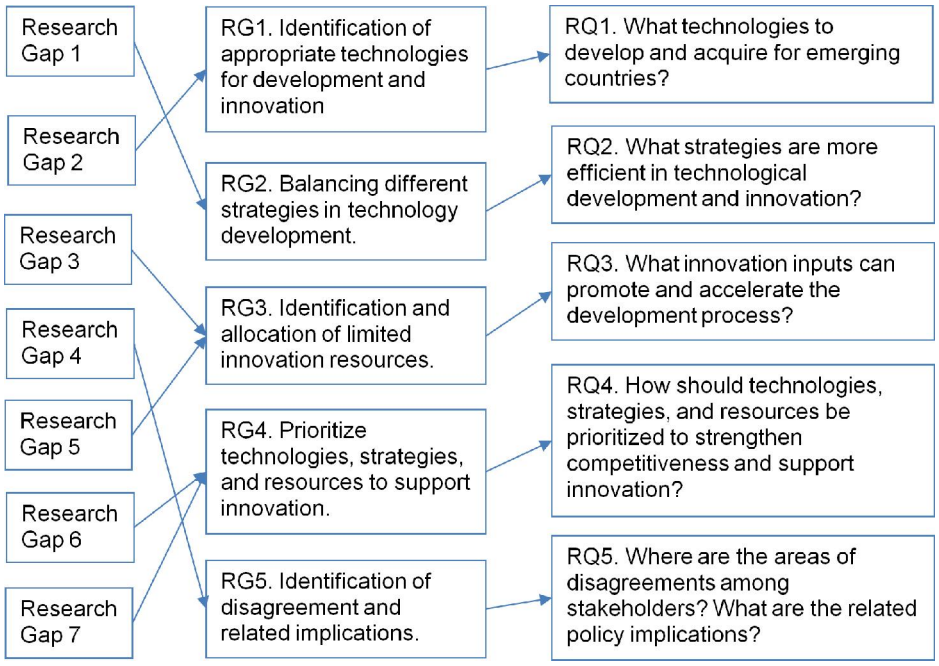


Figure 11: Connecting Research Gaps, Research Goals, and Research Questions

To answer the research questions and achieve research goals, it is necessary to incorporate various influencing factors identified in the literature review section. There is a need to construct a new research framework to obtain a proper balance of appropriate technologies, development strategies, and innovation resources. Based on the research methodologies used in international technology transfer, innovation systems, technology foresight, and technology policy, a research framework will be developed to address the above mentioned issues in technology development.

3.2 Research Methodology

With the research questions on mind, this research utilizes an analytical approach to create a model for exploring effective technology implementation mechanisms to align with national innovation objectives. Experts are invited to provide judgmental data in determining the relative relationships among the decision elements at various levels of the model. The methodology to be utilized is an Analytic Delphi study where experts assess the criteria related to technology, strategy, and innovation resources. The initial research includes face-to-face consultation of experts to identify critical issues and define the criteria. Subsequent pair-wise comparison instruments are developed based on the results provided by the experts in the interviews. The AHP method is followed to quantify experts' judgmental data on the issues.

Delphi offers an approach to make assessments via a panel of experts and is the chosen methodology because new technologies will be evaluated for an uncertain emerging market environment, where sufficient historical data were not available to effectively utilize other traditional quantification methodologies. Scholars have successfully applied the traditional Delphi method in technology forecasting research at various levels. For example, Gerdsri (2004) integrated the Delphi technique into his dissertation to identify technology strategies [210]. Martino describes three situations when the Delphi method is more suitable than other quantitative methods: "1) when no historical data exists and a forecast may be needed. This situation appears usually with the new technology; 2) when the impacts of external factors are more important than the internal ones of the phenomena; and 3) when ethical and moral considerations dominate the economical and technological goals of the development" [248].

The AHP provides a systematic approach to develop priorities for alternatives based on the experts' judgments. A hierarchy or network structure will be constructed to represent a decision problem. AHP utilizes pair-wise comparisons to give priorities for the alternatives or criteria based on the experts' opinions. The appropriate alternatives are selected based on the quantitative solution to these rankings. AHP is selected because of its many benefits: 1) AHP allows for the measurement of both objective and subjective factors; 2) Consistency measures are easily derived to evaluate the quality of the judgment; and 3) AHP enables group judgment to arrive at a unique decision that can represent the opinions of all participants.

AHP has been proven to be an effective quantitative decision-support method to deal with complex multi-attribute decisions. For instance, Gerdsri (2009) used AHP and expert judgment quantifications to develop national R&D strategies for agricultural nanotechnology in Thailand [208, 209]. The method has been widely applied in areas of management, policy-making, and conflict resolution. It can be utilized for structuring, measuring and synthesizing factors or elements that affect decision-making [249].

This research focuses on the implementation mechanisms and realization pathways for prospective technology areas in emerging economies. The research direction is to formulate policy actions rather than predict technology areas. It is based on available world-class technology foresight or forecasting reports, and to customize those identified technologies for implementation or realization in emerging economies. This research has shifted away from merely forecasting the technologies, and has moved forward into the area of decision making in strategy selection and resource allocation. Therefore, the research results are not comparable to current technology forecasting reports and

foresight studies because similar research has not been available yet. The outcome of this research will serve to support government and industry decision makers to buildup innovation capabilities for technological competitiveness. The decision making process makes the MCDA an appropriate methodology for this research.

3.3 Research Model

To tackle the research gaps through the above methodologies, a hierarchical research framework is developed based on pair-wise comparisons to quantify expert decisions. It takes into consideration several factors in the research process, including appropriate technologies, implementation strategies, and allocation of innovation resources according to desirability for long-term benefit. Through a series of judgmental quantifications from the experts, the prioritized value for each innovation resource can be calculated, which represents its desirability corresponding to the improvement of innovation capacity. The results can thus indicate better investment targets to be made in the industry for selected high technology fields.

The structure of the model can be used to develop implementation strategies for appropriate technologies for a host country. The HDM has four levels: mission, technology, strategy, and resource (Figure 12).

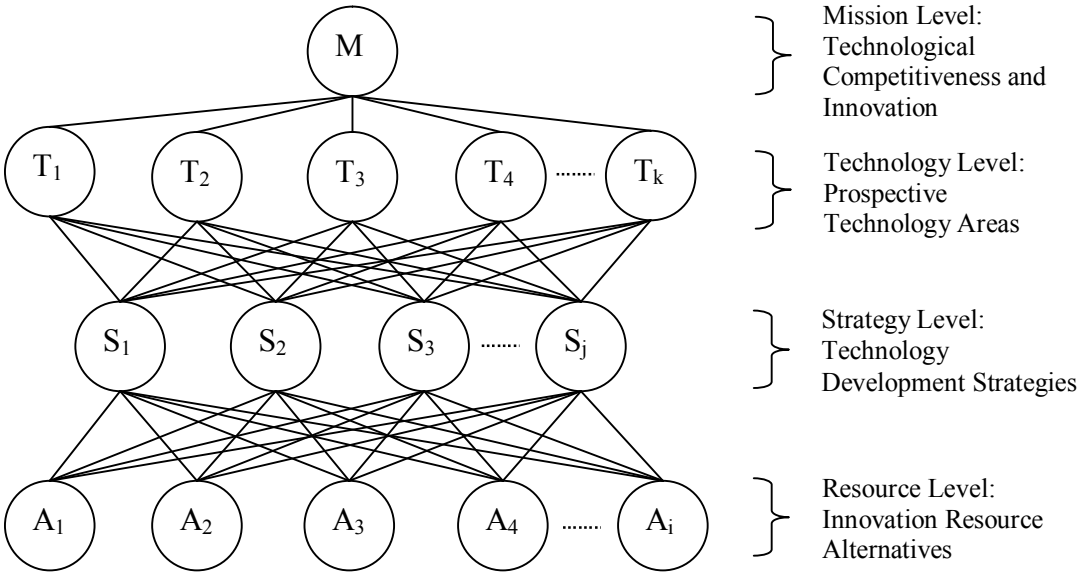


Figure 12: The Generalized Model

In Figure 12:

M: Mission – Technological Competitiveness and Innovation

T_k: Prospective Technology Areas (k) k = 1, 2, 3 … K

S_j: Technology Development Strategies (j) j = 1, 2, 3 … J

A_i: Innovation Resource Alternatives (i) i = 1, 2, 3 … I

The top level declares the technological innovation mission of the host country. Strengthening technological competitiveness and building innovative capabilities are common objectives of technology development in both developed and developing countries. Since this research will focus on emerging economies, the objective has been adjusted according to the findings from related literature review sections. Here it is defined as "Advancement of Technological Competitiveness and Innovation." Scholars have argued that technological competitiveness at the national level is conditional on

three key factors: access to competitive technologies, continuous innovation, and provision of the innovative environment [5] [6]. This matches the objective of technology development for nations, as well as the mission level of this research.

The second level consists of a list of prospective technology areas suitable for the target country's development in the future. The RAND Report 2008 argued that populous, low-income countries may achieve comparative advantage in R&D in certain areas if such countries develop the capacity and institutions necessary to apply new technologies [3]. The second level will identify such technology areas that support the innovation mission. These are high-tech fields that are suitable for leapfrogging or accelerated development in the host country. The focus of interest here is state-of-the-art technologies, including both incremental and disruptive technologies that can serve as possible "windows of opportunity" for innovation and leapfrogging. The selection of technology portfolios should be integrated into the overall national planning process at the higher level. Appropriate technologies should be developed to make effective use of the host country's available resources and help the country to further develop innovation capabilities.

The third level defines how the country should strategically develop the identified technologies. Several paths of technology development have been identified from the literature review: indigenous innovation, imitative innovation, cooperative innovation, and international technology transfer. In a globalized innovation network, it is necessary to balance the strategies for technology development to increase national competency. Scholars argue that the innovation strategies may vary from sector to sector and across time. To reveal sector/time-specific characteristics, comparative evaluations of

innovation strategies and their impact on organizational performance across various sectors and in multiple time frames may produce findings of greater relevance to policy makers [180].

The fourth level provides a list of input resources that buildup the innovation capability of the country. They are also regarded as innovators that generate various innovative outputs such as publications, patents, and new products. The innovation resources include all the entities that develop, implement, or provide support for the candidate technologies. These resources can come from different sources such as the public sector, private sector, and even foreign countries. Technology policies should be prioritized to strengthen the capability of these innovators, and to maximize their innovation outputs as a whole for national technology objectives.

The generalized model is applicable to technology development scenarios in both developed and developing countries. When applied to a developed country, the mission level may be adjusted and redefined as "strengthening technological competitiveness through sustained innovation" or similar. It is unrealistic for any country to invest in and pursue all technology opportunities totally on its own effort [102]. Decisions on the priority of investments in high technology industries for a rapidly evolving global market are complicated issues and highly risky for governments in all countries. The inputs for the technology level can be selected from various study reports in the related industry for evaluation. For the strategy level, the emphasis may be different from country to country. For example, a developed country may focus more on indigenous innovation or collaboration, while a developing country may rely more on imitation or international technology transfer. At the resources level, each country may have different conditions or

environmental contexts that influence the availability of resources. Given these many differences, the model is still applicable for any target country if the correct criteria are identified as inputs in each level.

3.4 Research Framework

This model uses a hierarchical structure to leverage various technologies, strategies, and resources. It combines a top-down and bottom-up approach to consider the needs and strategies of both government and enterprises. This requires the judgmental inputs of experts from diverse sources including government, industries, and academia. However, this diversity may cause inconsistencies and disagreements in the research process. It is necessary to have correct quantification measures to deal with such issues. The research framework is illustrated in the following steps.

Step 1: Criteria Definition:

Mission (M): Technological Competitiveness and Innovation.

Prospective Technology Areas with reference to M: T_k , with k = 1, 2, 3 ….., K

Technology Development Strategies with reference to T_k : S_j , with j = 1, 2, 3 … J

Innovation Resource Alternatives with reference to S_j : A_i , with i = 1, 2, 3 … I

Step 2: Identification of Prospective Technology Areas: T_k , with k = 1, 2, 3 ….., K

Sources to finalize the technology fields:

1. Industry research reports
2. Foresight / forecasting studies
3. Academic research

4. Expert recommendations

Step 3: Technological Development Strategies: S_j , with j = 1, 2, 3 … J

S_1: Indigenous Innovation

S_2: Imitative Innovation

S_3: Collaborative Innovation

S_4: International Technology Transfer

……

S_j : ……

Step 4: Innovation Resource Alternatives: A_i , with i = 1, 2, 3 … I

A_1: Public Research Institutes

A_2: University Research Programs

A_3: Multinational companies

A_4: State-owned Enterprises (SOEs)

A_5: High-tech Small-to-Medium Enterprises (SMEs)

……

A_i : ……

Step 5: Quantification and Analysis

The quantification process utilizes the Pair-wise Comparison Method (PCM), where experts are asked to allocate weights for the elements. By using the constant-sum method, a total of 100 points will be assigned between any two elements at the same level.

Under Mission (M), quantifying expert judgment of relevant technology fields to obtain V (T_k). For each T_k (k = 1, 2 …, K), using pair-wise comparison to determine the relative value of T_k in terms of their desirability for M.

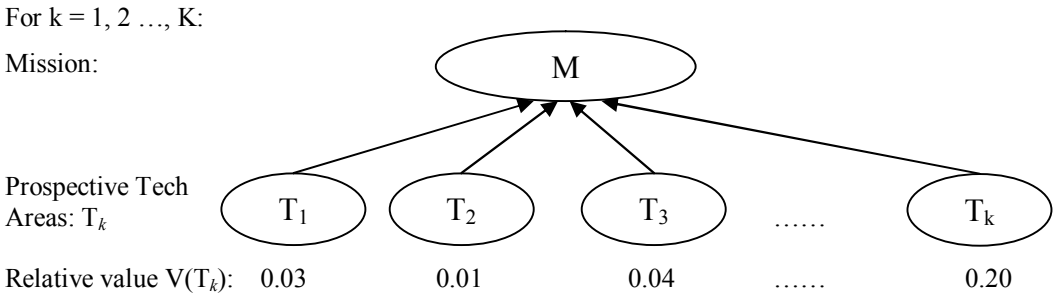


Figure 13: Determining the Priority Value of Prospective Technology Areas

Judgmental value of the best T_k for M is based on a scale of 0 – 100, and then normalized to be within the range of 0 – 1.

Determine relative importance of each strategy S_j (j = 1, 2 …, J) for T_k by pair-wise comparisons V(S_{jk}). Scaling and normalization methods are of the same ratio as the above level.

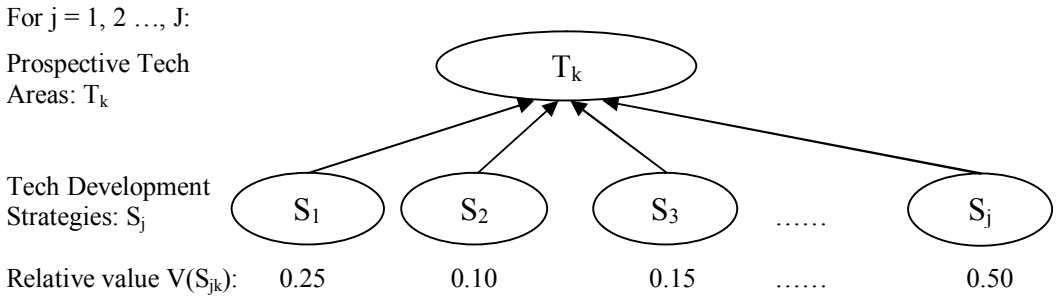


Figure 14: Determining the Priority Value of Technology Development Strategies

Determine relative importance of A_i (i = 1, 2 …, I) for S_j by pair-wise comparisons, V(A_{ij}).

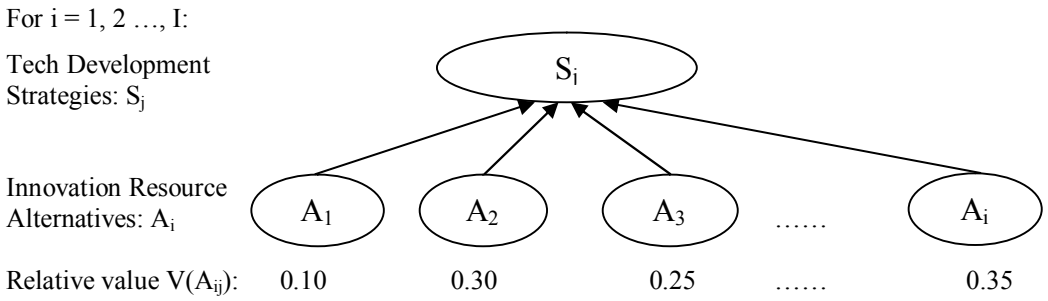


Figure 15: Determining the Priority Value of Innovation Resources

For any innovation resource alternative A_i, calculate the value of contribution toward M, sort $V(A_{iM})$ according to its numerical value, and discuss implications.

$$V(A_{iM}) = \sum_{j=1}^{J}\sum_{k=1}^{K} V(A_{ij})V(S_{jk})V(T_k) \qquad \text{for } i = 1, 2, \ldots I$$

Step 6: Validation and Recommendation

In this Phase, the researcher will validate the results and conduct related analysis. The intermediate results will be given back and forth among the experts. The experts will comment on the results after reviewing the summary reports. The process will stop after finding a greater consensus of the experts. Otherwise, the results need to be improved by revising the judgment questions, and retaking the evaluation process. Sensitivity analysis will assist the understanding of relationships among different levels. The analysis quantifies the range of difference of the optimal set if there are changes in related criteria, and it provides the basis to assist policy-makers in modifying the hierarchy for selection of the optimum strategy. Policy recommendations will be given by interpretating the results for identification of effective and ineffective innovation resources. The results

support decision makers to determine where the investments and policy measures should be given.

3.5 Inconsistencies

During the above processes, inconsistency values for the constant sum method are calculated as follows [269]: For n elements, the constant sum calculations will result in a total of n! orientations with vector values represented by r_1, r_2 ... r_n for each. If the expert is totally consistent, the relative values will be the same for each orientation. Otherwise, if inconsistency exists it will result in differences in the relative values in different orientations. According to Kocaoglu's research, if the inconsistency level is less than 10% or 0.1, the related judgmental data should be acceptable [252].

Let r_{ij} = relative value of the i^{th} element in the j^{th} orientation for an expert

$\bar{r}_i$ = mean relative value of the i^{th} element for that expert:

$$\bar{r}_i = (1/n!)\sum_{j=1}^{n!} r_{ij}$$

Variance in the relative value of the i^{th} element:

$$(1/n!)\sum_{j=1}^{n!}(\bar{r}_i - r_{ij})^2 \qquad i = 1, 2 \ldots n$$

Inconsistency of the expert in providing relative values for the n elements is defined as:

$$Inconsistency = \sqrt{(1/n)\sum_{i=1}^{n}(1/n!)\sum_{j=1}^{n!}(\bar{r}_i - r_{ij})^2}$$

3.6 Disagreements

The methodology for measuring disagreement is based on the Ph.D. dissertation done by N. Gerdsri (2004), and then expanded by P. Gerdsri' Ph.D dissertation in 2009 [210, 211] [208, 209]. The intraclass correlation coefficient (R_{IC}) is calculated to measure the degree to which k judges/experts are in agreement with one another on the ratings of n subjects/criteria. The coefficient R_{IC} may achieve the maximum of 1 when all experts assign the same mean values to the subjects (absolute agreement); or the value of R_{IC} is close to zero when there is a substantial difference between the mean judgment values among all experts. If R_{IC} has a negative value, the negative correlation is generally considered as zero. It has been accepted that a R_{IC} > 0.7 indicates a strong agreement among the experts [270]. The intraclass correlation coefficient can be calculated through the following equation. The related parameters are further decomposed and described below:

$$R_{IC} = \frac{MS_{BS} - MS_{res}}{MS_{BS} + (k-1)MS_{res} + \frac{k}{n}(MS_{BJ} - MS_{res})}$$

Where:

The mean square between-conditions $MS_{BJ} = SS_{BJ}/df_{BJ}$

The mean square between-subjects $MS_{BS} = SS_{BS}/df_{BS}$

The mean square between-residues $MS_{res} = SS_{res}/df_{res}$

$$SS_T = \sum X_T^2 - \frac{(\sum X_T)^2}{nk}$$

$$SS_{BJ} = \sum_{j=1}^{k}\left[\frac{(\sum X_j)^2}{n}\right] - \frac{(\sum X_T)^2}{nk}$$

$$SS_{BS} = \sum_{i=1}^{n}\left[\frac{(\sum S_i)^2}{n}\right] - \frac{(\sum X_T)^2}{nk}$$

The residual sum of squares (SS_{res}) $SS_{res} = SS_T - SS_{BJ} - SS_{BS}$

df_{BJ} = between-judges degrees of freedom = k - 1

df_{BS} = between-subjects degrees of freedom = n - 1

df_{res} = residual degrees of freedom = (n-1)(k-1)

df_T = total degrees of freedom

n: denotes the number of subjects

k: denotes the number of judges

T: subscript denotes total

Based on the intraclass correlation coefficient, Shrout and Fleiss (1979) developed a statistical procedure to test the hypothesis to discover whether or not there is an absolute disagreement among the judges [271].

The null hypothesis is defined as:

H_0: $R_{IC} = 0$

H_1: not H_0

The null hypothesis means there is no correlation among the judges, which indicates absolute disagreement among the experts. The authors suggested applying F-test as the statistical measure. The F-ratio for testing the agreement among experts is defined as: $F_{BS} = MS_{BS} / MS_{RES}$ The computed F-ratio will be compared with the critical F-values with degrees of freedom df_1 (= df_{BS}) and df_2 (= df_{RES}) at a desirable level of significance. H_0

will be rejected if the F-ratio is greater than the F-critical, which means that there is no statistically significant disagreement among the experts.

3.7 Sensitivity Analysis

In real world scenarios, there are various uncertainties that may lead to changes in policy decision-making. For example, disruptive technologies can have significant impact on the development of high tech industries, as well as on the decision-making in technology policies. It is especially meaningful for this model to characterize scenarios that could affect changes in the rankings of decision elements. This can be interpreted in reality that when technology policies give different priorities to the prospective technology areas, the priority rankings of supportive innovation resources may also change accordingly. It is beneficial to measure the range of tolerance of such changes through sensitivity analysis techniques. Having a good understanding of these changes will give policy makers better insights on investment, incentives, regulations, and other technology policy measures.

This study utilizes the sensitivity analysis algorithm for hierarchical decision models presented in Chen's dissertation and Kocaoglu's research [272] [273]. With this method, algorithms were developed based on a series of mathematical deductions. It is an accurate and comprehensive method to examine the impact of changes in different levels of a hierarchical decision model on the ranking of the alternatives. In this method, tolerance is defined as the allowable range in which a contribution value can vary without changing the ranking order of bottom level alternatives. In order to determine the tolerance, the allowable ranges of perturbations are always calculated first. The result will reveal the

tolerances of contributions of technology goals to the mission while the innovation resource rankings remaining the same. Before the application of the sensitivity analysis algorithm, it is necessary to redefine some symbols to be used in this research.

O_l : The l th objective, $l = 1,2...L$

In this research, the technologies have been adapted as objectives which include: Chemical Pharmaceutical Technology, Biopharmaceutical Technology, and Herbal Pharmaceutical Technology.

A_i : The i th action, $i = 1,2...I$

Here the actions represent input resources including: public research institutes, university programs, foreign R&D centers, state-owned enterprises, and high-tech small-to-medium enterprises.

a_{il} : Contribution of the i th action to the l th objective

a_i : Contribution of the i th action to the mission

i_r : The rank of i . A_r ranks higher than A_{r+n}, indicating $a_r \geq a_{r+n}$

o_l : Contribution of the l th objective to the mission

Let's denote the perturbation induced on one of the o_l s as ε_{l*},

Where $-o_{l*} < \varepsilon_{l*} < \sum_{l=1, l \neq l*}^{L} o_l$

(o_{l*} is used to differentiate it from the other o_l)

The original ranking order of A_r and A_{r+n} will not reverse if

$\varepsilon_{l*} \leq \frac{C_0}{C_{l*}}$ (if $\frac{C_0}{C_{l*}} > 0$) or $\varepsilon_{l*} \geq \frac{C_0}{C_{l*}}$ (if $\frac{C_0}{C_{l*}} < 0$)

Where $C_{l^*} = a_{r+n,l^*} - a_{r,l^*} - \sum_{l=1,l\neq l^*}^{L} a_{r+n,l} \times \frac{o_l}{\sum_{l=1,l\neq l^*}^{L} o_l} + \sum_{l=1,l\neq l^*}^{L} a_{r,l} \times \frac{o_l}{\sum_{l=1,l\neq l^*}^{L} o_l}$

and $C_0 = a_r - a_{r+n}$

The original ranking of all A_l will remain unchanged if the above condition is satisfied for n = 1, and r = 1, 2 … I-1 in this research. The top choice will remain the same if the above condition is satisfied for r = 1 and n = 1, 2 … I-1.

3.8 Expert Panels

The selection of expert panels is vital for the success of Analytic Delphi research. The judgmental data provided by experts strongly influence the final research outcome. According to the nature of this study, the experts will come from diverse sources to provide a balanced perspective representing both government and industry. Stakeholders from both domestic and foreign sources will be invited to represent different perspectives.

The experts will have several roles during the research process: to help validate the construct and content of the hierarchical model, to provide the judgmental data of relative impacts, and to validate the results of research [274]. Several criteria are used to select expert panel members. Firstly, it is necessary to work with experts who have essential knowledge sets in the research areas. They should have an in-depth understanding of the subject. Secondly, the experts should have the availability and willingness to participate in the research. Thirdly, they should have the ability to see technological competiveness in a holistic way from macro and micro perspectives. Ideally, they should be able to cross over both traditional viewpoints and unconventional angles. Last but not least, the expert

panel should consist of balanced perspectives and biases. There should be no dominance by loudness or silent bystanders.

The expert panel is recruited based on their expertise as well as their backgrounds. In the hierarchical structure, the top and second levels require more technically oriented people who are familiar with global technological trends. They also need to possess knowledge about the characteristics of local needs, capabilities, and trends. The third and bottom level requires more strategically oriented people who possess managerial experience or planning perspectives. Therefore, this research will include both "technological" and "strategic" types of experts in the priority setting process. Although different types of experts may be independent from each other, the members possessing multiple knowledge sets are extremely beneficial to the research. For example, senior managers with technical backgrounds are well-suited to represent the interests of enterprises and industry; Government officials who have a technical background, often called technocrats, are important candidates to represent the concerns of government. These experts can provide holistic perspectives in their judgments.

A balanced participation from various types of experts will be considered in the research. This ensures the generation of specific knowledge and consensus by eliciting judgments according to the unique backgrounds of the experts. The expert panel is divided into several subgroups according to the research purpose for each level. Subgroup-G may consist of policy makers and scientists from the government agencies; Subgroup-F experts have backgrounds or interests in various foreign organizations; Subgroup-L experts may come from local industrial organizations or research institutes. This is to consider the balanced interests and perspectives among different stakeholders.

It should be mentioned that different viewpoints are considered for each level of the model hierarchy. Experts from different subgroups are distributed in the judgmental quantification process for each level of the hierarchical structure. These experts serve to provide different perspectives representing the interests of government, domestic, or foreign stakeholders.

The diversity of viewpoints to be represented in the judgmental data will be measured by the disagreement value during the quantification process. A major concern of diversified participation is that the different backgrounds of the experts may lead to potential conflict or disagreement. However, the variety of judgments can also initiate a constructive conflict which is beneficial toward the research. By incorporating the Delphi method, the research aims for a greater consensus in the end.

3.9 Research Validation

The validation process consists of three major aspects: construct, content, and criterion-related validity. The purpose of validation is to enhance the credibility of the research. Experts are invited to verify the model for construct and content validity. The research results are tested for criterion-related validity.

Construct validity is to ensure the appropriateness and correctness of the model structure. Experts are asked to comment on the validity of the structure, and the feedbacks are used to improve the model. Content validity is to verify that the elements are appropriate and cover the range of necessary decision measurements for the research. The criteria to be validated are extracted from related academic literature and then further refined by the researcher. Drafts of the research instruments are developed to

communicate the rationale of the model and related measurements to the participating experts. Comments and feedback are consolidated by the researcher and then reviewed again by members of the expert panel to achieve consensus. The validation results are reflected in the preparation of the quantification research instruments. Criteria-related validity refers to the review and verification of the final research outcomes. When the research is done and results are analyzed, the researcher will contact the experts again to review and confirm the validity of the results. The research outcome will be thoroughly assessed, and practical implications and recommendations will be discussed accordingly. These three major aspects of validation (construct, content, and criterion-related) will be applied and discussed throughout the case application in the following Chapters.

Chapter 4 – Case Application and Research Development

Based on the generalized research model developed in Chapter 3, a case study focused on the Chinese biopharmaceutical sector will be presented in this Chapter. The criteria of the hierarchical model are customized according to case conditions. The research activities include formation of expert panels, research validations, preparation of research instruments, and data collection.

4.1 Case Background

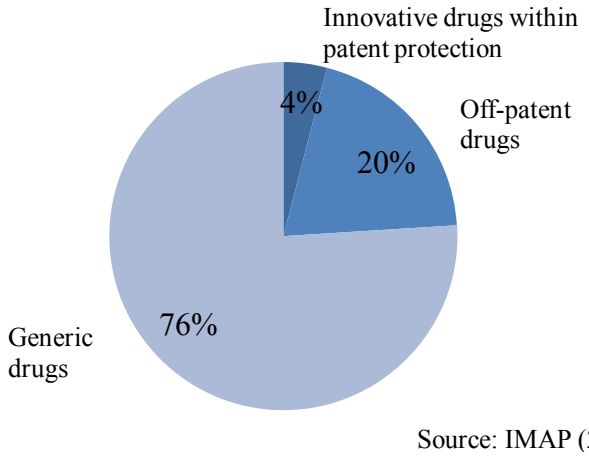
The pharmaceutical industry is often characterized as a research-driven sector because of its exceptionally high ratio of R&D inputs to sales. Development of novel drugs is very difficult because of several issues: 1) heavy investment; 2) high risks; and 3) long development cycle. A novel drug may need to go through many lengthy processes and stages which can easily add up to 10 - 15 years. With one wrong step over the years, the whole project may fail. Investment can easily be hundreds of millions of dollars or more.

4.1.1 The Pharmaceutical Market in China

China's pharmaceutical market is one of the most dynamic in the world. It grew 22% in 2010 to US$116 billion and ranked the fifth largest in the world [275]. With an average annual growth rate above 20% from 2005 to 2010, it is set to overtake Japan as the world's second largest market by 2015 [276]. Due to the economic recession in the Western countries, the Chinese pharmaceutical market is steadily moving up toward the

leading position globally. However, the Chinese pharmaceutical industry faces huge challenges in the area of technological innovation. Breakthrough technological innovation from the domestic Chinese pharmaceutical sector is rarely seen for decades. Although China is a major exporter of pharmaceuticals, it is specialized in the production of crude drug substances and low-tech generics, rather than novel drugs.

The Chinese pharmaceutical market is highly fragmented and very different from the market in developed countries. In 2010, generic drugs had about 76% of the entire pharmaceutical market in China, while only 4% of the market was comprised of innovative drugs still under patent protection. The remaining 20% of the market consisted of off-patent drugs (Figure 16) [275]. The generic drugs market has the largest segment and has mostly been controlled by domestic products. However, the profit margin is low due to intense competition. The innovative drug market has the smallest segment and is dominated by imported products, particularly those produced by MNCs. For the off-patent drug segment, both imported and domestically-produced branded drugs compete to survive.



Source: IMAP (2012)

Figure 16: Innovative and Generic Drug Market Share in China 2010

4.1.2 The Biopharmaceutical Sector

China's pharmaceutical industry consists of three major sectors: 1) chemical pharmaceuticals; 2) biopharmaceuticals; and 3) traditional herbal medicines. Although the chemical pharmaceutical technologies have been regarded as the industrial foundations in the last century, biopharmaceutical technologies have been emerging as a prospective area with huge growth potential. Many leading chemical pharmaceutical companies have already tapped into the biotechnology area. There has been a paradigm shift in industrial R&D from high-risk synthetic pharmaceuticals towards R&D in biopharmaceuticals. The top chemical pharmaceutical companies spent tens of billions of dollars to acquire biotechnology companies and in-licensing deals. Pfizer, Roche, Lilly, Astra Zeneca, Glaxo Smith Kline (GSK) and Bristol Myers Squibb have all underlined their strong commitment and highlighted their biological projects in R&D pipeline [277].

The Chinese biopharmaceutical industry has been developing rapidly in recent years. Since this is still a new area with good prospects, both established pharmaceutical companies and startup firms are trying to profit from the expanding market. Although the overall innovation capability of domestic players is not very strong, research in some specialty areas has already caught up with the level of leading countries. However, it is generally accepted that the Chinese biopharmaceutical industry still needs to increase its competitiveness globally, especially in high technology areas.

4.1.3 Policy Factors

The pharmaceutical sector is among the mostly regulated areas in healthcare. The innovation capability of the industry is largely influenced by macro factors including

regulations, economy, demographics, and technology level. For example, the reimbursement issue needs to be considered in the Chinese market. The government introduced the National Essential Drug List (NEDL) in 2009 to set the range of reimbursement and lower drug prices for the general public. NEDL sets upper limits of the retail prices for the drugs on the list. Innovative drugs are usually not included on the reimbursement list. These drugs are graded at the highest price in the market. Since no imbursement are available, the innovative drugs have a very limited market size. As illustrated in Figure 16, the market share was only 4% in 2010 [275]. Therefore policy factors can have significant impact on the direction of the pharmaceutical industry and its development. Successful technology policy relies on a better understanding of both global and domestic market environments. Decision makers need to evaluate related issues and adjust their strategy accordingly. In order to build a competitive and innovative pharmaceutical sector, both foreign factors and domestic settings call for effective strategic orientation to adapt to global market competition.

4.2 Model Development

This section will focus on crafting the model and applying it to the emerging Chinese biopharmaceutical sector. Decision criteria in each level of the hierarchical model are analyzed and customized according to the conditions in China's biopharmaceutical sector. This provides a foundation for further validation by experts. The model will be finalized based on the feedback from expert panels.

4.2.1 Mission Level

The top-level mission has been defined as "Technological Competitiveness and Innovation"[6]. This mission is applicable to the fast-developing biopharmaceutical industry in China [278] [279]. Due to historical reasons, the technology level of the Chinese biopharmaceutical sector remains less competitive globally, and it still faces challenges including weak innovative capacity and lack of R&D investment. Due to the high investment risk and long development cycle, the biopharmaceutical sector relies heavily on regulations and support from governments. Strengthening technological competitiveness and building up innovative capabilities are primary concerns of industry as well as policy makers.

4.2.2 Technology Level – Prospective Technology Areas

The rationale of the model's technology level is to identify global technology trends and adapt to local capabilities and needs. Choosing the right technology areas and guiding investment are major topics in technology policy. While it is unrealistic for the Chinese biopharmaceutical industry to excel in all high technology areas, it is more realistic to focus on key areas where the country has potential capabilities to achieve competitive advantages. From the perspective of industrializing countries, the appropriate technology can offer windows of opportunity to catch-up with leading countries. In other words, China should look into the global technology frontiers and seize the opportunities for catching up.

To represent the global technology trends and emerging areas in the model, this research will incorporate the findings from technology forecasting reports published by

international organizations such as the United Nations (UN) and Organization for Economic Co-operation and Development (OECD). The UN has published the research results in a report titled Top Ten Biotechnologies for Improving Health in Developing Countries (Table 8) [280]. More recently in 2009, OECD published the forecasting report Human Health Biotechnologies to 2015, which is based on the conditions of its member countries [281] [282].

Rank	Biotechnology
1	Modified molecular technologies for affordable, simple diagnosis of infectious diseases
2	Recombinant technologies to develop vaccines against infectious diseases
3	Technologies for more efficient drug and vaccine delivery systems
4	Technologies for environmental improvement (sanitation, clean water, bioremediation)
5	Sequencing pathogen genomes to understand their biology and to identify new antimicrobials
6	Female-controlled protection against sexually transmitted diseases, both with and without contraceptive effect
7	Bioinformatics to identify drug targets and to examine pathogen-host interactions
8	Genetically modified crops with increased nutrients to counter specific deficiencies
9	Recombinant technology to make therapeutic products more affordable
10	Combinatorial chemistry for drug discovery

Table 8: Top Ten Biotechnologies for Improving Health in Developing Countries

Source: UNESCO (2006)

The available research indicates that different countries have different needs for technologies due to various developmental conditions [283]. As an emerging nation, which walks in between the developed and developing cohort, China needs to identify prospective technology areas based on its needs and capabilities. The following model's criteria and definitions were developed based on the reports from the OECD and UN [280] [281] [282], and were verified by consultations with experts.

Recombinant therapeutic proteins – therapeutic proteins are used to treat many non-communicable diseases. These technologies provide affordable and sustainable sources for treatment of chronic disease [280-282].

Recombinant vaccines against infectious diseases – vaccines produced using recombinant DNA technology. The products can be used to effectively treat infectious diseases [280-282].

Monoclonal antibody technology – Monoclonal antibodies (mAb) can be used for therapeutic treatment and diagnostic tests. Many therapies are undergoing clinical trials. Most are concerned with immunological and oncology targets [281, 282].

Tissue engineering technologies – These technologies involve techniques that replace or act directly on cells and tissues in the body. The treatment repairs tissues damaged from injuries and diseases [281, 282].

Stem cell therapy – This type of treatment leads to the production of entire organs. These technologies include the use of stem cells as a therapeutic method, or to repair specific tissues or grow organs [281, 282].

Gene therapy – This technology involves the treatment of a disease by introducing a new gene into a cell. It either uses or acts directly on nucleic acids, which are the molecules that serve as the building blocks for DNA and RNA [281, 282].

Antisense therapy – Antisense drugs are being researched to treat a wide range of diseases such as cardiovascular diseases, asthma, and arthritis. There are currently more than 30 anti-sense therapies in clinical trials [281, 282].

RNAi (ribonucleic acid interference) – This includes all entries for products which act therapeutically via an RNA interference mechanism. There have been a great number

of research activities in this new area. Most proposed clinical uses are aimed at treating infections [281, 282].

Nanobiotechnology for efficient drug and vaccine delivery – This type of technology aims for improved drug delivery systems from the convergence between biotechnology and nanotechnology [281, 282].

Synthetic biology – The design and construction of new biological parts, devices and systems that do not exist naturally; The redesign of existing biological systems to perform specific tasks [281, 282].

Bioinformatics to identify drug targets and examine pathogen-host interactions – These technologies cover the manipulation and analysis of large datasets of genetic and health information [280-282].

Pharmacogenetics – This technology identifies inherited differences (variation) between individuals in drug metabolism and response. It can be applied in clinical trials and prescribing practices [281, 282].

Gene sequencing – Sequencing of pathogen genomes provides ways to identify new antimicrobials. These technologies can accelerate the process of drug discovery and fight against infectious diseases [280-282].

Biotechnology Diagnostics – This technology includes both in vitro diagnostics and in vivo diagnostics. Modified molecular technologies provide affordable and simple diagnosis of infectious diseases [280-282].

4.2.3 Strategy Level – Technology Development Strategies

The Strategy Level defines how technologies should be developed and implemented. As an industrializing country, China faces the decisions of "Make" or "Buy", or somewhere in between [259]. According to the findings from the literature review section, the following strategies are defined to describe the situation:

Indigenous Innovation – This strategy relies on the host country's local technology base and available innovation resources to build up indigenous competence [74-76].

Imitative Innovation – Also known as re-innovation in literature, it is based on imitation, adaptation, and improvement of the original innovators' technology [74] [77] [78].

Collaborative Innovation – This strategy means the participants cooperate and develop new ideas altogether. Competitors may share resources and work together toward innovation [74] [79].

International Technology Transfer – This includes technology import and acquisitions. This is a fast track to save valuable time and resources during the catching-up process [14] [19] [24] [284].

4.2.4 Resource Level – Innovation Resource Alternatives

Under the condition of a transitional economy, China's National Innovation system carries some characteristics from both a market economy and centrally-planned system. Here we need to identify the key contributors toward technology development and innovation in the Chinese biopharmaceutical sector. Subsidies and favorable policy measures should be designed and prioritized to strengthen the performance of effective

innovators. The following innovation resources have been identified by the literature review.

State-Owned Enterprises (SOEs) – SOEs are medium- to large-sized companies left by the centrally planned system. These companies constitute the main production capacity of the Chinese pharmaceutical industry, but most of them specialize in low-tech generics drugs. Compared with foreign counterparts, domestic pharmaceutical companies are weaker in terms of technology level and research capabilities [259] [285] [286] [287].

High-tech Small-to-Medium Enterprises (SMEs) – These smaller companies have emerged since the 1980s, when the government started to allow private ownership of companies. Many small dedicated biotechnology firms (DBFs) belong to this category. They probe into potential technology areas with the purpose of obtaining leadership status in some niche sub-sectors [285] [288] [286].

Multinational Company and subsidiaries (MNCs) – Currently, many top MNCs have established subsidiaries in China. These large American and European pharmaceutical companies have dominant innovative capability in most technological areas. They act as technology leaders in both production and R&D activities in the Chinese pharmaceutical sector [279] [288] [289].

Contract Research Organizations (CROs) and Contract Manufacture Organizations (CMOs) – These organizations provide services for both foreign and domestic companies. Through learning-by-doing from leading innovators, CROs and CMOs have shown increasing capabilities in developing advanced technologies and manufacturing practice aligning to international standards [290] [288] [291].

University Research Programs (URPs) – Some top research universities are emerging forces in pharmaceutical innovation, and they have been producing more publications and patents in recent years. Not only do these research universities innovate through laboratories, but they also cultivate talented young students for the domestic pharmaceutical industry [286] [288].

Equity Joint Ventures (EJVs) – This is a common way for foreign companies to enter the Chinese biopharmaceutical sector, especially during the 1990s. Two or more investors share the ownership and control over the equity, property (including IP), and operation [288] [292] [287].

Public Research Institutes (PRIs) – PRIs and national R&D laboratories are owned and managed by government departments. These organizations carry out research projects according to government instructions [286] [288].

Foreign R&D Centers (FR&D) – In recent years, some foreign invested R&D centers have been established in China. The biopharmaceutical sector is one of the target areas. This has also happened in India in recent years. Foreign R&D Centers are capable of carrying out comprehensive research to develop new medicines at the innovation frontiers [290] [293].

4.3 Model Validation

After the decision criteria for each level of the hierarchy were prepared by the researcher, the model was sent to related experts for validation. The researcher also provided background information about the research along with the model. During the validation process, each level was tested for the criteria's preferential independence. The

experts were asked to comment about the model construct, and they were allowed to add and/or remove criteria as appropriate.

The prospective technology areas in the biopharmaceutical industry are extracted from available foresight reports. There are two major reasons for these technology areas to be validated. Firstly, these reports were published a few years ago, and they need to be updated and validated according to recent development. For example, the OECD forecasting report was published in 2009. If we consider the publication lag, the research should be done between 2008 and 2009. Secondly, the OECD report represented the findings from a club of developed countries, while this research focuses on emerging economies. As discussed above, the rationale of the technology level is to identify global trends and customize to local needs and capabilities. These requirements of validation were declared in the introduction and instruction sections of related instruments (Appendix C). The results are presented in Table 9.

Prospective Technology Areas	Votes on Yes
Recombinant Therapeutic Proteins	13
Recombinant Vaccines	13
Monoclonal Antibody	13
Tissue Engineering	9
Stem Cell Therapy	9
Gene Therapy	10
Antisense Therapy	10
RNAi	10
Nanobiotechnology	12
Synthetic Biology	10
Bioinformatics	11
Pharmacogenetics	10
Gene Sequencing	10
Biotechnology Diagnostics	12
Total Votes	13

Table 9: Validation Results for Prospective Technology Areas

For the purpose of this research, most experts believed that the extracted technology areas are viable in the biopharmaceutical industry. Based on such feedback, the researcher included all identified technology areas in the model. Regarding preferential independence, several experts suggested combining two technology areas, i.e. "tissue engineering" and "stem cell technology" into "cell and tissue engineering." The researcher contacted other experts about it, and they all agreed to this change.

The technology development strategies were extracted from related literature, including indigenous innovation, imitative innovation, collaborative innovation, and international technology transfer. In general, most experts believe that these technology development strategies are observable in the biopharmaceutical industry. Table 10 presents the validation results of technology development strategies.

Technology Development Strategies	Votes on Yes
Indigenous Innovation	12
Imitative Innovation	13
Collaborative Innovation	13
International Technology Transfer	11
Total Votes	13

Table 10: Validation Results for Technology Development Strategies

Regarding the resources level, the prepared list of criteria includes: University Research Programs; Public Research Institutes; State-Owned Enterprises; High-tech SMEs; Equity Joint Ventures; Contract Research/Manufacture Organizations; Foreign R&D Centers; MNCs and Subsidiaries. The validation results of the innovation resources are summarized in Table 11. Although some resources have more votes than others, most

resources' votes are above 70%. Therefore, all prepared resources are included in the research.

After several iterations, the results were finalized when a consensus was reached. It should be acknowledged that the experts' feedback was very encouraging and informative. The validation of decision criteria helped to answer research questions RQ1, RQ2, and RQ3, as stated in Section 3.1.

Innovation Resources	Votes on Yes
University Research Programs	13
Public Research Institutes	13
State-owned Enterprises	10
High-tech Small-to-Medium Enterprises	13
Equity Joint Ventures	12
Contract Research/Manufacture Organizations	11
Foreign R&D Centers	12
Multinational Companies and Subsidiaries	13
Total Votes	13

Table 11: Validation Results for Innovation Resources

4.4 The Finalized Research Model

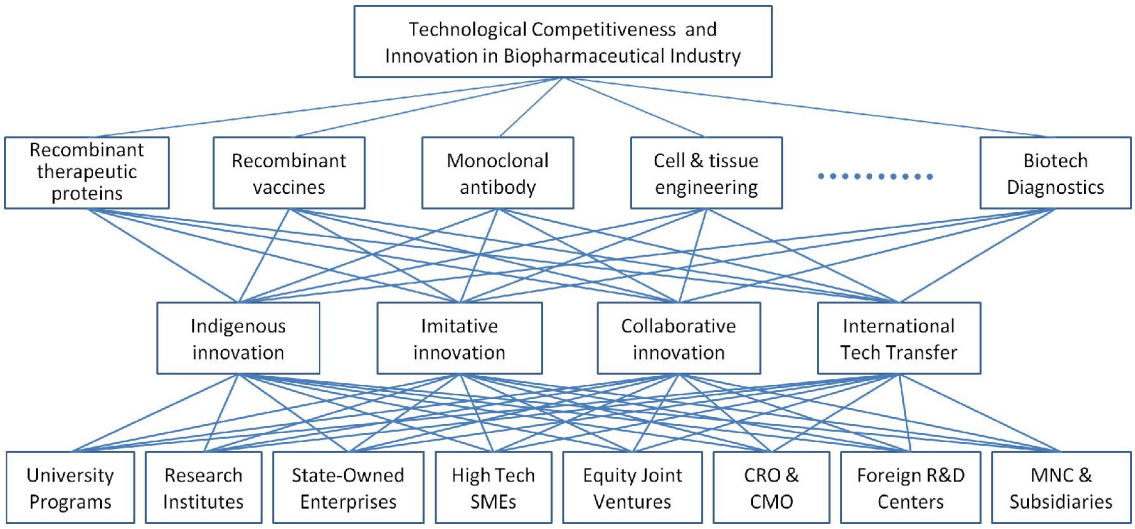


Figure 17: The Finalized Research Model

Based on the validation results, the finalized research model is illustrated in Figure 17. In summary, there are four levels as described above, and the complete sets of criteria associated with each level are listed below (Table 12):

Levels	Criteria
Mission Level (M):	M: Technological Competitiveness and Innovation in Biopharmaceutical Industry
Technology Level: Prospective Technology Areas (T_k):	T_1: Recombinant Therapeutic Proteins
	T_2: Recombinant Vaccines
	T_3: Monoclonal Antibody Technology
	T_4: Cell and Tissue Engineering
	T_5: Gene Therapy
	T_6: Antisense Therapy
	T_7: RNAi
	T_8: Nanobiotechnology
	T_9: Synthetic Biology
	T_{10}: Bioinformatics
	T_{11}: Pharmacogenetics
	T_{12}: Gene Sequencing
	T_{13}: Biotechnology Diagnostics
Strategy Level: Technology Development Strategies (S_j)	S_1: Indigenous Innovation
	S_2: Imitative Innovation
	S_3: Collaborative Innovation
	S_4: International Technology Transfer
Resource Level: Innovation Resource Alternatives (A_i):	A_1: University Research Programs
	A_2: Public Research Institutes
	A_3: State-owned Enterprises
	A_4: High-tech Small-to-Medium Enterprises
	A_5: Equity Joint Ventures
	A_6: Contract Research/Manufacture Organizations
	A_7: Foreign R&D Centers
	A_8: MNCs and Subsidiaries

Table 12: The Finalized Model Criteria

4.5 Formation of Expert Panel

In this research, the model was applied to the fast-growing biopharmaceutical industry in China. The expert panel included policy-makers from government agencies and technology management experts from the health industries. Some of the experts were stakeholders from the domestic and foreign organizations. These included domestic enterprises, top multinational pharmaceutical companies and foreign research institutions. Foreign stakeholders were included because of their technology strength and their long-term investment stakes in the Chinese pharmaceutical market. Domestic biopharmaceutical companies were selected to represent local perspective in research and development. The idea here is to reach a "Win-Win" situation in technology development.

A total of 20 experts participated in the research process (Table 13). According to the University's research policy on human subjects, the identities of the experts were coded to protect their privacy (Appendix A, B). By following the expert recruitment criteria discussed in Chapter 3, the expert panel was divided into three subgroups to match the purpose of this research. Subgroup-G experts have backgrounds from various Government agencies. All of them are senior officials or researchers from the National Medical Policy Research Center, MOH, State Food & Drug Administration, and Center of Drug Evaluation. Subgroup-F experts have Foreign backgrounds, and represent the interests of various foreign organizations, which include two foreign research institutions and three of the top-ten multinational enterprises (Roche, Sanofi-Aventis, and GSK). Subgroup-L consists of Local experts from the domestic industry and research organizations (non-government & without foreign backgrounds), which include bio-tech

SMEs, industrial associations, and public research institutions. Since the experts come from diverse sources, they can provide valuable judgment from different perspectives.

Expert	Affiliation	Subgroup - G	Subgroup - F	Subgroup - L
Exp - 1	Management			x
Exp - 2	Management			x
Exp - 3	Scientist/Researcher	x		
Exp - 4	Scientist/Researcher	x		
Exp - 5	Official	x		
Exp - 6	Official	x		
Exp - 7	Official	x		
Exp - 8	Official	x		
Exp - 9	Management		x	
Exp - 10	Official	x		
Exp - 11	Management			x
Exp - 12	Scientist/Researcher		x	
Exp - 13	Scientist/Researcher		x	
Exp - 14	Management		x	
Exp - 15	Management		x	
Exp - 16	Official	x		
Exp - 17	Management		x	
Exp - 18	Management			x
Exp - 19	Management		x	
Exp - 20	Management			x
Total		8	7	5

Table 13: Expert Panel and Subgroups

4.6 Data Collection

The data collection process includes the design of research instruments, validation of instruments, the formal quantification judgments, and related iterations. Here we discuss the major steps respectively.

Three sets of research instruments were developed to quantify the relative weights of decision criteria at each level. There are 19 tables of pair-wise comparisons for eight input resources, four innovation strategies, and two subgroups of technology areas. Each table has 6 to 28 pairs of comparisons for judgment. The confidence level measurement used Likert scaling (5 points means very high confidence, 4 points means high confidence, 3 points means medium confidence, 2 points means low confidence, and 1 point means very low confidence). Confidence scores with medium or above scores from the experts are acceptable for this research.

In the research instruments, the pair-wise comparison method (PCM) was used for quantifying experts' judgments. The constant sum (100) method was selected as the scaling standard during the quantification process because it is more precise than the conventional AHP's 1-9 scaling. Experts were to compare the relative weight of every two elements in the same level regarding their contribution to the element in the higher level. An expert may assign any value between 1 ~ 99 to represent the relative weight of a criterion. A larger number means a heavier weight of that criterion. For instance, if criterion A was assigned with the value of 75, and criteria B assigned with 25, then A is three times more important than B. Three sets of judgmental quantification instruments were developed for the model. Each set of instruments was designed in accordance with the requirements of a specific level. The judgmental quantification instruments are attached in the appendices of this dissertation (Appendix D).

The robustness of the quantification instruments was first validated in several trial runs before it was sent to the entire expert panel. This process ensured both usability and clarity of the instruments to capture the priorities of criteria in the hierarchy. During the

validation process, questions and suggestions on the instruments were collected for improvements. Several minor improvements to the instruments were made based on the feedback from the trial runs.

After all of the above preparation steps were completed, the research instruments were formally sent to experts for quantification. Different sets of instruments were sent to and filled out by different experts according to their expertise and areas of specialty. During this process, necessary information and questions regarding the methodology of the pair-wise comparisons were conducted through emails and phone calls. Due to various reasons, the data collection process was very lengthy. Reminder emails were sent repeatedly for feedback.

Upon receiving all of the completed research instruments from experts, the researcher started the data analysis process using the pair-wise comparison software. The results were calculated either in matrix or in vector formats. Some important indicators and values such as the inconsistencies and disagreements were evaluated. As discussed in the methodology section, if the inconsistency value is above 0.1, the input data need to be verified with the original expert. In the data collection process, three inconsistencies were observed, including one instance in the strategy level and two instances in the resource level. Although all inconsistency values were very close to the 0.1 threshold, these inputs were reported to the related expert for review. The researcher explained to them about the inconsistency measurement, and the experts improved their judgmental inputs. Similarly, if significant disagreement values were observed, iterations were also needed to verify the results with related experts. These issues are not uncommon for other AHP-based

research. In this research, such issues were resolved after several iterations of communication with the experts. The aggregated results are presented in the next chapter.

Chapter 5 – Results and Data Analysis

In this section, the results of data collection for each hierarchy level are calculated and shown in figures and tables. The data analyses include disagreement measurement and sensitivity analysis. The overall contributions of the bottom and intermediate levels toward the mission are also calculated and presented.

5.1 Quantification Results

All judgmental data collected from the experts were first put into PCM software to assess the relative weights of various criteria at different levels of the HDM. The inconsistency values of the finalized results were less than 10% or 0.1, which is an acceptable level according to available studies [208, 209]. Confidence level was measured using the Likert scaling (5 means very high confidence, 4 means high confidence, 3 means medium confidence, 2 means low confidence, and 1 point means very low confidence). The scores of all levels are very close to 4, indicating that most experts have high confidence level.

5.1.1 Contribution of Technologies to Mission

The following figure presents the results of the 13 technology areas' contribution toward the overall mission (Figure 18). The arithmetic means of relative priority of the technology areas toward the mission are shown as percentages. Individual relative priorities, mean values, and inconsistency values of each expert are shown in Table 14 and 15.

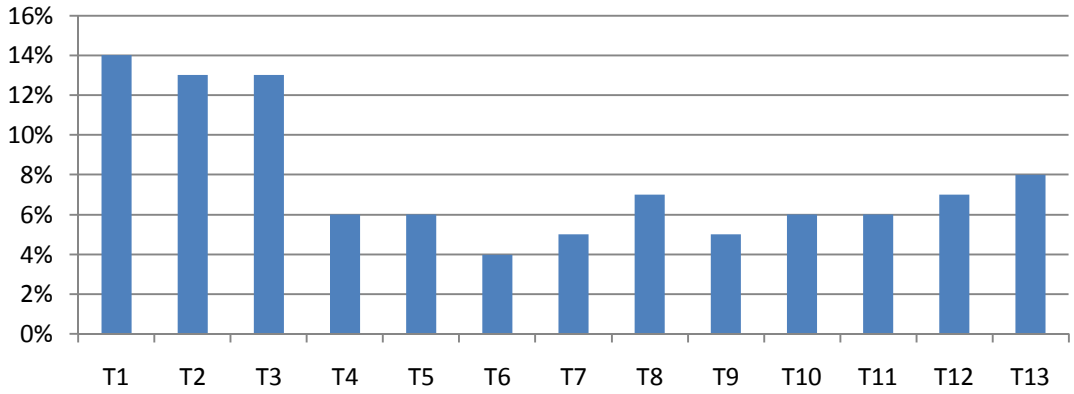


Figure 18: Contribution of Technology Areas to Overall Mission

Group A	T1: Recombinant Therapeutic Proteins	T2: Recombinant Vaccines	T3: Monoclonal Antibody	T4: Cell and Tissue Engineering	T5: Gene Therapy	T6: Antisense Therapy	T7: RNAi	Inconsistency
Exp1	0.13	0.13	0.21	0.16	0.16	0.10	0.12	0.010
Exp2	0.28	0.25	0.13	0.06	0.11	0.09	0.09	0.052
Exp3	0.21	0.21	0.21	0.13	0.10	0.09	0.06	0.014
Exp5	0.18	0.14	0.22	0.11	0.12	0.11	0.12	0.009
Exp8	0.35	0.20	0.26	0.07	0.04	0.04	0.04	0.020
Exp9	0.28	0.28	0.22	0.08	0.08	0.02	0.06	0.020
Exp11	0.20	0.38	0.21	0.07	0.07	0.04	0.03	0.079
Exp13	0.26	0.25	0.20	0.10	0.09	0.04	0.07	0.087
Exp15	0.18	0.16	0.25	0.16	0.08	0.06	0.12	0.007
Exp18	0.23	0.11	0.25	0.09	0.13	0.10	0.10	0.035
Mean	0.23	0.21	0.22	0.10	0.10	0.07	0.08	

Table 14: Contribution of Technology Areas to Mission, Group A

Group B	T1: Recombinant Therapeutic Proteins	T8: Nano-biotech	T9: Synthetic Biology	T10: Bio-informatics	T11: Pharmaco-genetics	T12: Gene Sequencing	T13: Biotech Diagnostics	Inconsistency
Exp1	0.13	0.19	0.13	0.15	0.09	0.15	0.17	0.016
Exp2	0.36	0.15	0.10	0.10	0.10	0.11	0.08	0.020
Exp3	0.16	0.15	0.11	0.16	0.11	0.16	0.16	0.013
Exp5	0.26	0.10	0.15	0.12	0.13	0.08	0.17	0.014
Exp8	0.33	0.10	0.09	0.08	0.16	0.09	0.16	0.024
Exp9	0.33	0.19	0.04	0.08	0.08	0.07	0.21	0.014
Exp11	0.41	0.10	0.09	0.12	0.05	0.10	0.13	0.026
Exp13	0.26	0.19	0.06	0.09	0.10	0.10	0.21	0.042
Exp15	0.17	0.10	0.11	0.14	0.19	0.15	0.14	0.008
Exp18	0.26	0.15	0.10	0.07	0.13	0.17	0.13	0.065
Mean	0.27	0.14	0.10	0.11	0.11	0.12	0.16	

Table 15: Contribution of Technology Areas to Mission, Group B

In the above tables, the priority judgment of the 13 technology areas was split into two groups. The purpose was to reduce the large number of pair-wise comparisons which may induce a heavy workload for the experts. This process is referred to as chained comparison and had been applied in available studies [252] [294]. The rationale of the process is that each group shares a common important comparison element, which will be utilized to normalize all other elements in each group. In this case, T1 was chosen during the validation process as the common important criterion of the two groups. The normalized values were calculated and are shown in Table 16 below.

Technology Areas	Contribution
T1: Recombinant Therapeutic Proteins	14%
T2: Recombinant Vaccines	13%
T3: Monoclonal Antibody	13%
T4: Cell and Tissue Engineering	6%
T5: Gene Therapy	6%
T6: Antisense Therapy	4%
T7: RNAi	5%
T8: Nanobiotechnology	7%
T9: Synthetic Biology	5%
T10: Bioinformatics	6%
T11: Pharmacogenetics	6%
T12: Gene Sequencing	7%
T13: Biotechnology Diagnostics	8%

Table 16: The Normalized Results

According to the results, T1 Recombinant Therapeutic Proteins has the highest contribution (14%) toward the mission. T2 Recombinant Vaccines and T3 Monoclonal Antibody Technology tie for the second and third places at 13%. T6 Antisense Therapy contributes the least at 4% toward the mission (Table 16).

Recombinant therapeutic proteins are used to treat many non-communicable diseases such as hematology, diabetes, endocrinology, and oncology. The technology to make

recombinant therapeutic proteins was among the most promising biotechnologies for improving health in developing countries. With the number of affluent people in China, the prevalence of chronic disease is growing at staggering rates due to increased levels of hypertension, diabetes, and obesity. This offers a huge demand for drug development in the local market [295]. Affordable and sustainable sources of therapeutic proteins for treating chronic disease are critical to developing countries like China [280].

Recombinant vaccines can be used to effectively treat infectious diseases. Vaccines are widely considered as essential for disease prevention in both developing and developed countries. Recombinant vaccines have proven to be cheaper as well as safer in testing and production than inactivated or attenuated vaccines [283]. With a large population, the outlook for vaccines remains bright in China. The growth rate of the Chinese vaccine market is around 20%, and its size will reach CNY 12 billion by 2013 [296]. Focusing on this area is absolutely critical for domestic needs in China.

Monoclonal Antibody is one of the fastest growing areas in the biopharmaceutical industry. The value of the global therapeutic mAb market exceeded US $17 billion in 2007, and many mAb applications become blockbuster drugs [297]. If China wants to be competitive and innovative in the world's biotech arena, mAb is an area that cannot be overlooked.

5.1.2 Contribution of Development Strategies to Technologies Areas

This section presents the results of the relative contribution of strategies toward the prospective technology areas. The results are illustrated in sequential order from T1 to T13. The experts' individual judgments for each technology area are also included. These

findings give us the answer for "which strategy is better for the development of the target technology."

5.1.2.1 Strategies for T1: Recombinant Therapeutic Proteins

T1: Recombinant Therapeutic Proteins	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.43	0.35	0.16	0.07	0.013
Exp6	0.24	0.33	0.24	0.18	0.004
Exp11	0.25	0.43	0.20	0.12	0.005
Exp12	0.19	0.40	0.15	0.26	0.031
Exp15	0.18	0.39	0.22	0.22	0.032
Exp16	0.40	0.26	0.14	0.20	0.002
Exp19	0.33	0.21	0.20	0.26	0.001
Exp20	0.36	0.29	0.16	0.19	0.009
Mean	0.30	0.33	0.18	0.19	

Table 17: Contribution of Strategies to T1 Recombinant Therapeutic Proteins

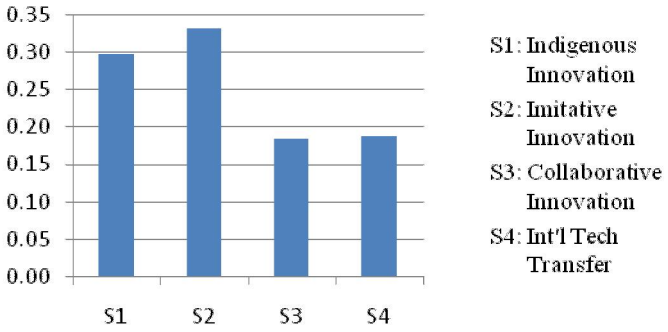


Figure 19: Contribution of Strategies to T1 Recombinant Therapeutic Proteins

As shown in the results (Figure 19), S2 Imitative innovation strategy (33%) ranked the first for T1 Recombinant Therapeutic Proteins, followed by S1 Indigenous innovation strategy (30%) at the second position. S3 Collaborative innovation and S4 International technology transfer ranked relatively low at 18% and 19% respectively. It should be noted that the rankings of imitative innovation strategy and indigenous innovation

strategy are relatively close, meaning that China should focus on catching up with leading innovators, and also try to indigenously develop novel drugs in the area of recombinant therapeutic proteins (Table 17).

5.1.2.2 Strategies for T2 Recombinant Vaccines

T2: Recombinant Vaccines	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.21	0.54	0.21	0.05	0.080
Exp6	0.32	0.33	0.21	0.14	0.034
Exp11	0.27	0.41	0.16	0.16	0.031
Exp12	0.38	0.19	0.30	0.13	0.035
Exp15	0.33	0.27	0.22	0.18	0.008
Exp16	0.48	0.17	0.17	0.18	0.007
Exp19	0.39	0.15	0.30	0.16	0.005
Exp20	0.46	0.21	0.18	0.15	0.023
Mean	0.36	0.28	0.22	0.14	

Table 18: Contribution of Strategies to T2 Recombinant Vaccines

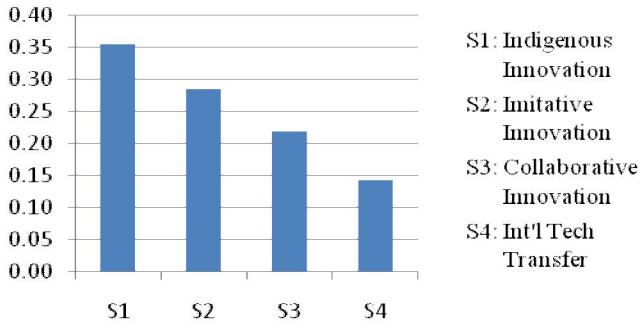


Figure 20: Contribution of Strategies to T2 Recombinant Vaccines

For T2 Recombinant Vaccines, S1 Indigenous innovation strategy ranked highest at 36%. S2 Imitative Innovation ranked second place at 28%, while S3 Collaborative Innovation ranked third at 22%. Lastly, S4 International Technology Transfer ranked the

lowest at 14%. The results indicate that China should focus on developing innovative products, and building up indigenous competence in the vaccine area (Table 18 and Figure 20).

5.1.2.3 Strategies for T3 Monoclonal Antibody Technology

T3: Monoclonal Antibody	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.16	0.68	0.10	0.06	0.044
Exp6	0.24	0.36	0.26	0.14	0.004
Exp11	0.16	0.67	0.13	0.04	0.038
Exp12	0.30	0.28	0.27	0.15	0.045
Exp15	0.18	0.22	0.33	0.27	0.008
Exp16	0.36	0.29	0.19	0.16	0.027
Exp19	0.27	0.25	0.30	0.18	0.010
Exp20	0.31	0.32	0.28	0.09	0.003
Mean	0.25	0.38	0.23	0.14	

Table 19: Contribution of Strategies to T3 Monoclonal Antibody Technology

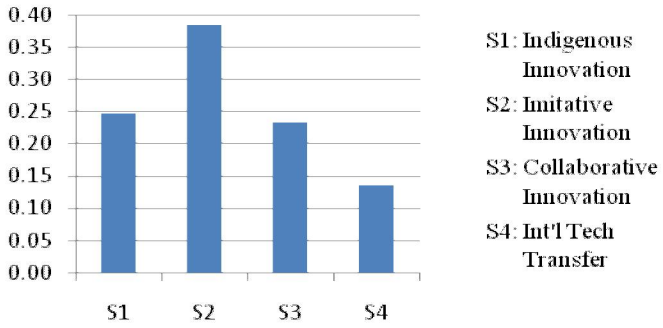


Figure 21: Contribution of Strategies to T3 Monoclonal Antibody Technology

For T3 Monoclonal Antibody Technology, S2 Imitative innovation strategy ranked the highest at 38%. S1 Indigenous innovation ranked second at 25% and S3 Collaborative innovation was third at 23%. Again, S4 International Technology Transfer ranked the

lowest at only 14%. The results indicate that China should focus on catching up with foreign leaders in the area of monoclonal antibody technologies (Table 19 and Figure 21).

5.1.2.4 Strategies for T4 Cell and Tissue Engineering

T4: Cell & Tissue Engineering	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.49	0.31	0.15	0.05	0.008
Exp6	0.24	0.36	0.26	0.14	0.004
Exp11	0.09	0.48	0.26	0.17	0.046
Exp12	0.23	0.24	0.31	0.22	0.063
Exp15	0.25	0.18	0.30	0.27	0.004
Exp16	0.37	0.34	0.21	0.08	0.015
Exp19	0.26	0.22	0.29	0.23	0.025
Exp20	0.15	0.36	0.30	0.19	0.008
Mean	0.26	0.31	0.26	0.17	

Table 20: Contribution of Strategies to T4 Cell and Tissue Engineering

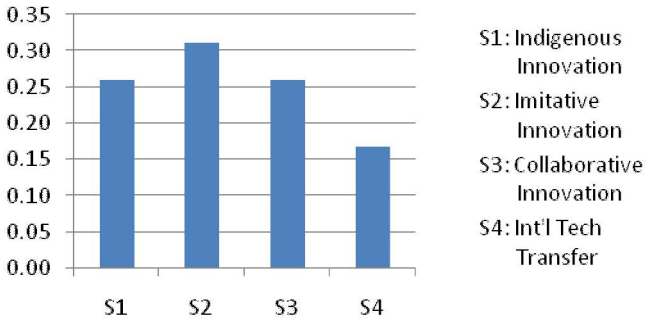


Figure 22: Contribution of Strategies to T4 Cell and Tissue Engineering

For T4 Cell and Tissue Engineering, S2 Imitative innovation strategy ranked the highest at 31%. In second place, S1 Indigenous innovation and S3 Collaborative innovation tied with each other at 26%. S4 International Technology Transfer ranked the lowest at 17%. The results indicate that China should favor the imitative option, but the

indigenous and collaborative approaches are also quite viable for the current conditions (Table 20 and Figure 22).

5.1.2.5 Strategies for T5 Gene Therapy

T5: Gene Therapy	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.31	0.47	0.14	0.07	0.015
Exp6	0.24	0.36	0.26	0.14	0.004
Exp11	0.07	0.63	0.21	0.09	0.013
Exp12	0.27	0.23	0.30	0.19	0.007
Exp15	0.24	0.21	0.38	0.16	0.017
Exp16	0.34	0.31	0.20	0.15	0.012
Exp19	0.29	0.26	0.27	0.18	0.011
Exp20	0.27	0.35	0.21	0.18	0.022
Mean	0.25	0.35	0.25	0.15	

Table 21: Contribution of Strategies to T5 Gene Therapy

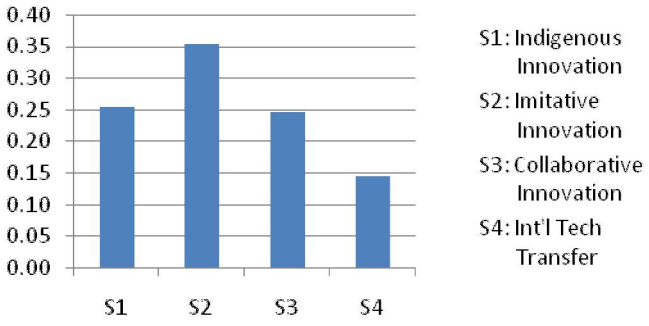


Figure 23: Contribution of Strategies to T5 Gene Therapy

For T5 Gene Therapy, S2 Imitative innovation strategy received the highest ranking at 35%. S1 Indigenous innovation and S3 Collaborative innovation tied again for second place, but at 25% in this case. S4 International Technology Transfer ranked the lowest at 15%. The results indicate that China should focus on catching up with advanced countries in the area of gene therapy.

5.1.2.6 Strategies for T6 Antisense Therapy

T6: Antisense Therapy	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.35	0.35	0.19	0.12	0.018
Exp6	0.13	0.47	0.22	0.18	0.045
Exp11	0.08	0.64	0.19	0.09	0.019
Exp12	0.08	0.31	0.31	0.31	0.001
Exp15	0.26	0.16	0.38	0.19	0.009
Exp16	0.30	0.34	0.20	0.16	0.006
Exp19	0.18	0.28	0.30	0.23	0.014
Exp20	0.23	0.35	0.22	0.20	0.003
Mean	0.20	0.36	0.25	0.19	

Table 22: Contribution of Strategies to T6 Antisense Therapy

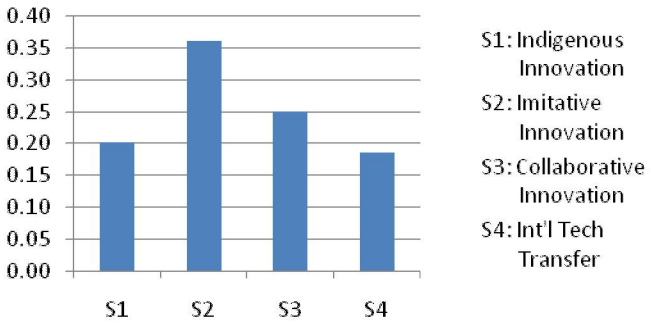


Figure 24: Contribution of Strategies to T6 Antisense Therapy

For T6 Antisense Therapy, S2 Imitative innovation strategy ranked first at 36%. S3 Collaborative innovation ranked second at 25%. S1 Indigenous innovation ranked third at 20%, while S4 International Technology Transfer ranked slightly lower at 19%. The results indicate that China should focus on catching up with foreign countries in the area of antisense therapy (Table 22 and Figure 24).

5.1.2.7 Strategies for T7 RNAi

T7: RNAi	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.35	0.35	0.19	0.12	0.018
Exp6	0.15	0.44	0.25	0.16	0.032
Exp11	0.06	0.55	0.26	0.12	0.002
Exp12	0.25	0.26	0.29	0.20	0.001
Exp15	0.22	0.18	0.33	0.27	0.008
Exp16	0.32	0.34	0.16	0.17	0.003
Exp19	0.28	0.24	0.30	0.17	0.001
Exp20	0.26	0.39	0.22	0.13	0.012
Mean	0.24	0.34	0.25	0.17	

Table 23: Contribution of Strategies to T7 RNAi

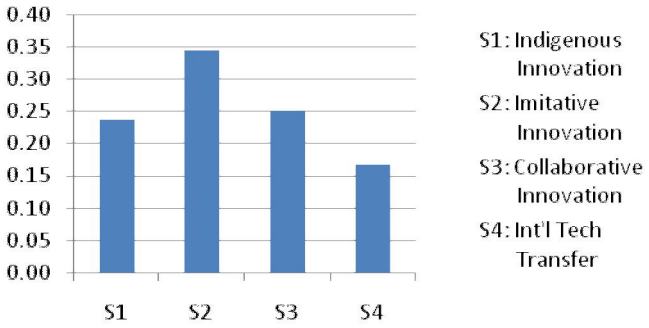


Figure 25: Contribution of Strategies to T7 RNAi

For T7 RNAi, S2 Imitative innovation strategy ranked first place at 34%. S3 Collaborative innovation and S1 Indigenous innovation ranked closely for second and third places at 25% and 24% respectively. S4 International Technology Transfer ranked the lowest at 17%. The results also indicate that China should focus on catching up with advanced countries in the area of RNAi (Figure 25).

5.1.2.8 Strategies for T8 Nanobiotechnology

T8: Nanobiotech	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.25	0.43	0.22	0.10	0.004
Exp6	0.10	0.46	0.19	0.24	0.056
Exp11	0.06	0.66	0.21	0.07	0.017
Exp12	0.24	0.29	0.27	0.20	0.015
Exp15	0.23	0.18	0.33	0.26	0.005
Exp16	0.28	0.33	0.18	0.21	0.003
Exp19	0.27	0.28	0.24	0.21	0.005
Exp20	0.23	0.35	0.23	0.19	0.006
Mean	0.21	0.37	0.23	0.19	

Table 24: Contribution of Strategies to T8 Nanobiotechnology

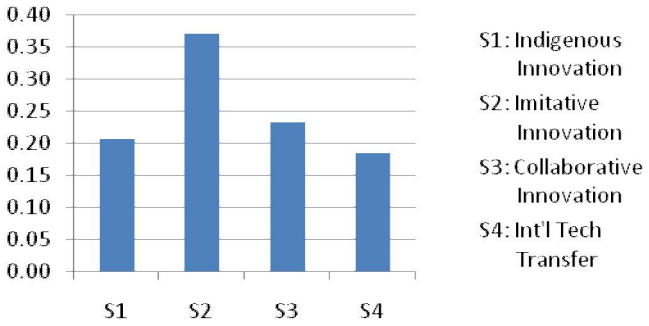


Figure 26: Contribution of Strategies to T8 Nanobiotechnology

For T8 Nanobiotechnology, S2 Imitative innovation strategy ranked first at 37%. S3 Collaborative innovation ranked second at 23%. S1 Indigenous innovation ranked third at 21%. S4 International Technology Transfer ranked fourth at 19%. The results are obvious that China should focus on catching up with leading innovators in the area of nanobiotechnology (Table 24 and Figure 26).

5.1.2.9 Strategies for T9 Synthetic Biology

T9: Synthetic Biology	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.33	0.47	0.12	0.07	0.005
Exp6	0.38	0.22	0.26	0.14	0.079
Exp11	0.07	0.67	0.19	0.07	0.018
Exp12	0.15	0.37	0.28	0.20	0.018
Exp15	0.22	0.18	0.39	0.22	0.032
Exp16	0.36	0.30	0.19	0.15	0.003
Exp19	0.24	0.36	0.25	0.15	0.007
Exp20	0.23	0.34	0.27	0.16	0.019
Mean	0.25	0.36	0.24	0.15	

Table 25: Contribution of Strategies to T9 Synthetic Biology

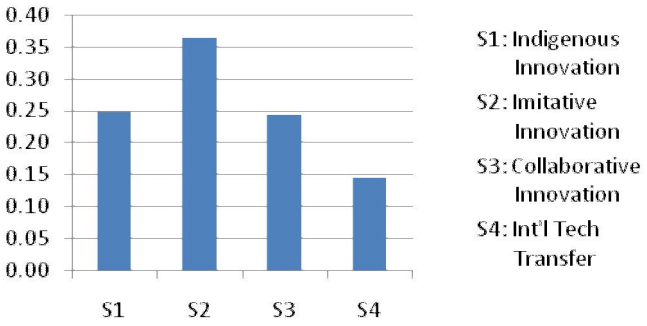


Figure 27: Contribution of Strategies to T9 Synthetic Biology

For T9 Synthetic Biology, S2 Imitative innovation strategy ranked first at 36%. S1 Indigenous innovation and S3 Collaborative innovation have relatively close priority at 25% and 24% respectively. S4 International Technology Transfer ranked the lowest at 15%. The results indicate that China should focus on catching up with leaders in the area of synthetic biology (Table 25 and Figure 27).

5.1.2.10 Strategies for T10 Bioinformatics

T10: Bio-informatics	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.41	0.34	0.15	0.10	0.005
Exp6	0.24	0.36	0.26	0.14	0.004
Exp11	0.10	0.50	0.27	0.13	0.018
Exp12	0.35	0.20	0.23	0.22	0.008
Exp15	0.24	0.18	0.33	0.24	0.004
Exp16	0.45	0.25	0.18	0.12	0.034
Exp19	0.34	0.21	0.31	0.14	0.019
Exp20	0.37	0.23	0.25	0.15	0.031
Mean	0.31	0.28	0.25	0.16	

Table 26: Contribution of Strategies to T10 Bioinformatics

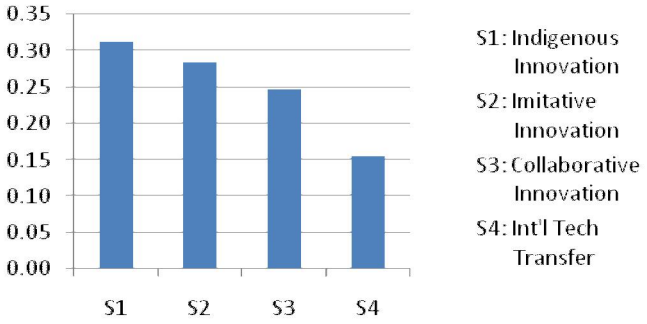


Figure 28: Contribution of Strategies to T10 Bioinformatics

For T10 Bioinformatics, S1 Indigenous innovation strategy ranked highest at 31%. S2 Imitative Innovation ranked second place at 28%. S3 Collaborative Innovation ranked third at 25%. S4 International Technology Transfer ranked the lowest at 16%. The results indicate that China should focus on developing new applications, and building up indigenous competence in the area of bioinformatics (Table 26 and Figure 28).

5.1.2.11 Strategies for T11 Pharmacogenetics

T11: Pharmaco-genetics	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.33	0.41	0.17	0.09	0.006
Exp6	0.22	0.30	0.22	0.25	0.004
Exp11	0.04	0.60	0.25	0.11	0.042
Exp12	0.27	0.24	0.30	0.19	0.021
Exp15	0.25	0.22	0.33	0.20	0.012
Exp16	0.29	0.37	0.18	0.16	0.014
Exp19	0.23	0.26	0.29	0.23	0.027
Exp20	0.27	0.35	0.21	0.18	0.008
Mean	0.24	0.34	0.24	0.18	

Table 27: Contribution of Strategies to T11 Pharmacogenetics

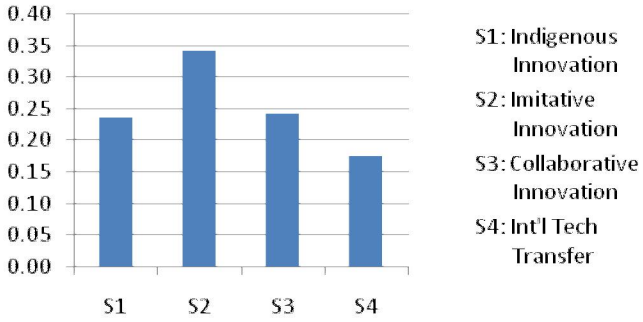


Figure 29: Contribution of Strategies to T11 Pharmacogenetics

For T11 Pharmacogenetics, S2 Imitative innovation strategy ranked first at 34%. S1 Indigenous innovation and S3 Collaborative innovation tied for second place at 24%. S4 International Technology Transfer ranked the last at 18%. The results indicate that China should focus on catching up with foreign leaders in the area of pharmacogenetics (Table 27 and Figure 29).

5.1.2.12 Strategies for T12 Gene Sequencing

T12: Gene Sequencing	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.40	0.26	0.17	0.17	0.000
Exp6	0.29	0.30	0.27	0.14	0.021
Exp11	0.07	0.45	0.29	0.19	0.009
Exp12	0.19	0.30	0.26	0.25	0.001
Exp15	0.18	0.22	0.33	0.27	0.008
Exp16	0.27	0.31	0.26	0.16	0.014
Exp19	0.20	0.27	0.32	0.21	0.005
Exp20	0.15	0.36	0.26	0.23	0.028
Mean	0.22	0.31	0.27	0.20	

Table 28: Contribution of Strategies to T12 Gene Sequencing

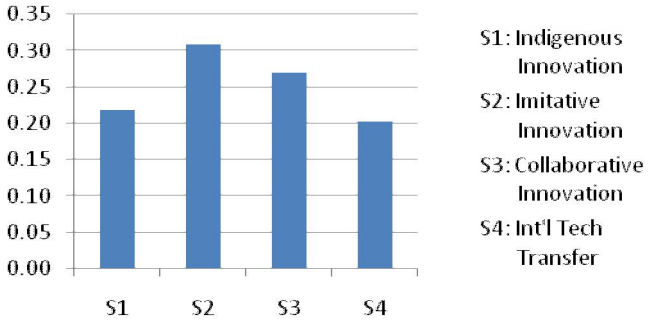


Figure 30: Contribution of Strategies to T12 Gene Sequencing

For T12 Gene Sequencing, S2 Imitative innovation strategy ranked first at 31%. S3 Collaborative innovation ranked second at 27%. S1 Indigenous innovation ranked third at 22%. S4 International Technology Transfer ranked fourth at 20%. The results indicate that China should focus more on imitative innovation, and also try the collaborative approach in the area of gene sequencing (Table 28 and Figure 30).

5.1.2.13 Strategies for T13 Biotechnology Diagnostics

T13: Biotech Diagnostics	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer	Inconsistency
Exp4	0.37	0.37	0.17	0.09	0.002
Exp6	0.20	0.30	0.22	0.27	0.004
Exp11	0.10	0.56	0.15	0.19	0.024
Exp12	0.21	0.32	0.23	0.23	0.004
Exp15	0.18	0.20	0.39	0.24	0.022
Exp16	0.27	0.35	0.24	0.15	0.035
Exp19	0.15	0.31	0.33	0.21	0.016
Exp20	0.19	0.33	0.28	0.20	0.001
Mean	0.21	0.34	0.25	0.20	

Table 29: Contribution of Strategies to T13 Biotechnology Diagnostics

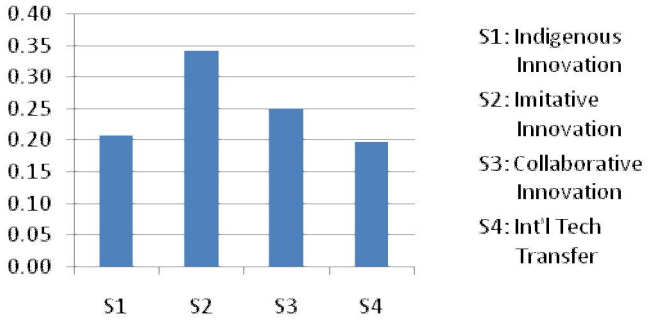


Figure 31: Contribution of Strategies to T13 Biotechnology Diagnostics

For T13 Biotechnology Diagnostics, S2 Imitative innovation strategy ranked the highest at 34%. S3 Collaborative innovation ranked second at 25%. S1 Indigenous innovation ranked third at 21%. S4 International Technology Transfer ranked the lowest at 20%. The results indicate that China should focus on catching up with foreign leaders in the area of biotechnology diagnostics (Table 29 and Figure 31).

Technology Areas	S1: Indigenous Innovation	S2: Imitative Innovation	S3: Collaborative Innovation	S4: Int'l Tech Transfer
T1: Recombinant Therapeutic	0.30	0.33	0.18	0.19
T2: Recombinant Vaccines	0.36	0.28	0.22	0.14
T3: Monoclonal Antibody	0.25	0.38	0.23	0.14
T4: Cell and Tissue Engineering	0.26	0.31	0.26	0.17
T5: Gene Therapy	0.25	0.35	0.25	0.15
T6: Antisense Therapy	0.20	0.36	0.25	0.19
T7: RNAi	0.24	0.34	0.25	0.17
T8: Nanobiotechnology	0.21	0.37	0.23	0.19
T9: Synthetic Biology	0.25	0.36	0.24	0.15
T10: Bioinformatics	0.31	0.28	0.25	0.16
T11: Pharmacogenetics	0.24	0.34	0.24	0.18
T12: Gene Sequencing	0.22	0.31	0.27	0.20
T13: Biotechnology Diagnostics	0.21	0.34	0.25	0.20

Table 30: Summary of Strategy Level

Lastly, as a short summary of the strategy level, the above results show that imitative innovation strategy should be selected for 11 out of the 13 technology areas. The remaining two technology areas belong to the indigenous innovation strategy. For most cases, the ranks of collaborative innovation strategy and indigenous innovation strategy are relatively close, which even tied for the second place in several areas. International technology transfer received relatively low priority for most technology areas (Table 30).

5.1.3 Contribution of Resources to Strategies

The following tables present the results of the relative contribution of the input resources toward the innovation strategies. These findings answer the question "What innovation resources can contribute more to the technological development strategy?" or "What innovation resources should be emphasized in policy development toward the preferred innovation strategy?"

5.1.3.1 Indigenous Innovation

S1: Indigenous Innovation	A1: URPs	A2: PRIs	A3: SOEs	A4: SMEs	A5: EJVs	A6: CROs	A7: FR&D	A8: MNCs	Inconsistency
Exp7	0.07	0.11	0.05	0.13	0.13	0.15	0.18	0.19	0.013
Exp8	0.05	0.06	0.09	0.14	0.16	0.18	0.16	0.16	0.016
Exp10	0.17	0.15	0.07	0.09	0.09	0.09	0.13	0.21	0.012
Exp11	0.20	0.16	0.03	0.17	0.04	0.07	0.06	0.27	0.071
Exp14	0.09	0.08	0.04	0.09	0.12	0.13	0.17	0.29	0.005
Exp17	0.10	0.08	0.06	0.13	0.15	0.05	0.24	0.19	0.012
Exp18	0.06	0.04	0.07	0.21	0.13	0.14	0.17	0.19	0.063
Exp19	0.12	0.08	0.06	0.29	0.11	0.08	0.16	0.10	0.008
Exp20	0.14	0.11	0.08	0.25	0.15	0.12	0.10	0.06	0.029
Mean	0.11	0.10	0.06	0.17	0.12	0.11	0.15	0.18	

Table 31: Contribution of Resources to Indigenous Innovation

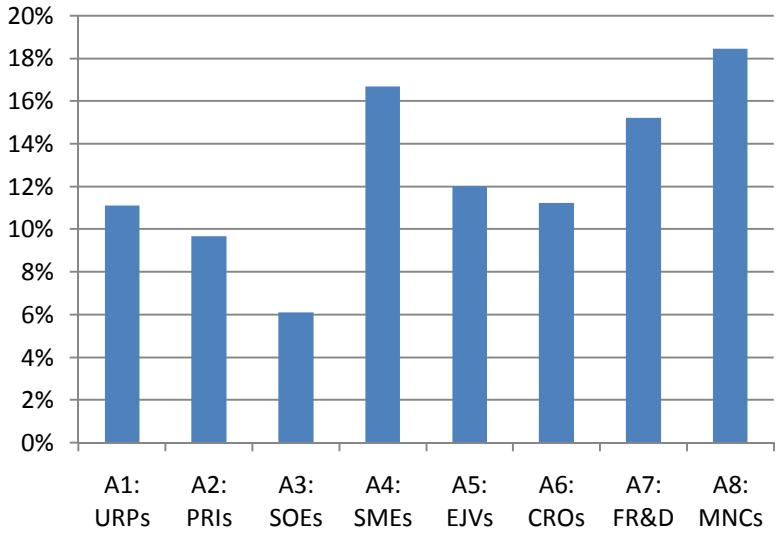


Figure 32: Contribution of Resources to Indigenous Innovation

In Table 31, the results show that A8 Multinational companies and subsidiaries (18%) contribute the most toward Indigenous Innovation, followed by A4 High-tech SMEs

(17%). Their priority rankings are very close, which indicate both resources should be encouraged for the improvement of China's indigenous innovation capability (Figure 32).

A deeper inspection of recent studies reveals that the above findings are reasonable. Research claimed that "MNCs pave the way for an innovative pharmaceutical industry in China" [298]. MNCs' penetration will set the quality standards for local industries. They will initially absorb and be responsible for the training of local talents. MNCs' investment in local businesses will also be a substantial source of capital for Chinese R&D. As opportunities provided by domestic players improve, the migration of skilled talents from conglomerates will nurture the thriving small businesses [298].

Biotech SMEs constitute the largest group of players in the Chinese biopharmaceutical sector [299]. Almost all of the private SMEs emerged during the 1990's and 2000's. Private ownership of companies was not allowed in China until the mid 1980's. The majority of biotech SMEs consists of spinoffs from other institutions such as universities, research institutes, SOEs, and MNCs. In recent years, an increasing number of firms were founded by foreign-trained returnees from developed countries. Biotech SMEs have gradually become more influential players in the local industry. The innovation capability of SMEs will largely decide the competitiveness of China's biopharmaceutical industry.

5.1.3.2 Imitative Innovation

As presented in Table 32 and Figure 33, the experts think that A4 High-tech SMEs (23%) contribute more to imitative Innovation, followed by A1 University Research Programs (17%) and A2 Public Research Institutes 13%.

S2: Imitative Innovation	A1: URPs	A2: PRIs	A3: SOEs	A4: SMEs	A5: EJVs	A6: CROs	A7: FR&D	A8: MNCs	Inconsistency
Exp7	0.12	0.10	0.06	0.14	0.11	0.14	0.18	0.16	0.012
Exp8	0.06	0.06	0.08	0.18	0.16	0.17	0.16	0.15	0.004
Exp10	0.13	0.10	0.06	0.18	0.09	0.12	0.14	0.19	0.011
Exp11	0.16	0.23	0.06	0.35	0.06	0.09	0.04	0.02	0.044
Exp14	0.20	0.18	0.17	0.22	0.08	0.07	0.05	0.04	0.034
Exp17	0.24	0.15	0.12	0.19	0.10	0.05	0.07	0.08	0.012
Exp18	0.16	0.08	0.10	0.19	0.14	0.14	0.10	0.09	0.050
Exp19	0.21	0.15	0.08	0.28	0.11	0.06	0.06	0.05	0.006
Exp20	0.23	0.09	0.07	0.31	0.07	0.09	0.08	0.06	0.013
Mean	0.17	0.13	0.09	0.23	0.10	0.10	0.10	0.09	

Table 32: Contribution of Resources to Imitative Innovation

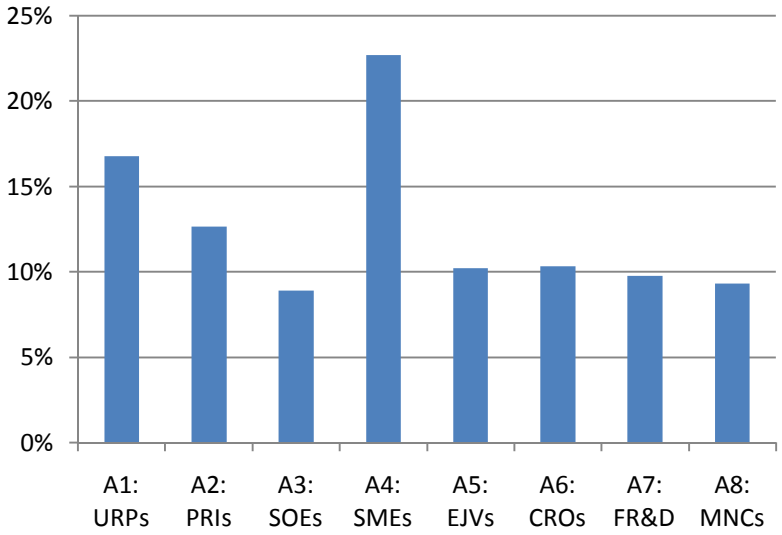


Figure 33: Contribution of Resources to Imitative Innovation

High-tech SMEs may contribute more toward imitation for several reasons [299]: aggressive thinking and action; flexible business strategy; low operational cost and high efficiency; better control in designated territory; and good service provision. University Research Programs and Public Research Institutes are ranked high because they possess a

huge number of biotechnical R&D personnel as well as considerable technical capability and experience [295]. Such factors are essential elements for technological learning in high-tech areas.

5.1.3.3 Collaborative Innovation

S3: Collaborative Innovation	A1: URPs	A2: PRIs	A3: SOEs	A4: SMEs	A5: EJVs	A6: CROs	A7: FR&D	A8: MNCs	Inconsistency
Exp7	0.11	0.12	0.08	0.14	0.14	0.14	0.14	0.15	0.013
Exp8	0.05	0.09	0.09	0.13	0.17	0.15	0.16	0.16	0.008
Exp10	0.13	0.10	0.07	0.13	0.11	0.13	0.16	0.18	0.016
Exp11	0.13	0.22	0.10	0.34	0.07	0.10	0.04	0.02	0.023
Exp14	0.08	0.07	0.10	0.12	0.11	0.14	0.14	0.25	0.016
Exp17	0.19	0.15	0.12	0.24	0.08	0.10	0.05	0.06	0.012
Exp18	0.16	0.10	0.10	0.21	0.14	0.10	0.09	0.10	0.020
Exp19	0.16	0.13	0.10	0.18	0.13	0.13	0.11	0.08	0.012
Exp20	0.15	0.12	0.11	0.17	0.08	0.16	0.09	0.12	0.011
Mean	0.13	0.12	0.10	0.18	0.11	0.13	0.11	0.12	

Table 33: Contribution of Resources to Collaborative Innovation

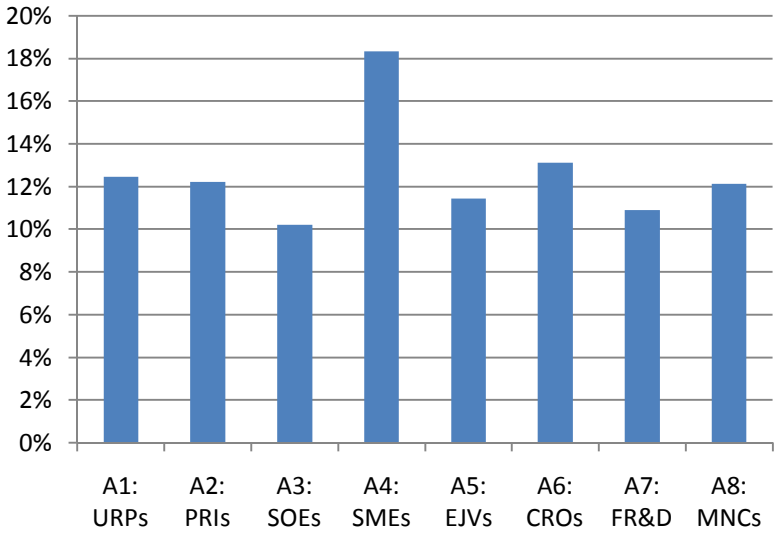


Figure 34: Contribution of Resources to Collaborative Innovation

In Table 33 and Figure 34, the results show that A4 High-tech SMEs contributed the most toward collaborative innovation at 18%. A1 University Research Programs and A6 Contract Research/Manufacturing Organizations tied at 13% and ranked in second place.

High-tech SMEs are often very active players in collaborative activities. SMEs need to seek complementary resources due to limited company size, financial funding, and research capacity [299]. Cooperation with other players is among the best choices for them. Universities are well known to be specialized in the area of basic research. Both domestic and foreign players collaborate with Chinese universities in early-stage preclinical studies. Contract Research/Manufacturing Organizations are more focused on providing clinical trial or production services for other players.

5.1.3.4 International Technology Transfer

S4: Int'l Tech Transfer	A1: URPs	A2: PRIs	A3: SOEs	A4: SMEs	A5: EJVs	A6: CROs	A7: FR&D	A8: MNCs	Inconsistency
Exp7	0.08	0.09	0.09	0.14	0.15	0.15	0.15	0.15	0.007
Exp8	0.05	0.07	0.08	0.15	0.16	0.15	0.18	0.17	0.007
Exp10	0.11	0.09	0.08	0.16	0.11	0.13	0.15	0.17	0.009
Exp11	0.05	0.07	0.18	0.06	0.15	0.12	0.12	0.25	0.078
Exp14	0.05	0.03	0.02	0.05	0.05	0.09	0.16	0.56	0.030
Exp17	0.10	0.08	0.06	0.13	0.15	0.05	0.24	0.19	0.012
Exp18	0.09	0.10	0.20	0.09	0.18	0.15	0.11	0.09	0.049
Exp19	0.05	0.06	0.08	0.10	0.12	0.13	0.19	0.28	0.028
Exp20	0.07	0.06	0.10	0.13	0.11	0.11	0.16	0.26	0.011
Mean	0.07	0.07	0.10	0.11	0.13	0.12	0.16	0.24	

Table 34: Contribution of Resources to International Technology Transfer

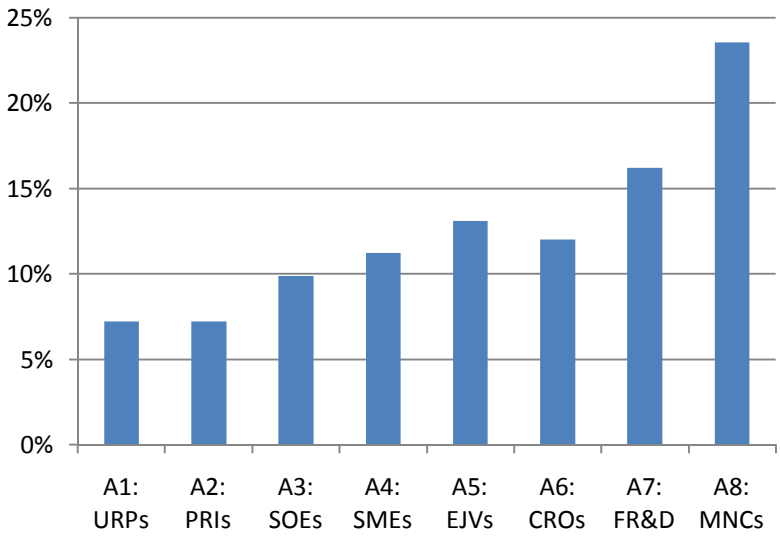


Figure 35: Contribution of Resources to International Technology Transfer

In Table 34 and Figure 35, the results show that A8 MNCs contributed the most toward international technology transfer at 24%, followed by A7 Foreign R&D Centers at 16%. A5 Equity Joint Ventures ranked third at 13%.

As seen from the literature review, most China-related technology transfer studies deal with multinational companies, which are the most important technology carriers in the international technology transfer process [71]. Foreign R&D Centers and Joint Ventures were also ranked high because they have better access to foreign technologies. However, in recent years, there have been more cases of technical transactions from domestic players to foreign players. Many MNCs have acquired domestic companies or research outcomes to broaden their research pipelines [300]. International technology transfer has become a mutual process to benefit both sides in the Chinese biopharmaceutical sector.

5.1.4 Overall Contributions

After validating the values of relative priority at each level, the contribution of lower level elements toward the overall mission can be calculated by vector and matrix manipulations. The following matrix calculations demonstrate the process and results. This includes: Innovation Strategies to Mission [S/M], Resource Alternatives to Prospective Technology Areas [A/T], and Resource Alternatives to Mission [A/M]. The other two matrixes represent Strategies to Technology Areas [S/T] and Resource Alternatives to Strategies [A/S].

Contribution of Strategies to Mission:

[S/M] = [S/T] x [T/M] Equation (1)

$$\begin{vmatrix} 0.30 & 0.36 & 0.25 & 0.26 & 0.25 & 0.20 & 0.24 & 0.21 & 0.25 & 0.31 & 0.24 & 0.22 & 0.21 \\ 0.33 & 0.28 & 0.38 & 0.31 & 0.35 & 0.36 & 0.34 & 0.37 & 0.36 & 0.28 & 0.34 & 0.31 & 0.34 \\ 0.18 & 0.22 & 0.23 & 0.26 & 0.25 & 0.25 & 0.25 & 0.23 & 0.24 & 0.25 & 0.24 & 0.27 & 0.25 \\ 0.19 & 0.14 & 0.14 & 0.17 & 0.15 & 0.19 & 0.17 & 0.19 & 0.15 & 0.16 & 0.18 & 0.20 & 0.20 \end{vmatrix} \begin{vmatrix} 0.14 \\ 0.13 \\ 0.13 \\ 0.06 \\ 0.06 \\ 0.04 \\ 0.05 \\ 0.07 \\ 0.05 \\ 0.06 \\ 0.06 \\ 0.07 \\ 0.08 \end{vmatrix} = \begin{vmatrix} 0.26 \\ 0.33 \\ 0.23 \\ 0.17 \end{vmatrix}$$

Contribution of Resource Alternatives to Technology Areas:

[A/T] = [A/S] x [S/T] Equation (2)

$$\begin{vmatrix} 0.11 & 0.17 & 0.13 & 0.07 \\ 0.10 & 0.13 & 0.12 & 0.07 \\ 0.06 & 0.09 & 0.10 & 0.10 \\ 0.17 & 0.23 & 0.18 & 0.11 \\ 0.12 & 0.10 & 0.11 & 0.13 \\ 0.11 & 0.10 & 0.13 & 0.12 \\ 0.15 & 0.10 & 0.11 & 0.16 \\ 0.18 & 0.09 & 0.12 & 0.24 \end{vmatrix} \begin{vmatrix} 0.30 & 0.36 & 0.25 & 0.26 & 0.25 & 0.20 & 0.24 & 0.21 & 0.25 & 0.31 & 0.24 & 0.22 & 0.21 \\ 0.33 & 0.28 & 0.38 & 0.31 & 0.35 & 0.36 & 0.34 & 0.37 & 0.36 & 0.28 & 0.34 & 0.31 & 0.34 \\ 0.18 & 0.22 & 0.23 & 0.26 & 0.25 & 0.25 & 0.25 & 0.23 & 0.24 & 0.25 & 0.24 & 0.27 & 0.25 \\ 0.19 & 0.14 & 0.14 & 0.17 & 0.15 & 0.19 & 0.17 & 0.19 & 0.15 & 0.16 & 0.18 & 0.20 & 0.20 \end{vmatrix}$$

$$= \begin{vmatrix} 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 \\ 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 \\ 0.08 & 0.08 & 0.09 & 0.09 & 0.09 & 0.09 & 0.09 & 0.09 & 0.09 & 0.08 & 0.09 & 0.09 & 0.09 \\ 0.18 & 0.18 & 0.19 & 0.18 & 0.18 & 0.18 & 0.18 & 0.18 & 0.19 & 0.18 & 0.18 & 0.18 & 0.18 \\ 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 \\ 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 \\ 0.13 & 0.13 & 0.12 & 0.13 & 0.12 & 0.12 & 0.12 & 0.12 & 0.12 & 0.13 & 0.13 & 0.13 & 0.13 \\ 0.15 & 0.15 & 0.14 & 0.15 & 0.14 & 0.14 & 0.14 & 0.14 & 0.14 & 0.15 & 0.15 & 0.15 & 0.15 \end{vmatrix}$$

Contribution of Resource Alternatives to Mission:

[A/M] = [A/S] x [S/T] x [T/M] = [A/T] x [T/M] Equation (3)

$$\begin{vmatrix} 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 & 0.13 \\ 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 \\ 0.08 & 0.08 & 0.09 & 0.09 & 0.09 & 0.09 & 0.09 & 0.09 & 0.09 & 0.08 & 0.09 & 0.09 & 0.09 \\ 0.18 & 0.18 & 0.19 & 0.18 & 0.18 & 0.18 & 0.18 & 0.18 & 0.19 & 0.18 & 0.18 & 0.18 & 0.18 \\ 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 \\ 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 & 0.11 \\ 0.13 & 0.13 & 0.12 & 0.13 & 0.12 & 0.12 & 0.12 & 0.12 & 0.12 & 0.13 & 0.13 & 0.13 & 0.13 \\ 0.15 & 0.15 & 0.14 & 0.15 & 0.14 & 0.14 & 0.14 & 0.14 & 0.14 & 0.15 & 0.15 & 0.15 & 0.15 \end{vmatrix} \begin{vmatrix} 0.14 \\ 0.13 \\ 0.13 \\ 0.06 \\ 0.06 \\ 0.04 \\ 0.05 \\ 0.07 \\ 0.05 \\ 0.06 \\ 0.06 \\ 0.07 \\ 0.08 \end{vmatrix} = \begin{vmatrix} 0.13 \\ 0.11 \\ 0.09 \\ 0.18 \\ 0.11 \\ 0.11 \\ 0.13 \\ 0.15 \end{vmatrix}$$

5.1.4.1 Overall Contribution of Strategies to Mission

The relative contribution of the strategies to the mission can be calculated by multiplying the arithmetic mean of the strategic priority and the mean values of the relative contribution of technology areas to mission. According to Matrix [S/M], the results are presented in Figure 36.

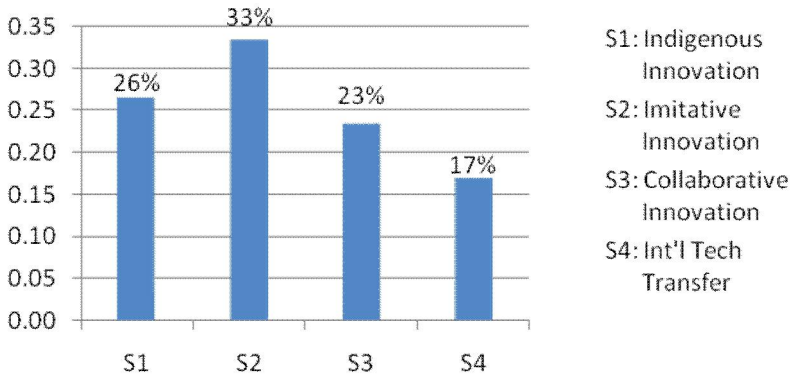


Figure 36: Contribution of Strategies to Mission

The above results show that technology development strategy should focus more on imitative innovation (33%). Indigenous innovation (26%) is regarded as the second best option to improve national competitive capability and to obtain high industry value for China. Collaborative innovation ranked third at 23%. Lastly, international technology transfer contributed 17% to the overall mission.

Imitative innovation strategy has the highest overall ranking because it ranks highest for 11 technology areas out of the total 13 areas. This conforms to the fact that China has limited capability in developing novel drugs. Referring to Figure 16, generic drugs are the mainstay of China's pharmaceutical industry, and that is unlikely to change in the short term. While the government encourages and relies upon innovation to meet industry

targets, China will probably continue to rely upon widespread prescriptions of generics in public insurance plans to reduce the overall healthcare expenditures, and the current R&D capability also limits the possibility of launching domestic patented drugs in the near future [301]. It is more realistic for the country to focus on catching up with advanced countries in the high-tech areas. Biosimilars offer one legal way of widening access and enabling better value to be obtained for latecomer countries like China. Here, the need to broaden healthcare coverage to large populations must be balanced against limited budgets and growing demand for innovative drugs [302].

5.1.4.2 Overall Contribution of Resource Alternatives to the Mission

The relative contribution of bottom level resources toward the mission can be calculated by multiplying the arithmetic mean of the resources to strategies, strategies to technology areas, and technology areas to mission. The results are presented in Figure 37.

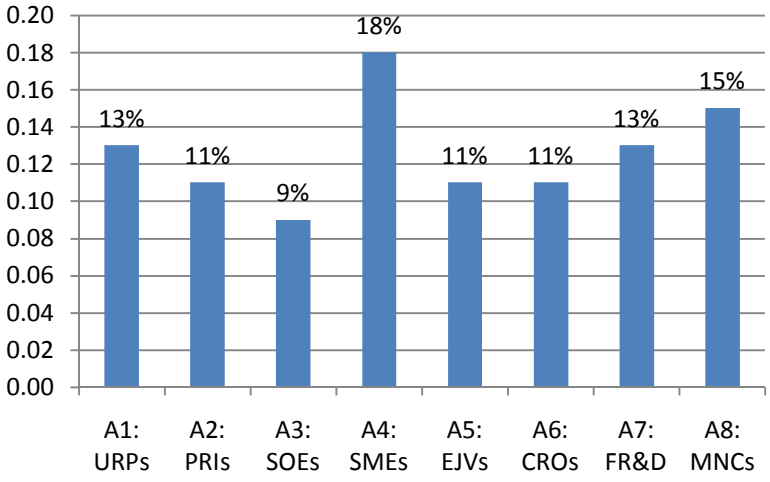


Figure 37: Contribution of Resources to Mission

From the above results, we can observe that A4 High-tech SMEs contributed about 18% and ranked first toward the overall mission, indicating its important position in technological innovation. A8 MNCs ranked second in overall contribution at 15%. Lastly, A3 SOEs are ranked surprisingly low with 9% in overall contribution, indicating an area for improvement in terms of innovative performance.

There are several reasons for high-tech SMEs to rank the highest. Firstly, biotech SMEs have a higher contribution toward indigenous innovation. After a burst of growth for 20 years, SMEs have become the mainstay players in China's biopharmaceutical sector. China is now home to more than 700 biopharmaceutical companies, among which over 500 are small enterprises with net assets of less than US$10 million [303] [304]. The capabilities of these SMEs have a significant impact on China's indigenous innovation. Secondly, SMEs contribute more toward the imitative innovation strategy, which has been identified as the most preferred strategy in China's biopharmaceutical sector today. As discussed in the above sections, biotech SMEs are more flexible and efficient in product development. They have cost advantages and are more focused in specialty high-tech areas. Thirdly, SMEs contribute more toward collaborative innovation. Due to limited scale, biotech SMEs actively cooperate with other players for complementary resources. The areas of cooperation include all aspects such as financial investment, joint research, and production.

Multinational companies and subsidiaries ranked second toward the overall mission, indicating that foreign investments are important sources in China's current innovation ecosystems. Firstly, MNCs ranked very high in terms of international technology transfer. These companies have brought some of the latest technologies into the local market.

MNCs played important roles in upgrading the local industrial structure during the last two decades. Secondly, MNCs also ranked high for indigenous innovation. MNCs are expected to lead the way for the innovative biopharmaceutical industry in China [298]. Through demonstration effects, MNCs set the industrial standards according to internationally accepted practice. Employee training and turnovers also benefited the domestic players in the long run [160]. In fact, without the open door policy and foreign investment from MNCs, the local industries would not have achieved what is happening today. Therefore, it can be predicted that the presence of MNCs will continue to contribute to technological innovations in China.

5.2 Measurement of Disagreement

It is natural to have different opinions among the experts during the research process. The diverse social backgrounds and working experiences of the experts may cause significant differences in opinions or perspectives toward any research topic. This section addresses such disagreement issues at each level of the research model.

According to the methdology illustrated in Section 3.6, the intraclass correlation coefficient R_{IC} was calculated to measure the disagreement among experts. Shrout and Fleiss (1979) developed a statistical procedure to test the hypothesis about whether or not there is an absolute disagreement among the judges [271]. F-test was applied in the calculation process. The application of this methodology on HDM was first done by N. Gerdsri (2004), and expanded by P. Gerdsri (2009) [210, 211] [208, 209].

5.2.1 Technology Level

Referring to the data presented in Section 5.1.1, the following hypothesis was tested for disagreement among the experts:

H_0: $R_{IC} = 0$ there is disagreement

H_1: $R_{IC} > 0$ there is statistically significant evidence that there is some level of agreement

The calculation process of the intraclass correlation coefficient and F-test was done through SPSS software (Appendix E). The results are shown in Table 35.

The coefficient for the ten experts in Group A is 0.67, and for Group B it is 0.57. Both values are relatively high (scale 0 to 1). Therefore, it can be argued that there is high agreement among the group of experts. F-test was further applied to approve this argument. The process was done through computing the F_{BS} value and comparing it to the F-critical value. The F_{BS} value of Group A is 18.08. The F-critical with $df_1 = 6$ and $df_2 = 6*9 = 54$ at the 0.01 level is less than 3.29. While $df_2 = 54$ is not provided in the table, an even larger value of $df_2 = 40$ is used. This is a more conservative value which makes it more difficult to obtain significance. Since the F_{BS} value is larger than F-critical (0.01), the null hypothesis can be rejected. This result confirms that there is statistically significant agreement in Group A at F-test 0.01 level. Similarly, the F_{BS} value of Group B is 12.11, which is also larger than F-critical (0.01); the null hypothesis is also rejected. The result confirms that significant agreement exists in Group B at F-test 0.01 level.

	P-value	F_{BS}	$F_{critical}(0.01)$	F-test Results
Group A	<0.001	18.08	3.29	H_0 rejected at 0.01 level
Group B	<0.001	12.11	3.29	H_0 rejected at 0.01 level

Table 35: Calculation of Disagreement at the Technology Level

Since the null hypotheses in both tables were rejected at the 0.01 level, we may conclude that the experts reached a very high level of agreement for the technology level. Although the experts come from different sources and have different backgrounds, their perceptions about prospective technology areas for China are very similar.

5.2.2 Strategy Level

Referring to the data presented in Section 5.1.2, the intraclass correlation coefficient and F-test were calculated for the strategy level (Table 36). The results show that R_{IC} coefficients range from 0.20 to 0.49, indicating that a certain degree of agreement exists among the experts in all examined technology areas. F-test was further applied to compare the F_{BS} value and the F-critical value with $df_1 = 3$ and $df_2 = 21$. As we examine the results from Table 36, the results have the following features:

1) All of the F_{BS} values are larger than F-critical at the 0.1 level. This means disagreements among experts for all technology areas can be rejected at the 0.1 level.

2) There are 11 of 13 technology areas where the F_{BS} value is larger than F-critical (0.05). This indicates that the disagreements for these 11 areas can be rejected at the 0.05 level. The two exceptions are T4 Cell and Tissue Engineering and T12 Gene Sequencing, where the values of F_{BS} are smaller than the F-critical (0.05). The results indicate that disagreements for these two areas cannot be rejected at the 0.05 level.

3) There are four technology areas, where the F_{BS} values are larger than the F-critical (0.01), indicating that disagreements for these four areas can be rejected at the 0.01 level. These areas include T1 Recombinant Therapeutic Proteins, T2 Recombinant Vaccines,

T5 Gene Therapy, and T8 Nanobiotechnology. For the remaining nine technology areas, where the F_{BS} values are smaller than the F-critical (0.01), disagreements cannot be rejected at this highest level at 0.01.

	P-value	F_{BS}	$F_{critical}(0.01)$	F-test results
T1	0.002	6.80	4.87	H_0 rejected at 0.01 level
T2	0.003	6.21	4.87	H_0 rejected at 0.01 level
T3	0.011	4.79	4.87	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level
T4	0.084	2.53	4.87	H_0 rejected at 0.1 level, but cannot be rejected at 0.05 level
T5	0.008	5.16	4.87	H_0 rejected at 0.01 level
T6	0.023	3.89	4.87	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level
T7	0.015	4.41	4.87	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level
T8	0.009	4.94	4.87	H_0 rejected at 0.01 level
T9	0.015	4.36	4.87	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level
T10	0.029	3.67	4.87	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level
T11	0.022	3.96	4.87	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level
T12	0.058	2.92	4.87	H_0 rejected at 0.1 level, but cannot be rejected at 0.05 level
T13	0.022	3.94	4.87	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level

Table 36: Calculation of Disagreement at the Strategy Level

When compared with the technology level, the strategy level has more disagreement issues. Although all null hypotheses can be rejected at the 0.1 level, the degree of agreement is relatively low. In many available studies, the 0.05 level has been used as a medium range. However, in the above results, two technology areas are still below the medium level. Moreover, most technology areas cannot reach the highest 0.01 level. Therefore, more discussions are needed below.

5.2.2.1 Contribution of Strategies to T4 Cell and Tissue Engineering

In Table 36, we can see that T4 Cell and Tissue Engineering has a F_{BS} value of 2.53 which is less than the F-critical at 0.05 level (3.07). This indicates that as a whole group, the experts' disagreement cannot be rejected at the medium level. In this section, the experts' judgmental data will be reevaluated in subgroups for R_{IC} and F-test. The results are illustrated in Table 37:

T4	P-value	F_{BS}	$F_{critical}(0.01)$	F-test results
Subgroup-G	0.023	6.81	9.78	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level
Subgroup-F	0.030	6.03	9.78	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level
Subgroup-L	0.043	10.32	29.5	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level

Table 37: Subgroup Analysis on T4 Cell and Tissue Engineering

5.2.2.2 Contribution of Strategies to T12 Gene Sequencing

Another area that has higher disagreement (cannot be rejected at the 0.05 level) is T12 Gene Sequencing. Following a similar process, the data was reevaluated in expert subgroups. The results are presented in Table 38:

T12	P-value	F_{BS}	$F_{critical}(0.01)$	F-test results
Subgroup-G	0.041	5.24	9.78	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level
Subgroup-F	0.048	4.88	9.78	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level
Subgroup-L	0.041	10.79	29.5	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level

Table 38: Subgroup Analysis on T12 Gene Sequencing

The above analyses provides positive results. The disagreement values among experts within subgroups improved to have values higher than the 0.05 level. This is true

for both T4 and T12. This also indicates that there are certain differences of opinion among subgroups which need more exploration.

5.2.3 Variance among Subgroups

Due to the disagreement issues raised in the above analyses, this section further explores the different perspectives of the three expert subgroups. Tables with disagreements that cannot be rejected at the 0.01 level will be reexamined based on each expert's judgmental rankings.

5.2.3.1 Subgroup-G

There are 9 technology areas where disagreements cannot be rejected at the 0.01 level. The judgmental rankings of Subgroup-G experts were first pulled out and examined in Table 39. These experts have backgrounds in government agencies. The rankings range from 1 – 4, meaning from the highest to the lowest. A smaller mean value in the bottom row means a higher average ranking.

Exp4	S1	S2	S3	S4
T3	2	1	3	4
T4	1	2	3	4
T6	1	1	3	4
T7	1	1	3	4
T9	2	1	3	4
T10	1	2	3	4
T11	2	1	3	4
T12	1	2	3	4
T13	1	1	3	4
Mean	1.3	1.3	3.0	4.0

Exp6	S1	S2	S3	S4
T3	3	1	2	4
T4	3	1	2	4
T6	4	1	2	3
T7	4	1	2	3
T9	1	3	2	4
T10	3	1	2	4
T11	3	1	3	2
T12	2	1	3	4
T13	4	1	3	2
Mean	3.0	1.2	2.3	3.3

Exp16	S1	S2	S3	S4
T3	1	2	3	4
T4	1	2	3	4
T6	2	1	3	4
T7	2	1	4	3
T9	1	2	3	4
T10	1	2	3	4
T11	2	1	3	4
T12	2	1	3	4
T13	2	1	3	4
Mean	1.6	1.4	3.1	3.9

Table 39: Subgroup-G Ranking Analysis

The results reveal that Subgroup-G experts tend to give the highest rank to S2 Imitative Innovation Strategy. They tend to give a lower rank to S4 International Technology Transfer. Expert4 and Expert16 also tend to give a higher rank to S1 Indigenous Innovation.

5.2.3.2 Subgroup-F

The individual judgmental rankings of Subgroup-F experts are presented in Table 40. These experts have backgrounds or interests from various foreign organizations.

Exp12	S1	S2	S3	S4
T3	1	2	3	4
T4	3	2	1	4
T6	4	1	1	1
T7	3	2	1	4
T9	4	1	2	3
T10	1	4	2	3
T11	2	3	1	4
T12	4	1	2	3
T13	4	1	2	2
Mean	2.9	1.9	1.7	3.1

Exp15	S1	S2	S3	S4
T3	4	3	1	2
T4	3	4	1	2
T6	2	4	1	3
T7	3	4	1	2
T9	2	4	1	2
T10	2	4	1	2
T11	2	3	1	4
T12	4	3	1	2
T13	3	3	1	2
Mean	2.8	3.6	1.0	2.3

exp19	S1	S2	S3	S4
T3	2	3	1	4
T4	2	4	1	3
T6	4	2	1	3
T7	2	3	1	4
T9	3	1	2	4
T10	1	3	2	4
T11	3	2	1	3
T12	4	2	1	3
T13	4	2	1	3
Mean	2.8	2.4	1.2	3.4

Table 40: Subgroup-F Ranking Analysis

The above information reveals that Subgroup-F experts tend to give a higher rank to S3 Collaborative Innovation Strategy. Among others, expert15 ranks S3 as the first priority for all technology areas.

5.2.3.3 Subgroup-L

The individual judgmental rankings of Subgroup-L experts were pulled out and are presented in Table 41. These are experts from the local industry or domestic research organizations (non-government and without foreign backgrounds).

Exp11	S1	S2	S3	S4
T3	2	1	3	4
T4	4	1	2	3
T6	4	1	2	3
T7	4	1	2	3
T9	3	1	2	3
T10	4	1	2	3
T11	4	1	2	3
T12	4	1	2	3
T13	4	1	3	2
Mean	3.7	1.0	2.2	3.0

Exp20	S1	S2	S3	S4
T3	2	1	3	4
T4	4	1	2	3
T6	2	1	3	4
T7	2	1	3	4
T9	3	1	2	4
T10	1	3	2	4
T11	2	1	3	4
T12	4	1	2	3
T13	4	1	2	3
Mean	2.7	1.2	2.4	3.7

Table 41: Subgroup-L Ranking Analysis

The above results indicate that Subgroup-L experts tend to give a higher rank to S2 Imitative Innovation Strategy. For example, Expert11 ranked S2 as the first priority for all technology areas. Another observation is that the experts are more likely to rank S3 Collaborative Innovation as the second highest option.

For the strategy level, the subgroup analysis confirms that experts from different subgroups tend to give different weight for different strategies. The experts showed certain tendencies in their judgments as a whole in terms of subgroups. These tendencies caused some disagreements in the last section. The reasons for such disagreements were investigated during the result validation stage, which will be discussed in the next chapter.

5.2.4 Resource Level

Referring to the data presented in Section 5.1.3, the intraclass correlation coefficient was calculated and F-test was applied for the resource level. The results show that R_{IC} coefficients range from 0.12 to 0.42, indicating that agreement exists among the experts in all examined tables. F-test was carried out to test the F_{BS} value, and the F-critical value at $df_1 = 7$ and $df_2 = 56$. Since $df_2 = 56$ is not provided in the table, an even larger value of $df_2 = 40$ is used. This is because we always act conservatively and choose a larger value, which makes it more difficult to obtain significance.

As we examine the data from Table 42, the results show that F_{BS} values are larger than the F-critical (0.01) for S1 Indigenous Innovation, S2 Imitative Innovation, and S4 International Technology Transfer. This indicates that disagreements can be rejected at the 0.01 level in these tables. For S3 Collaborative Innovation, $F_{BS} = 2.44$ is larger than the F-critical (0.05) = 2.25, but smaller than the F-critical (0.01) = 3.12. Therefore, the null hypothesis can be rejected at the 0.05 level, but it cannot be rejected at the 0.01 level.

	P-value	F_{BS}	$F_{critical}(0.01)$	F-test Results
S1	<0.001	4.94	3.12	H_0 rejected at 0.01 level
S2	<0.001	6.76	3.12	H_0 rejected at 0.01 level
S3	0.030	2.44	3.12	H_0 rejected at 0.05 level, but cannot be rejected at 0.01 level
S4	<0.001	6.40	3.12	H_0 rejected at 0.01 level

Table 42: Calculation of Disagreement at the Resource Level

The above results indicate that the contribution of resource alternatives toward collaborative innovation has an acceptable but slightly higher disagreement level (0.05 level). A careful analysis of the data reveals that expert 14 has a very different judgement

when compared to others. This expert gave a higher priority value for A8 MNCs but a lower value for A4 SMEs. The researcher contacted the experts to verify their judgemental inputs. They were confident about their judgements and confirmed that the judgemental values represented their opinion regarding the issue. Expert 14 chose to retain the original judgement and provided a website to the researcher for more information. The website of this MNC clearly indicates that a dedicated organization for collaboration and partnering was established in 2009. The Chinese branch is one of the four global collaboration centers, while the other three are located in the US, EU, and Japan respectively. This fact explained the disaggreement with others. The existance of disagreement reveals that even though these experts all have foreign backgrounds, they may disagree with each other since they came from different companies or institutions.

5.2.5 Summary on Disagreement Analysis

The experts have very low disagreement in the judgment of technology level toward mission. It is within a very high acceptable level of 0.01. However, the experts have a certain level of disagreement regarding the strategies. By using subgroup analysis, we found that there are lower disagreements within subgroups. The analysis also revealed the trend of disagreement among subgroups. These disagreements were mainly caused by the different backgrounds of the subgroups. For the resource level, the only area with higher disagreement is about collaborative innovation. Through contacting the experts, the disagreement was explained by the organizational differences.

Instead of trying to eliminate subjectivity and smooth out the differences, it is more important to understand the disagreement. Assessment of disagreement among experts at

each level of the model gives valuable insight on the expert's position on the issues and provides even more useful information for policy makers.

5.3 Sensitivity Analysis

Since judgments involve subjectivity, the input data always bring uncertainty. Sensitivity analysis is necessary to test the robustness and stability of the results. There are several types of methods for carrying out sensitivity analysis on a hierarchical decision model, including: numerical incremental analysis, simulations, and mathematical deduction. Numerical incremental analysis is an iteration-based process where different numerical values are applied to the model to test corresponding changes in the ranking orders of the decision alternatives. The simulation method can be done through software packages such as Crystal Ball. However, the probabilistic input may return in stochastic output, which is undeterministic in nature. The method is more suitable to verify the results, but not to conduct the sensitivity analysis.

This study utilizes the sensitivity analysis algorithm for HDM developed in Chen's dissertation and Kocaoglu's research [272] [273]. This is a mathematical deduction type method to examine the impact of changes in different levels. The algorithm has been applied to the criteria level, which is the technology level. The purpose is find how changes in the technology areas will impact the rankings of innovation resources. Here the known conditional figures have been adapted from previous matrix calculations in the results discussion section (Table 43 and 44).

	A1: URPs	A2: PRIs	A3: SOEs	A4: SMEs	A5: EJVs	A6: CROs	A7: FR&D	A8: MNCs
Contribution	0.1279	0.1096	0.0861	0.1821	0.1127	0.1130	0.1257	0.1462
Ranking	3	7	8	1	6	5	4	2

Table 43: Contribution and Ranking of the Input Resources to the Mission

	A1: URPs	A2: PRIs	A3: SOEs	A4: SMEs	A5: EJVs	A6: CROs	A7: FR&D	A8: MNCs
T1	0.1258	0.1078	0.0847	0.1802	0.1135	0.1122	0.1282	0.1509
T2	0.1256	0.1086	0.0828	0.1806	0.1136	0.1130	0.1286	0.1500
T3	0.1318	0.1118	0.0862	0.1867	0.1115	0.1122	0.1232	0.1404
T4	0.1270	0.1094	0.0865	0.1810	0.1129	0.1138	0.1258	0.1467
T5	0.1300	0.1110	0.0865	0.1845	0.1120	0.1130	0.1240	0.1425
T6	0.1290	0.1101	0.0884	0.1827	0.1122	0.1133	0.1239	0.1440
T7	0.1286	0.1101	0.0870	0.1827	0.1124	0.1133	0.1247	0.1446
T8	0.1292	0.1100	0.0879	0.1831	0.1122	0.1128	0.1242	0.1443
T9	0.1304	0.1111	0.0864	0.1850	0.1119	0.1127	0.1239	0.1422
T10	0.1254	0.1086	0.0848	0.1797	0.1135	0.1138	0.1276	0.1494
T11	0.1280	0.1096	0.0870	0.1820	0.1126	0.1132	0.1252	0.1458
T12	0.1260	0.1087	0.0881	0.1793	0.1131	0.1143	0.1257	0.1479
T13	0.1274	0.1092	0.0882	0.1809	0.1127	0.1136	0.1250	0.1464

Table 44: Intermediate Matrix of Input Resources to Technology

For $n = 1$ and $r = 1$, based on the definition $-o_{l^*} < \varepsilon_{l^*} < \sum_{l=1, l\neq l^*}^{L} o_l$, we have the following calculations:

$$-0.14 < \varepsilon_1 < 0.86$$

$$C_0 = a_1 - a_2 = 0.1821 - 0.1462 = 0.0359$$

$$C_1 = a_{2,1} - a_{1,1} - \sum_{l=2}^{13} a_{2,1} \times \frac{o_l}{\sum_{l=2}^{13} o_l} + \sum_{l=2}^{13} a_{1,1} \times \frac{o_l}{\sum_{l=2}^{13} o_l}$$

$$= 0.1509 - 0.1802 - 0.1454 + 0.1825$$

$$= 0.0077$$

$$\frac{C_0}{C_1} = \frac{0.0359}{0.0077} = 4.658$$

We can obtain that $\varepsilon_1 \le 4.658$

Repeating the similar calculation steps for $n = 1$ and $r = 2, 3..., 7$ we get the following allowable range of ε_1.

$-0.14 < \varepsilon_1 < 0.86$
$\varepsilon_1 \le 4.658 \quad (When\, r = 1, n = 1)$
$\varepsilon_1 \ge -2.34 \quad (When\, r = 2, n = 1)$
$\varepsilon_1 \le 4.407 \quad (When\, r = 3, n = 1)$
$\varepsilon_1 \ge -3.29 \quad (When\, r = 4, n = 1)$
$\varepsilon_1 \le 0.172 \quad (When\, r = 5, n = 1)$
$\varepsilon_1 \ge -1.05 \quad (When\, r = 6, n = 1)$
$\varepsilon_1 \le 5.441 \quad (When\, r = 7, n = 1)$

By finding out the intersection of the above inequality sets, we can obtain the perturbation of the weight of the chemical pharmaceutical technology:

$-0.14 \le \varepsilon_1 \le 0.172$

The allowable range of the perturbation on O_l is denoted as $[\delta_{1l}, \delta_{2l}]$, and the tolerance of O_l is defined as $[\delta_{1l} + o_l, \delta_{2l} + o_l]$. From the calculations above, we can calculate the result that the tolerance of O_l, which is T1 Recombinant Therapeutic Proteins, to keep the current ranking of all the input resources is [0, 0.312]. In the HDM Sensitivity Analysis algorithm [272], the sensitivity coefficient for O_l is defined as:

$$sens(O_l) = \frac{1}{|\delta_{1l} - \delta_{2l}|}$$

After repeating similar steps for each technology area, the results of calculations are summarized in Table 45. The related explanations are explained in Table 46.

Criteria	Range of Perturbations	Tolerance of Weights	Sensitivity Coefficient
T1: Recombinant Therapeutic Proteins	[-0.14, 0.172]	[0, 0.312]	3.205
T2: Recombinant Vaccines	[-0.13, 0.306]	[0, 0.436]	2.293
T3: Monoclonal Antibody	[-0.13, 0.794]	[0, 0.924]	1.082
T4: Cell & Tissue Engineering	[-0.06, 0.94]	[0, 1]	1
T5: Gene Therapy	[-0.06, 0.94]	[0, 1]	1
T6: Antisense Therapy	[-0.04, 0.96]	[0, 1]	1
T7: RNAi	[-0.05, 0.95]	[0, 1]	1
T8: Nano-biotechnology	[-0.07, 0.93]	[0, 1]	1
T9: Synthetic Biology	[-0.05, 0.95]	[0, 1]	1
T10: Bioinformatics	[-0.06, 0.464]	[0, 0.524]	1.908
T11: Pharmaco-genetics	[-0.06, 0.94]	[0, 1]	1
T12: Gene Sequencing	[-0.07, 0.93]	[0, 1]	1
T13: Biotech Diagnostics	[-0.08, 0.92]	[0, 1]	1

Table 45: Sensitivity Analysis on Technologies to the Ranks of Input Resources

The most critical criterion for keeping the current ranking of input resources corresponds to the technology area with the biggest sensitivity coefficient. As seen in the results, T1 Recombinant Therapeutic Proteins is determined as the most critical criterion among the technology areas in keeping current resource rankings, followed by T2 Recombinant Vaccines. T1 Recombinant Therapeutic Proteins contributes the most toward the overall mission, and at the same time it is also the most critical technology area to keep the current rankings of resources.

Criteria	Tolerance of Weights	Descriptions
T1: Recombinant Therapeutic Proteins	[0, 0.312]	When the weight of T1 changes to a value larger than 0.312, the contribution of Joint Ventures will surpass CROs to become the 5th. When the changes are within the range from 0 to 0.312, the ranks of the input resources remain the same.
T2: Recombinant Vaccines	[0, 0.436]	When the weight of T2 is larger than 0.436, the contribution of Foreign R&D Centers will surpass University Research Programs to become the 3rd. When the changes are within the range from 0 to 0.436, the ranks of the input resources remain the same.
T3: Monoclonal Antibody	[0, 0.924]	When the weight of T3 changes to a value larger than 0.924, the contribution of Joint Ventures will surpass CROs to become the 5th. When the changes are within the range from 0 to 0.924, the ranks of the input resources remain the same.
T10: Bioinformatics	[0, 0.524]	When the weight of T10 is larger than 0.524, the contribution of Foreign R&D Centers will surpass University Research Programs to become the 3rd. When the changes are within the range from 0 to 0.524, the ranks of the input resources remain the same.

Table 46: Explanation of the Results of Sensitivity Analysis

Sensitivity analysis gives more information on how changes in upper level criteria can impact on lower level alternatives. In this case, the overall results are not very sensitive to changes, especially for the top-ranked strategy criteria and resource alternatives. This is primarily due to the high priority in favor of imitative innovation strategies for most technology areas and high contribution of certain resources (SMEs and MNCs) toward strategies. The results have demonstrated the process of how to assess the impact of technology changes on the resource rankings. Sensitivity analysis is a useful supplemental tool for policy makers to explore the relationships of the decision criteria.

Chapter 6 – Discussions and Recommendations

Based on the data analysis and expert feedback, this chapter focuses on the discussions and policy recommendations. During the result validation process, aggregated results and a short summary regarding the disagreement issues were sent to the expert panel for further review. The experts were asked to validate the findings of this research. They provided valuable feedback and opinions, which largely facilitated the following discussions and recommendations. These findings are summarized in several major aspects according to each level of the model, including: 1) prospective technology areas, 2) technology development strategies, and 3) innovation resources. Table 47 illustrates the main results from the data analysis.

6.1 Prospective Technology Areas

With achieving technological competitiveness and sustained innovation as the mission, this research examines a number of prospective technology areas in the biopharmaceutical industry. Although the experts come from different backgrounds, they have reached a high level of agreement in their judgments. The results can be classified under three categories: high >10%, medium 6%-10%, and low 1%-5% (Table 47).

6.1.1 High Priority Technology Areas

The "high" category is defined where the contribution is larger than 10%. These are the technology areas that should be China's highest priorities for R&D. The

recommended areas include T1 Recombinant Therapeutic Proteins, T2 Recombinant Vaccines, and T3 Monoclonal Antibody Technology.

Category	Prospective Technology Areas	Preferred Technology Development Strategies	Preferred Innovation Resource Alternatives (Top Three)
High >10%	T1: Recombinant therapeutic proteins	S2: Imitative Innovation	1. High-tech Small-to-Medium Enterprises 2. University Research Programs 3. Public Research Institutes
	T2: Recombinant vaccines	S1: Indigenous Innovation	1. MNCs and Subsidiaries 2. High-tech Small-to-Medium Enterprises 3. Foreign R&D Centers
	T3: Monoclonal antibody technology	S2: Imitative Innovation	1. High-tech Small-to-Medium Enterprises 2. University Research Programs 3. Public Research Institutes
Medium (6-10)%	T4: Cell and tissue engineering	S2: Imitative Innovation	1. High-tech Small-to-Medium Enterprises 2. University Research Programs 3. Public Research Institutes
	T5: Gene therapy	S2: Imitative Innovation	1. High-tech Small-to-Medium Enterprises 2. University Research Programs 3. Public Research Institutes
	T8: Nano-biotechnology	S2: Imitative Innovation	1. High-tech Small-to-Medium Enterprises 2. University Research Programs 3. Public Research Institutes
	T10: Bioinformatics	S1: Indigenous Innovation	1. MNCs and Subsidiaries 2. High-tech Small-to-Medium Enterprises 3. Foreign R&D Centers
	T11: Pharmaco-genetics	S2: Imitative Innovation	1. High-tech Small-to-Medium Enterprises 2. University Research Programs 3. Public Research Institutes
	T12: Gene sequencing	S2: Imitative Innovation	1. High-tech Small-to-Medium Enterprises 2. University Research Programs 3. Public Research Institutes
	T13: Biotechnology Diagnostics	S2: Imitative Innovation	1. High-tech Small-to-Medium Enterprises 2. University Research Programs 3. Public Research Institutes
Low (1-5)%	T6: Antisense therapy	S2: Imitative Innovation	1. High-tech Small-to-Medium Enterprises 2. University Research Programs 3. Public Research Institutes
	T7: RNAi	S2: Imitative Innovation	1. High-tech Small-to-Medium Enterprises 2. University Research Programs 3. Public Research Institutes
	T9: Synthetic biology	S2: Imitative Innovation	1. High-tech Small-to-Medium Enterprises 2. University Research Programs 3. Public Research Institutes

Table 47: Summary of Findings

For T1 Recombinant Therapeutic Proteins, the preferred strategy is imitative innovation. The ideal innovation resources include: high-tech SMEs, university research programs, and public research institutes. The development of recombinant proteins is well known to have relied on blockbuster revenue, primarily derived from 16 brands. For example, Amgen's blockbusters Enbrel, Neulasta and Aranesp are the sector's key leading blockbusters, with combined sales of more than US$10.8billion in 2010. The expected growth during 2012-2014 will be around 13% [305]. Hematology, diabetes, endocrinology and oncology are the most valuable therapy areas for recombinant proteins. Taking the imitative innovation strategy means that China should focus on developing biosimilars in this area; and biotech SMEs, Universities, and Research Institutes should play more important roles.

For T2 Recombinant Vaccines, the preferred strategy is indigenous innovation. The recommended innovation leaders include: MNCs and subsidiaries, high-tech SMEs, and foreign R&D centers. Vaccines are among the most lucrative segments in the global pharmaceutical market. With an average growth of over 13% during 2009-2012, the global market for human vaccines is forecasted to reach US$32 billion by the year 2017 [306]. The US and EU are the two largest vaccine markets in the world. The vaccine market in China has the potential to record phenomenal growth in the coming years. The growth rate will be around 20% and its size will reach CNY 12 billion by 2013 [296]. The quantity and the variety of vaccines produced in China are similar to those of developed countries, but China needs to improve the production capability and critical technology in order to produce higher quality vaccines [279]. Taking the indigenous innovation strategy indicates that China should develop more novel products, and focus

on the improvement of local competence. For such a purpose, innovation resources like multinationals and subsidiaries, biotech SMEs, and Foreign-invested R&D centers can take the lead.

For T3 Monoclonal antibody technology, the preferred strategy is imitative innovation. The recommended innovation leaders include: high-tech SMEs, university research programs, and public research institutes. In the global market, the antibody bandwagon has been joined by 200 companies with hundreds of new projects and targets that have attracted billions of dollars in R&D investment, acquisitions and licensing deals leading to monoclonal antibody [277]. The total global monoclonal antibody (mAb) sales are forecasted to reach US$49 billion by 2013. The "big five" mAbs – Avastin, Herceptin, Rituxan, Humira, and Remicade – have dominated the market, cornering almost 80 percent of sales [297]. There has been a great gap between China and Western countries in the research, development and manufacture of monoclonal antibody drugs [307]. Since the imitative innovation strategy has a higher priority, China should focus on the development of biosimilars, especially for the blockbuster drugs. Ideally, biotech SMEs, Universities, and Research Institutes should play more important roles in this process.

6.1.2 Medium Priority Technology Areas

The "medium" category is defined as being where the contribution ranges from 6% to 10%. These technology areas are recommended as medium priorities for China to carry out R&D. This list consists of seven technology areas including T4 Cell and tissue engineering, T5 Gene therapy, T8 Nanobiotechnology, T10 Bioinformatics, T11 Pharmacogenetics, T12 Gene sequencing, and T13 Biotechnology Diagnostics.

For T4 Cell and tissue engineering, the preferred strategy is imitative innovation. The recommended innovation leaders include: high-tech SMEs, university research programs, and public research institutes. According to market reports, there are more than 60 tissue engineering products in the global market and about 30 in clinical trials. China's biomedical materials industry is largely driven by foreign technology, and domestic companies accounted for a mere 3% of global market share in 2011 [308]. By following the imitative innovation strategy, China should focus on catching up with the advanced countries. The results suggest that biotech SMEs, Universities, and Research Institutes should play more important roles.

For T5 Gene therapy, the preferred strategy is imitative innovation. The recommended innovation leaders include: high-tech SMEs, university research programs, and public research institutes. Gene therapy is a high-tech area with very few available products. However, there about 80 gene therapies are in clinical trials [281]. Many experts believe that gene therapy will play a significant role in future medical treatment. The research recommends imitative innovation strategy, indicating that China should focus on learning from advanced countries. The results also suggest that biotech SMEs, Universities, and Research Institutes play more important roles.

For T8 Nanobiotechnology, the preferred strategy is imitative innovation. The recommended innovation leaders include: high-tech SMEs, university research programs, and public research institutes. The applications of nanobiotechnology in the biomedical field are principally directed towards development of novel drug delivery systems. According to a market report in 2012, the global nanobiotechnology market will reach $6.0 billion by 2017 [309]. As a catching up country in this area, it is recommended that

China follow the imitative innovation strategy. The results also suggest that biotech SMEs, Universities, and Research Institutes should play more important roles in the process.

For T10 Bioinformatics, the preferred strategy is indigenous innovation. The recommended innovation leaders include: MNCs and subsidiaries, high-tech SMEs, and foreign R&D centers. The applications in bioinformatics are increasingly powerful, allowing researchers to garner more knowledge about more complex organisms and systems. The worldwide bioinformatics market was estimated at US$3.0 billion in 2010, and the applications will continue to have very rapid growth to 2015 [281]. Today, bioinformatics research in China still lags behind the best in the world. There are relatively few applications for drug discovery in the domestic market [310]. Since the indigenous innovation strategy is recommended, China should focus on developing new applications in bioinformatics. To support this strategy, innovators such as MNCs, high-tech SMEs, and Foreign R&D centers can take the leading roles.

For T11 Pharmacogenetics, the preferred strategy is imitative innovation. The recommended innovation leaders include: high-tech SMEs, university research programs, and public research institutes. Pharmacogenetics is a prospective field that could lead to personalized medicines. According to market reports, the worldwide pharmacogenetics market was estimated at US$3.7 billion in 2009, but there will be a limited number of new pharmacogenetic products arriving on the market by 2015 [281]. The experts recommend the imitative innovation strategy, indicating that China should focus on catching up with advanced countries. The results also suggest that biotech SMEs, universities, and research institutes should play more important roles in this process.

For T12 Gene sequencing, the preferred strategy is imitative innovation. The recommended innovation leaders include: high-tech SMEs, university research programs, and public research institutes. Applications of gene sequencing technology will help researchers to find genes associated with human disease. China is catching up rapidly in the field of gene sequencing. The acquisition in 2012 of a California-based DNA sequencing company by a Chinese firm (BGI) led to wide concerns. Some American scientists, politicians and industry executives said the takeover represented a threat to American competitiveness in DNA sequencing [311]. So far, the experts in this research still recommend an imitative innovation strategy, where biotech SMEs, Universities, and Research Institutes should take the lead in China's catching-up process.

For T13 Biotechnology Diagnostics, the preferred strategy is imitative innovation. The recommended innovation leaders include: high-tech SMEs, university research programs, and public research institutes. The diagnostics market was estimated at $ 52.4 billion in 2012, and it is expected to grow at a rate of 7% during 2012-2017 [312]. Roche Diagnostics is the dominant leader with 20% market share. Nine of the world's top 15 firms are based in the United States. Other firms are based in either Europe or Japan. In this research, the experts recommend an imitative innovation strategy for China. The country should focus on catching up with advanced countries. The results suggest that biotech SMEs, universities, and research institutes play more important roles in this process.

6.1.3 Low Priority Technology Areas

The "low" category is where the contribution is equal to or less than 5%. These technology areas are regarded as having lower priorities for China. This list consists of three technology areas including T6 Antisense therapy, T7 RNAi, and T9 Synthetic biology.

The above three technology areas have one thing in common: there are still very few or even no approved applications in the market today. However, these drugs have good prospects in that some candidate drugs are already in clinical trials [281]. The related studies in China are still in initial stages. The experts recommend an imitative innovation strategy for all three technology areas. China should focus on catching up with advanced countries. The results also suggest that biotech SMEs, universities, and research institutes should play more important roles in this process.

6.1.4 Summary on Prospective Technology Areas

The research results of technology levels highlights the directions for investment and improvement. For most of the above discussed high-tech areas, the Unites States is the dominant leader worldwide. Research has shown that American academic publications and patents comprise more than 40% of the world. China and some major European countries belong to the second tier in these areas. As a latecomer country in the biopharmaceutical industry, China's innovation capabilities have been steadily growing since the mid 1990s. However, China's technology level is still lagging behind the world's leading standard, and the country needs to take a learning position as discussed in

the above analyses. In order to accelerate the catching-up process, the government's role of long-term investment in these identified areas cannot be overemphasized.

6.2 Technology Development Strategies

Any static strategy is often less effective for latecomer countries since competitive advantage could be accumulated through multiple approaches or sources. From an industrial perspective, a country's technology strategies need to be dynamic for its unique but changing developmental contexts. Therefore, policy makers should adopt a comprehensive approach to technology strategy using all possible resources, and engage various stakeholders in the process of technology development. Such an approach entails decision makers becoming more involved in governance initiatives to improve the innovation environment, or scaling their influence over the relevant high-tech areas for the long-term innovation goals. This involves balancing various technology development strategies to build up industrial innovation capacity for competitiveness and future success.

6.2.1 Imitative Innovation and Biosimilars

Accumulation of technological capacities to compete in the global market has become a major concern for China. The research brings to light that imitative innovation is still the best option to achieve such a purpose under the current conditions. The experts' judgments give high priority to imitative innovation (33%) in the development of biopharmaceutical technologies. This conforms to the fact that technology leaders in high-tech areas are mostly foreign enterprises, which mainly belong to the United States

and Western Europe. If the latecomers want to catch up with the technological frontiers, their strategies are likely to start from imitation. This has been the case for many of the East Asian economies – first for Japan, then for Taiwan, Korea and Singapore – and now for China [82]. The results of this research indicate that China's biopharmaceutical industry is at the stage of learning from advanced countries.

When discussing imitative innovation in the biopharmaceutical industry, biosimilars are topics that cannot be circumvented. Novel biologics are noted for their high production cost and expensive purchase prices. Biosimilars bring clear potential for payers in the emerging pharmaceutical or "pharmerging" markets, such as Brazil, India and China [302]. Developing biosimilar products is also a relatively low-risk strategy for newcomers entering the health biotech space and generating short-term revenues [313]. Of the approximate 150 approved originator biologic drugs on the market today, almost half of them have lost or are close to losing their patent protection. This provides an external condition for cheaper biosimilar products to enter the market and be available for consumers. However, under the current registration regime, biosimilar drugs and new biologic drugs are not treated with any differences in China. Both applications require the same process for clinical trials. Although the United States does not currently have related regulations, India and the European Union have developed abbreviated approval processes for biosimilar products [302]. China should consider adopting similar approaches to remove or lower the legislative hurdles for the development of biosimilars.

6.2.2 India's Experience in Pharmaceutical Development

The rise of India's pharmaceutical industry in the last few decades may provide some insight for other emerging economies. The Indian government adopted an imitative strategy in the pharmaceutical industry during the 1970s [314]. The weak IPRs regime fostered the development of domestic technology capabilities in that period. If an Indian domestic company could merely modify the manufacturing process of a foreign medicine, the company was allowed to produce the same product without patent infringement [315]. This strategy established low cost leadership advantage among local companies and increased domestic social welfare due to the lowered drug prices. It was remarkable achievement that new drugs can be introduced to India only within four to five years after their introduction in foreign countries. However, the negative effect was that most MNCs chose to leave the Indian market for afraid of patent infringement.

As a large number of medicines went off patent protection during the late 1980s, Indian medicines further experienced a rapid growth of exports to the world market. Moreover, an interesting effect was that the increased technological capabilities of Indian pharmaceutical companies have brought back the FDI from the Western developed countries. New joint ventures or R&D centers were setup mainly draw upon trained manpower and research infrastructure available in the country, despite the fact that the Indian patent regime did not provide strong patent protection [316]. By introduction and assimilation of advanced technologies from abroad, the Indian pharmaceutical companies have emerged as competitive suppliers in the world.

The Indian experience highlights the fact that government strategy may lead to industrial success. However, India's imitative strategy can no longer be duplicated by

other emerging economies because the global innovation environment has changed significantly in recent years. Many countries have joined WTO and endorsed the TRIPS Agreement, which requires strengthened IPR protection. Therefore, direct replication of foreign products will not be applicable, and even India has to make a change in recent years. Nowadays, emerging economies should focus on re-innovation or imitative innovation, which is beyond pure replication. In summary, the Indian experience in pharmaceutical development strengthened the findings in this research.

6.2.3 Indigenous Innovation, Collaborative Innovation, and Novel Drugs

Indigenous innovation strategy ranks second at 26%, followed by collaborative innovation strategy at 23%. These strategies cannot be overlooked as optional choices for China's current technology capabilities. China should try to develop its indigenous strengths and also collaborate with leading countries. In most technology areas, China belongs to the second cohort among the worldwide biopharmaceutical communities. Therefore, the country cannot afford to totally rely on indigenous innovation. The open-door policy in the last 30 years has proven that foreign elements are extremely important resources for the local industries. China would not have achieved the current technology level if the doors were closed for FDI and MNCs. As a long term goal, indigenous innovation strategy should be encouraged in China. Past experiences from other countries have repeatedly demonstrated that an emerging economy will ultimately move from the imitative stage to the innovative stage [82].

Although the collaborative innovation strategy did not rank the highest for any specific technology areas, it has been regarded as an increasingly important strategy in

recent years. In reality, some industrial players have come up with new channels to develop novel drugs through bridging collaborative and indigenous innovation. For example, Chinese-based SinoPharm struck a cooperation deal with American-based Harbor Biosciences to develop novel drugs in the area of therapeutic protein drugs. The two sides share resources in terms of financial investment, technology know-how, and research facilities. Regarding the research outcomes, SinoPharm has exclusive rights in China, while Harbor Biosciences maintains rights in other countries. This type of collaboration is very attractive to both parties: the foreign player benefits from lowered investment and more research resources, while the Chinese player is able to gain access to advanced R&D techniques and essentially obtain their very own novel drugs [298] [300].

6.2.4 International Technology Transfer

Compared with other strategies, international technology transfer ranks relatively low in the overall contribution toward mission. MNCs and Foreign R&D Centers are the major contributors for this strategy. The Chinese industries have benefited substantially from international technology transfer deals during the 1980s and 1990s. The MNCs transferred many technologies which helped China to upgrade its industries. However, as local technology capability matured, the reliance on foreign technologies decreased. In recent years, there have been many cases where foreign companies began acquiring domestic firms or technologies [304]. International technology transfer deals no longer travel in one direction from abroad to local, but also from home to abroad. Nevertheless, in high-tech areas such as the biopharmaceutical industry, foreign players still play more

important roles in international technology transfer in China. From a government perspective, China needs to establish effective macro-level technology policies to guide and promote technology transfer activities in high-tech areas.

6.2.5 Disagreement on Technology Development Strategies

The experts' judgments recorded a relatively high disagreement regarding the strategy level. Experts with different backgrounds suggested different strategies for China to follow. Government experts have higher expectations for imitative innovation or indigenous innovation. Indeed, due to noticeable gaps between China and the global innovation frontiers, it is more realistic to expect some learning and imitative activities. This process happened to other countries during their catching up stages, such as Japan in the 1960's and South Korea in the 1970s. India's pharmaceutical industry grew very fast during the 1970's when the government adopted similar strategies to imitate foreign drugs [314]. However, in today's more globalized environment, China's strategy should focus on re-innovation or imitative innovation, which goes beyond simple imitation. The domestic industrial experts have suggested more on imitative innovation strategy, indicating the catching up trends in the industry. They also have higher expectations for collaborative innovation, which confirms that collaborations are necessary for domestic companies. Although the foreign experts suggested relying more on collaborative innovation, the reality is that some MNCs have limited collaborations with domestic players, as seen from the results of resource levels. Their major concerns are loss of technology edge or IPR. However, the results have demonstrated that foreign players have the motive or interests to collaborate with domestic players.

The global biotech communities are well aware of the advantages and attractions China can offer. As China's economy grows and incomes rise, it can be anticipated that people will increase their spending on healthcare and medicines. This brings great opportunities not only for domestic companies, but also for multinationals. The government should welcome global partners to jointly share the development and prosperity of the nation's emerging industry. To facilitate internationalization of China's biopharmaceutical industry, policy makers should plan to establish ideal conditions for attracting foreign innovators. Promoting research collaboration between domestic companies and their overseas counterparts will benefit the technology learning process, as well as the mission of sustained industrial growth. For its innovation goals to be met, China needs to have more integrated strategies for technology development. Past experiences revealed that the country needs to be more integrated into the global innovation networks. This means keeping an open-door policy and encouraging foreign investment in high-tech areas.

6.3 Supportive Innovation Resources

This case application provides the Chinese biopharmaceutical industry a performance report of various innovators with regard to their contribution toward global strategies and technology objectives. This will assist policy makers in determining which infrastructure items require improvement or investment. Based on the feedback from result validation, the research suggests improving the conditions and environment for innovation. The result analyses indicate that High-tech SMEs are the most important contributors for China's biopharmaceutical industry in the current development stage.

The second group of important contributors is considered to be the MNCs and subsidiaries. The Foreign R&D Centers and University Research Programs tie for the third place toward mission. These important innovation resources will be discussed in this section.

6.3.1 High-tech SMEs

Owing to the narrowed gaps of competitive advantages in recent years, many emerging biotech SMEs have entered the race for technology development. These companies have certain advantages over large established enterprises, including greater flexibility, better efficiency, less bureaucracy, and profit-seeking behaviors which allow them to succeed in the fast-changing markets. Many biotech SMEs in the Chinese biopharmaceutical sector share similar advantages and traits. For example, they are more successful in some specialized high-tech areas, and most of them are very eager or active in collaborative innovations with other players. This is mainly due to the reality that SMEs are usually not strong as standalone innovators. They need to search for complementary resources to cover their deficiencies in certain aspects.

Despite a clear evidence of progress in recent years, biotech SMEs still have some key issues to be addressed. One of the main challenges faced by biotech SMEs is to obtain funding, not only for their business purposes but also for their R&D activities. With lower research inputs, most biotech SMEs are not well prepared to compete globally in many high-tech fields. The government should provide services to expand biotech SMEs' networking with other players so that interactions can create a synergy where knowledge, expertise, and experiences are shared. This is also a measure to avail

biotech SMEs with complementary resources and related activities that they lacked. Moreover, the government has the ability to alleviate biotech SMEs' tax burdens, and induce them to invest more in R&D activities with incentives.

6.3.2 Multinational Companies and Subsidiaries

MNCs' technological strength, institutional heritage, and their global coverage generate specific advantages for their operations in the Chinese biopharmaceutical sector. MNCs are in a better competing position because they are better endowed with both R&D capacities and funding capital. Chiesa and Chiaroni (2005) found that the presence of foreign pharmaceutical firms can make a number of important contributions to the success of the industrial networks of the host country. For example, these firms have better expertise in developing and protecting intellectual property with high commercial potential, they have well-established marketing and distribution channels, and they are experienced in both shaping and working within strict regulatory guidelines [317]. Domestic players in the host country may benefit from technology spillover through MNCs' demonstration effects, labor turnover, and overall industrial structure upgrading (both upstream and downstream) [160, 318]. These are essential factors to build up a better innovation ecosystem for the biopharmaceutical industry in China.

The research results have revealed that there are certain disagreements on whether MNCs collaborate with other players. According to the feedback from result validation, the contributions of MNCs toward collaborative innovation are uneven. One expert claimed that her company has initiated many partnership programs in recent years, which indicates higher contribution. On the other hand, several other experts argued that their

collaborative programs are limited in clinical trials which do not contribute much to innovation. Most of the MNCs in China focus on the collaborations with domestic players in the late-stage clinical trials, which are required by domestic regulations. The Chinese government does not allow First-in-Human clinical research for foreign drugs in China. Even if the drug is approved for marketing in a foreign country, the drug company still needs to restart all three phases of clinical trials locally. Although some MNCs also collaborate with Chinese universities and research institutes in early-stage discoveries, the cases are relatively few, and the MNCs would eventually acquire the research outcomes to enrich their own product pipelines. Therefore, the government should provide more favorable policies to facilitate and support collaboration between MNCs and domestic players, especially in early-stage drug discovery. This presupposes that both sides will benefit from cooperation or even competition with their counterparts. The trend of globalization and industrial liberalization needs such a change in attitude or business orientation where even competitors can cooperate with each other to achieve mutual success [319]. From a foreign perspective, MNCs also need to achieve a better balance between their demands in exploiting the potential Chinese market and utilizing the plentiful local resources.

6.3.3 University Research Programs

According to the results, the contribution of University Research Programs ties with that of Foreign R&D Centers for third place. This is mainly due to a university's higher contribution toward collaborative innovation and imitative innovation. University programs are more oriented toward basic research. Many biotech startups and spinoffs

were created to take advantages of discoveries in academic research. MNCs collaborate with top Chinese universities in early-stage drug discoveries. Many universities also have academic connections with foreign research institutions. Moreover, university partnerships are not limited to R&D. They are important for training future talents with advanced research techniques, as well as providing companies the opportunity to recruit a highly qualified workforce [313]. In the past two decades, Chinese universities have trained about 100,000 biotech researchers. Nearly 1,000 universities and colleges in China offer biology-related courses, and more than 500 universities and colleges offer biology-related programs. More than 20,000 university students graduated each year in biology-related fields before 2006 [320]. Universities provide the foundations for China to catch up with developed countries.

6.3.4 Foreign R&D Centers

Foreign R&D Centers also contribute the third highest toward the overall mission. This is largely due to their contributions toward international technology transfer and indigenous innovation. In recent years, more and more foreign-invested R&D centers have been established in China. This is a new approach to R&D in that it builds Chinese portals to the global biotech communities. On the one hand, these innovation centers have stringent ties with research resources in their own countries. On the other hand, they hire and train many domestic scientists and researchers to carry out local R&D projects. The vast population and different disease patterns in China provide a convenient condition for the application of new technologies. There are plenty of opportunities for both early-stage drug discovery and late-stage clinical trials. These organizations bring some of the latest

research techniques, routines, and practices to China. Many of these research centers focus on finding specific biomarkers and genes related to diseases that are more prevalent in China and Asian regions. This is an important aspect because they contribute to indigenous innovation as well as technology transfer.

6.3.5 Other Innovation Resources

Although the research model can be utilized to identify a single best contributor toward the mission, the research goal is far beyond such a finding. The technology development process in reality involves complementary technologies which can be developed by different innovators in the innovation systems. In other words, the current model is not merely for choosing the only innovator for each candidate technology. For example, when the model proposes high-tech SMEs, as the best contributing resource toward the overall mission of competitiveness and innovation, it should not be interpreted that other innovators are excluded from the development strategy; rather, they just contribute less than the ideal option but still remain as contributors. Because rankings provide guidelines and direction for the design of technology policies to leverage investment input, such as time, effort, human capital, and related monetary support.

6.4 Policy Recommendations

Based on the above discussions and experts' feedback, major areas of policy recommendations include: 1) Establishing a clear vision for technology objectives and implementation strategies in the biopharmaceutical sector; 2) Creating actors or organizations with responsibility for promoting or executing such strategies; 3) Nurturing

a collaborative environment and innovation ecosystem. 4) Providing service platforms, education, and training; and 5) Legislating support and financial incentives for innovators at a micro or organizational level.

6.4.1 Establishing a Clear Vision for Technology Objectives and Strategies

In the development of high-tech industries in emerging economies, the synergies of two major aspects need to be considered, which will reap some of the benefits of globalization while remaining responsive to local market needs. Technology objectives and strategies serve to provide direction and schemes for the making of innovation policy within the sectoral regime. This research suggests that emerging economies must set clear technology goals before formulating their global strategies. The decision makers have the roles of clarifying the vision for those undertaking risky R&D activities in the high-tech areas, determining proper regulations, and industrial standards to maintain the desired boundaries of research activities, and making sure that an effective innovation environment is provided with appropriate market mechanisms. The concern is to enhance competitiveness for the industry's present needs in globalization and local applications.

A major achievement of the Technology Level results is that the experts with diverse backgrounds have reached unanimous agreement for prospective technology areas in China. This means that the identified high-tech areas are in need of attention not only for the local biotech community to upgrade but also for the overseas stakeholders to invest. These high priority areas include Recombinant Therapeutic Proteins, Recombinant Vaccines, and Monoclonal Antibody Technology. As a large country, China should not give up developing other technologies, but the focus here is to make priorities based on

both global trends and local needs. The long-term objective is to develop a full-fledged biopharmaceutical sector that ranks among the higher end of the global industrial value chain.

6.4.2 Creating Actors and Organizations to Improve Innovation Capacity

Global strategies often require substantial supporting resources during the implementation processes. This research suggests that policy makers actively consider the strategic need and ensure adequate resources are provided. The results bring to light that China should strive to build an enterprise-centered innovation system for the biopharmaceutical sector. The change from a structural and institutional context of scientific research to an entrepreneurial mode may be beneficial for the biopharmaceutical industry in the long run. This concern needs to be taken for policy making.

To build a more competitive biopharmaceutical Industry, the government can strengthen the development of enterprises by enhancing the factors that lead them to business success. Research shows that institutional support, especially support from the government, can play a major role in SMEs' competitiveness development within the domestic market [319]. The actions can include executing an elite promotion program to support a number of flagship enterprises, and motivate them toward innovation. In order to stimulate innovation in the identified priority high-tech areas, policies can be designed to encourage Chinese scientists overseas to return to China and contribute their experience and expertise to the local industry. Domestic scientists should be encouraged to participate in the commercialization process or even to become technological

entrepreneurs themselves. Policy responses should be developed with regard to supporting innovation and investment in high-tech areas.

6.4.3 Nurturing a Collaborative Environment and Innovation Ecosystem

A major concern of the government is to improve the innovation ecosystem in the biopharmaceutical sector. The research results showed that both indigenous innovation and collaborative innovation are contributing strategies for the biopharmaceutical industry in China. Under the present conditions and status of China's biopharmaceutical industry, imitative innovation is the preferred strategy. However, increasing international collaboration, as well as appropriate competition, is crucial for technological innovations and scientific breakthroughs. With increased partnerships and collaborations, both domestic and foreign actors cooperate to carry out scientific research that leads to innovations.

The situation of limited collaborations between foreign and domestic biotech companies has been discussed in the literature. There are suggestions that foreign firms should adjust their IP strategies and change from a defensive position of filing and enforcing patents to a more active exploitation of the commercial value of their technologies in China [321]. First, large MNCs usually have a broad range of non-commercialized patents where they are willing to open their innovation processes through patent transactions. Chinese firms may have opportunities either to buy or in-license some of the foreign state-of-the-art technologies. Second, smaller or medium-sized foreign firms usually have more specific and state-of-the-art technologies. They may

consider out-licensing such technologies before their IPs are infringed by Chinese firms [321].

In short, the foreign firms should be encouraged to employ an open innovation strategy. In China's context, the government can play a decisive role in promoting innovation activities in the high-tech areas. Measures can include setting up appropriate institutional frameworks, opening up more business opportunities, and providing generous incentives for various innovators. Policy makers must have a strong commitment to establish a more innovative environment for various players. Promoting the development of new ventures and encouraging foreign investment from MNCs are not only very necessary, but also represent the current needs and future trends for high-tech development.

6.4.4 Providing Service Platforms, Education, and Training

In order to support innovation, the government can provide various services and facilities. These include clinical trial facilities and R&D service platforms that align with international best practices. The government should promote the development of biotech contract research services for clinical trial phase I & II, and establish biotech contract manufacturing services for clinical trial phase III. The government can also provide support through education, information propaganda, and procurement programs. The need for high quality scientists and engineers arises from both industry and research institutes. The investment in the higher education system should keep up with rapidly growing demand. The availability of human resources will ultimately contribute to the increase of industrial competitiveness.

6.4.5 Legislating Support and Financial Incentives for Innovators

The nature of innovation networks in China is different from those in developed countries such as the United States and EU. The infrastructure and supporting systems are mainly policy driven. Favorable policies and economic support from the government are key factors to drive continuous growth in the long run. Substantial investments may be required in reforming established SOEs, cultivating startups, and supporting various academic/research institutes. Another area that needs improvement is the efficiency of the drug evaluation process and reviewing mechanism. The bureaucratic nature of decision making due to the involvement of government agencies has deterred the progress of technological development and cooperation. Such barriers should be simplified or removed completely. For example, the registration procedures for biosimilars could be simplified according to related practices in advanced foreign countries.

Policies can serve to arouse the market participants' interests in high-tech areas through fiscal incentives. Such measures may include offering support to SMEs in preferred research areas through investment incentives or low-interest loans. The government can provide startups with special funding to lower their burden of initial sunk cost. Lastly, the competitiveness of companies also depends on how well the companies handle their networks of complementary relationships with other players in the biotech sector. Institutional setup, active collaboration, and financial support from the government will enhance the companies' capabilities with regard to innovation and competitiveness [319].

Chapter 7 – Conclusions

With the implications and recommendations discussed in the last Chapter, this Chapter summarizes and concludes the project in several major aspects including: contributions, assumptions, limitations, and future research directions.

7.1 Research Contribution

The research contribution is summarized in Table 48 and explained below.

Research Gaps	Research Outcomes
1. Latecomers face the dilemma of ‘‘make or buy’’ decisions in high tech development [12] [84] [258] [259].Technology export control at various levels complicates their problems [16] [80] [138].	This research has identified four types of viable strategies for technology development in the emerging economies and latecomer countries.
2. Latecomer countries and emerging economies need to identify the “windows of opportunity” for catching-up and leapfrogging [27] [29].	Identified and categorized thirteen prospective high-tech areas for the biopharmaceutical industry in China.
3. International technology transfer activities may not necessarily result in sustained innovation, technology diffusion not efficient and spillover not obvious [23] [25] [34].	The research has suggested more effective technology development strategies, including imitative innovation, indigenous innovation, and collaborative innovation strategies.
4. Different attitudes toward appropriate technology. Common concerns exist but different interests and motivations are obvious among the stakeholders [30] [32] [37].	This research has identified the areas of disagreement or agreement in different hierarchy levels.
5. Globalization brought new challenges in the research of innovation systems, innovation resources are across boundary [7] [72] [260].	This research has identified eight types of input resources to support technological innovations in China’s biopharmaceutical industry.
6. Transitional innovation systems: allocation of innovation resources is not effectively linked to national or regional tech development strategies [196] [197].	This research has prioritized the innovation resources to support the identified technology development strategies in China’s biopharmaceutical industry.
7. No viable framework has been developed to deal with technology policy problems in latecomer countries. A decision model for the implementation mechanism of selected technologies is needed in such countries [180] [208] [261].	This research has developed a comprehensive research framework that links various technologies, strategies, and resources to assist technology policy decision in emerging economies.

Table 48: Research Contribution

7.1.1 Contribution to Technology Management Literature

Catching up and leapfrogging development in high-tech industries is a complicated issue for latecomer countries. It is a great challenge for decision makers because of limited innovation capacities and input resources. The literature review has revealed the necessity for proactive technology posture, strategy adaptation, and resource allocation to gain competitive advantage and innovation capability. However, little was known about the inner relationships and their combined impact on competitiveness. This research serves to fill the gap in the technology management literature. The findings of this research have identified prospective technology areas, effective innovation strategies, and resource allocation mechanisms. Along with the trend of globalization, technological innovations are more scattered around the world. The model helps latecomer countries to deal with the ‘‘make or buy’’ dilemma in technology development. The research process has considered the interests of both domestic and foreign stakeholders by incorporating multiple perspectives during data collection. It also combined a top-down and bottom-up approach to consider the needs and concerns of both governments and enterprises. Experts from diverse sources provided their valuable judgments for the research.

7.1.2 Contribution to Methodology

Conventional technology assessment methods are applied to evaluate and assign priority to technology alternatives for economic, social, or environmental objectives. However, such methods are not an appropriate means for determining a workable solution during the implementation stages. The biopharmaceutical industry encompasses many high-tech areas and complex aspects, and the realization mechanism of a particular

area may involve interconnected decision elements such as technology, strategy, and resources. Because of the many criteria involved and the different perceptions of experts with different backgrounds, this study has employed the HDM method proposed by Dundar Kocaoglu in 1976 to construct a new framework for the assessment of innovation potential in the biopharmaceutical sector [252].

AHP provides an effective methodology allowing the collective decision making process among various experts to be systematically integrated. It consolidates different opinions brought by experts' backgrounds, and presents the results in an aggregated manner. Moreover, the disagreement among experts can be measured by the calculation of the intra-class coefficient and F-test. Through exploring the variance of opinions among different experts, policy makers can understand the exact area of disagreement and make tradeoffs accordingly. This provides an effective decision making mechanism for resource allocation, implementation strategy, and technology directions.

7.1.3 Contribution to the Biopharmaceutical Industry

The case application contributes to policy development in China's bio-pharmaceutical industry in time and in need. China is resolute to reform its health sector and promote innovations in high-tech areas. However, policy controversy exists in China's pharmaceutical industry, and technological innovation is remarkably difficult [278]. Moreover, globalized competition has significantly complicated the innovation environments for local companies. Since the biopharmaceutical industry is noted for high regulatory control, the government plays an important role in guiding industrial development. The case study's most important contribution lies in its having consolidated

the valuable inputs of policy makers, industry representatives, and specialists from various biopharmaceutical fields to provide policy directions encompassing innovation resources, technology development strategies, and prospective high-tech areas. The resulting information allows the comparison of each innovator's level of development and provides a robust basis for policy improvement in the biopharmaceutical sector.

In summary, this research continues and broadens the related technology management research in academic literature, and it develops a new analytic framework to deal with real world problems in the Chinese biopharmaceutical sector. Findings and implications of the research can provide new perspectives for high-tech development in other emerging economies.

7.2 Assumptions and Limitations

This section discusses some research assumptions and limitations, and how such issues were addressed in this research process.

7.2.1 Research Assumptions

The research has several assumptions in the area of AHP model development and expert recruitment. The development of an AHP model has its assumptions. The impact relationships between adjacent levels were assumed to be linear and unidirectional. The decision criteria at each level were assumed to be preferentially independent. To cope with such assumptions, the research model was conceptually developed based on a comprehensive literature review. The model structure was further tested in a pilot study.

The finalization of criteria and level of relationships were validated by the experts before the data collection process.

The appropriate selection of experts is critical for the success of this research. The experts were assumed to be knowledgeable in their fields. Individual biases were assumed to be balanced in the expert panel and subgroups, and they had minimal effect on the overall quantification measurement. In order to meet such assumptions, experts were recruited according to their professional backgrounds and industrial experience. The researcher tried to minimize the biases by inviting experts from diverse sources including government agencies, domestic industrial associations, and foreign organizations. Moreover, the influential biases were avoided since the experts did not know who else participated in the research.

7.2.2 Limitations

Several limitations need to be clarified for this research. The experts provide their opinions based on their perception of reality, as well as their professional backgrounds and experience. The research process evaluated their judgmental preferences at a certain period of time, and the results only reflected their perceptions during that period of time. Their judgments may change over time due to other influencing factors such as social or economic changes. The model has been demonstrated through a case application in the biopharmaceutical sector. However, due to industrial differences, the research criteria may need to be modified for applications in other industries.

This research is not to find a panacea for all the problems related to technology policy. The objective is to develop an analytic approach to assist policy design in

building a more effective innovation infrastructure to support technology implementation. The model may yield different outcomes for different countries, different political institutions, and different development stages. The idiosyncrasies of ideological frameworks are beyond the consideration of this research.

7.3 Future Research

The limitations discussed above leave some room for future research. Further exploration may lead to one or more of the following directions.

7.3.1 Other Emerging Economies and Industries.

Although the research framework has been demonstrated with a case study in China's biopharmaceutical sector, additional research can be applied to other emerging economies such as Brazil, India, and Russia. Addressing industry-specific characteristics and examining the influence of regional characteristics would clearly be a future direction. The types and number of technologies and resources may vary from industry to industry, and from country to country. More criteria and alternatives could be identified and included in new models to reflect the reality according to different conditions. Policymakers can tailor this framework to the needs of particular sectors in the host country. The related research outcomes can provide insights for designing policies to improve the country's innovation capacity.

7.3.2 Enterprise-Level Applications

Selection of appropriate technology for a rapidly evolving market environment is a complicated issue at both the industrial and enterprise level. It should be acknowledged that the experts provided valuable feedback and suggestions, which was incisive, intelligent, and very thoughtful. One of them suggested that the model can be applied at both the industrial level and enterprise level. The future is uncertain and enterprises are engaged in the effort to sustain innovation. Many decision makers have the question "How do enterprises innovate consistently?" The difficulties of this go into making the right decisions about how many resources to pour into innovation, and how to choose the right products to innovate around. Enterprises leverage various innovation resources, but funding is relatively internal and constrained by various factors. It is crucial to have a discipline of execution around the innovation process. The research model can therefore serve to help enterprises in making balanced investments, innovating in the right areas, and making the right bets for the future.

7.3.3 Deployment of Policy Tools

The application of an analytical hierarchical structure gave meaningful results in identifying the effective innovation resources and comparing the relative importance of strategies. The purpose of this research, as well as the model, is to guide policy directions that will build up the innovation capability for the country. However, more specific policy tools and measures are not discussed in detail. Follow up policy research can focus on the development of favorable policy tools to support the identified criteria. For example, the results suggest that High-tech SMEs and MNCs have more contributions

toward the overall mission of competitiveness and innovation. These research outcomes can lead future work to the deployment of more specific policy tools to support the identified players. Moreover, technology policies should also be revised in a dynamic manner to keep up with the rapid trend of globalization and trade liberalization.

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Appendix A – Human Subject Agreement

Informed Consent Form

Policy Choice Framework for Sustainable Technological Innovation

Dear [Expert's Name],

You are invited to participate in a research study conducted by Leong Chan from Portland State University, Engineering and Technology Management Department. The researcher hopes to identify the innovation resources that contribute to the technological competitiveness of an industry. This project is being conducted in partial fulfillment for the requirements of a PhD's degree under supervision by Dr. Tugrul Daim. You are invited as a possible participant because you have innovation management experience in the industry that the researcher is examining in the study.

If you decide to participate, you will be asked to provide judgments through pair-wise comparisons among the model criteria in the research instrument. This is a numerical quantification process, thus it presents no hazard to the participants. The task takes about 15 to 30 minutes to complete. You will not receive any direct benefit from taking part in this study, but the study may help to increase knowledge which may help others in the future.

Your name and responses will be confidential and will not be shared with any third party. Any data linked to your identification will be kept confidential by storing in secured places only accessible by the researcher. The data will be stored in the researcher's computer and backed up in university's secured server. The data will be destroyed within one year after the completion of research. Participation in this research is totally voluntary. You have the right to withdraw at any time or refuse to participate entirely. You may also withdraw from this study at any time without affecting your relationship with the researcher or any institute.

If you have concerns or problems about your participation in this study or your rights as a research subject, please contact the Human Subjects Research Review Committee, Office of Research Strategic Partnerships, 1600 SW Fourth Avenue, Suite 620, Portland, OR, 97201, (503) 725 3423. If you have any questions about the study itself, contact Leong at 1802 SW 11th Ave #404, Portland, OR, 97201, (503) 442 8428.

Your signature indicates that you have read and understand the above information and agree to take part in this study. Please understand that you may withdraw your consent at any time without penalty, and that by signing, you are not waiving any legal claims, rights or remedies. The researcher will provide you with a copy of this form for your records.

Signature: Date:

Appendix B – Subject Recruitment Letter

Policy Choice Framework for Sustainable Technological Innovation

Dear Sir or Madam,

My name is Leong Chan, and I am a Ph.D. student at Department of Engineering and Technology Management (ETM), Portland State University. I am conducting a research to develop a policy choice framework for sustainable technological innovation, and would like to invite you to participate. You are being asked to take part because you are considered as an expert in the area of innovation management due to your qualification and professional experience. I am impressed with your expertise in innovation management, and I hope that your expert judgment will help me to better understand the innovation mechanism from different perspectives. Your participation will help to increase the knowledge in policy decisions to foster technological innovation. This study is being conducted in partial fulfillment of the requirements for a doctoral degree in Technology Management at Portland State University.

If you decide to participate, an Informed Consent Form will be sent to you for signature before the research. I will be sending some data collection instruments to you after I receive the signed form. You will be asked to provide your opinions by doing some pair-wise comparisons among the research criteria. The research instrument will take about 15-30 minutes to complete. When you return the research instruments, I will quantify the judgmental data and prioritize the related research criteria. The result can demonstrate what strategies and resources are more important in policy decisions.

There is no risk for the involvement in this research. No identifiable data is collected, and will not be reported. All data will remain confidential by the researcher. The data obtained from the participants will only be reported in the aggregate format, and the individual information will be kept confidential. All responses will be concealed, and no one other than the researcher will have access to them. The information will be deleted or destroyed by the researcher within one year after the completion of this research.

The benefits for participation include two things: 1) at the end of the research, a copy of the aggregated results will be provided to you at no cost; 2) through your participation as an expert, researcher, and decision-maker, we will all learn more about how innovation resources contribute to technology policy decisions, which will ultimately lead to the benefit of whole society.

Participation in this research is completely voluntary. You have the right to withdraw at any time or refuse to participate entirely and it will not affect your relationship with the investigator or any institute.

If you have questions regarding this study, you may contact Leong Chan at leong@pdx.edu, 1802 SW 11th Ave #404, Portland, OR, 97201, (503) 442 8428. If you have concerns or problems about your participation in this study or your rights as a research subject, please contact the Human Subjects Research Review Committee, Research and Strategic Partnerships, Market Center Building, 6th Floor, 1600 SW 4th Ave, Portland, OR 97201, (503) 725-4288 / 1-877-480-4400.

Sincerely,

Leong Chan

Ph.D. student

Department of Engineering and Technology Management

Portland State University

Appendix C – Validation Instruments

Validation Instrument I A

Identification and validation of Prospective Technology Areas in the Biopharmaceutical Industry

1. Introduction

Identification and investment on prospective technology areas are crucial for improving competiveness in the biopharmaceutical industry. Emerging countries not only need to identify global technology trends, but also have to adapt to local needs and capabilities. The purpose of this instrument is to identify and validate such technology areas.

A preliminary list of technology areas has been prepared according to comprehensive literature review. The following list contains the prospective technology areas in the biopharmaceutical industry as suggested by OECD'S forecasting report. However, the lists might need to be updated and validated because it was originally published in 2009.

2. Instructions

In the following table, you are invited to validate the technology areas and provide suggestions. The goal is to identify a list of prospective high tech areas to enhance competitiveness from a global perspective.

In your opinion, if you think the technology is novel and prospective in the future, please check the YES column; or if you think a technology is matured enough or less prospective, please check the NO column.

Moreover, you can suggest new technology areas that you think as prospective in the biopharmaceutical industry. Please kindly provide your opinions in the following table.

3. List of prospective technology areas and your opinions:

Prospective Technology Areas	Prospective in future?	
	Yes	No
Recombinant therapeutic proteins - treat many non-communicable diseases; provide affordable and sustainable sources for treatment of chronic disease.		
Recombinant vaccines - vaccines produced using recombinant DNA technology; can be used to effectively treat infectious diseases.		
Monoclonal antibody technology - used for both therapeutic treatment and diagnostic tests. Most are concerned with immunological and oncology targets.		
Tissue engineering technologies - replace or act directly on cells and tissues in the body; repairs damaged tissues from injuries and diseases.		
Stem cell therapy - the use of stem cells as a therapeutic or to repair specific tissues or to grow organs. Treatment leads to the production of entire organs.		
Gene therapy - treatment of diseases by introducing new gene into a cell. These technologies either use or act directly on nucleic acids.		
Antisense therapy - treat a wide range of diseases such as cardiovascular diseases, asthma, and arthritis.		
RNAi (ribonucleic acid interference) - products that act therapeutically via an RNA interference mechanism. Most are aimed at treating infections.		
Nanobiotechnology - aim for improved drug delivery systems from the convergence between biotechnology and nanotechnology.		
Synthetic biology - the design and construction of new biological parts, devices and systems that do not exist naturally; the redesign of existing biological systems to perform specific tasks		
Bioinformatics - manipulation and analysis of large datasets of genetic and health information to identify drug targets		
Pharmacogenetics - identify inherited differences (variation) between individuals in drug metabolism and response. It can be applied in clinical trials and in prescribing practice.		
Gene sequencing - provides ways to identify new antimicrobials. It can accelerate the process of drug discovery and fight against infectious diseases.		
Biotechnology Diagnostics - includes both in vitro diagnostics and in vivo diagnostics; Provides affordable, simple diagnosis for infectious diseases.		

Other Suggestions (if necessary):

_____

_____

Validation Instrument I B

Identification and validation of Technology Development Strategies for the Biopharmaceutical Industry in Emerging Countries

The technology development strategies describe how new technologies should be realized and implemented. As latecomers in technology development, emerging countries face the decisions of "make or buy", or somewhere in between. This means to develop the technology locally, or import from advanced countries, etc.

The following innovation strategies have been identified through literature review. Please indicate whether these strategies are observable in the biopharmaceutical industry. You are also welcome to suggest other innovation strategies, that you believe, are observable in the biopharmaceutical industry.

Technology Development Strategies in Emerging Countries	**Observable in bio-pharmaceutical industry?**	
	Yes	**No**
Indigenous Innovation – relies on local technology base and available innovation resources to build up indigenous competence		
Imitative Innovation – based on imitating, following, and improvement of leading innovators' technology		
Collaborative Innovation – cooperates with other innovators, shares resources and develops new technology altogether		
International Technology Transfer – technology import and acquisitions, introducing new technology from leaders		

Other Suggestions (if any): _____

Validation Instrument I C

Identification and Validation of Innovation Resources to Support Technology Development Strategies in the Biopharmaceutical Industry

The Innovation Resources contribute to the implementation of technology development strategies. These are innovators that generate various innovative outputs such as patents, publications, and new products or designs. The innovation resources can include all the entities that develop, implement, or provide support for the realization of prospective technologies. These resources can come from different sources such as public sector, private sector, or even foreign countries.

For the biopharmaceutical industry, various types of innovation resources have been extracted through literature review. In the following tables, please indicate and validate whether these innovators are supportive to the technology strategies identified in Validation Instrument I b.

You are also welcome to suggest other innovation resources that you believe important for the biopharmaceutical industry in emerging countries.

1. Supportive Innovators and resources for the technology development strategies	**Contributor?**	
	Yes	**No**
University Research Programs		
Public Research Institutes		
State-owned Enterprises		
High-tech Small-to-Medium Enterprises		
Equity Joint Ventures		
Contract Research/Manufacture Organizations		
Foreign R&D Centers		
Multinational Companies and Wholly-owned Subsidiaries		

Other Suggestions (if necessary):_____

Appendix D – Research Instruments

Pair-wise Comparison Instrument I A

Prioritization of Prospective Technology Areas in the Biopharmaceutical Industry

1. Introduction

Identification and investment on prospective technology areas are crucial for improving competiveness in the biopharmaceutical industry. Emerging countries not only need to identify global technology trends, but also have to adapt to local needs and capabilities. The purpose of this instrument is to prioritize such technology areas. The following prospective technology areas in the biopharmaceutical industry were suggested by literature review and validated by experts. As an expert, you will be asked to make pair-wise comparisons among the technologies for the objective of enhancing competitiveness and innovation in the biopharmaceutical industry.

2. Instructions

In the pair-wise comparison tables, please allocate a total of 100 points to represent your perceived judgment about how many times an element is more or less important than the other. Use any number from 1 to 99 to represent your judgment (Exclude 0 or 100). For example, if you think ‘sub-criterion1’ is 3 times more important than ‘sub-criterion2’ for the upper level Criterion, then fill "75" in the blank cell on the left, and then “25” (100-75) in the cell on the right. If you believe that one element is completely irrelevant in comparison to the other element of a pair, allocate 1 and 99 respectively. The working process is similar for other pairs, but the judgment values might be very different even for the same pair when under a different upper level criterion. The following 2 tables demonstrate this procedure. For example:

Contribution to upper level Criterion1				
Sub-criterion1	75	Vs.	25	Sub-criterion2

Contribution to upper level Criterion2				
Sub-criterion1	1	Vs.	99	Sub-criterion2

3. Descriptions of Criteria

Overall Objective:

The mission is to achieve technology competitiveness and sustainable innovation in the biopharmaceutical industry.

Prospective Technology Areas:

- T_1 Recombinant therapeutic proteins - treat many non-communicable diseases; provide affordable and sustainable sources for treatment of chronic disease.
- T_2 Recombinant vaccines - vaccines produced using recombinant DNA technology; can be used to effectively treat infectious diseases.
- T_3 Monoclonal antibody technology - used for both therapeutic treatment and diagnostic tests. Most are concerned with immunological and oncology targets.
- T_4 Cell and tissue engineering - replace or act directly on cells and tissues in the body; repairs damaged tissues from injuries and diseases. Including stem cell therapy.
- T_5 Gene therapy - treatment of diseases by introducing new gene into a cell. These technologies either use or act directly on nucleic acids.
- T_6 Antisense therapy - treat a wide range of diseases such as cardiovascular diseases, asthma, and arthritis.
- T_7 RNAi (ribonucleic acid interference) - products that act therapeutically via an RNA interference mechanism. Most are aimed at treating infections.
- T_8 Nanobiotechnology - aim for improved drug delivery systems from the convergence between biotechnology and nanotechnology.
- T_9 Synthetic biology - the design and construction of new biological parts, devices and systems that do not exist naturally; the redesign of existing biological systems to perform specific tasks
- T_{10} Bioinformatics - manipulation and analysis of large datasets of genetic and health information to identify drug targets
- T_{11} Pharmacogenetics - identify inherited differences (variation) between individuals in drug metabolism and response. It can be applied in clinical trials and in prescribing practice.
- T_{12} Gene sequencing - provides ways to identify new antimicrobials. It can accelerate the process of drug discovery and fight against infectious diseases.
- T_{13} Biotechnology Diagnostics - includes both in vitro diagnostics and in vivo diagnostics; Provides affordable, simple diagnosis for infectious diseases.

Please provide you judgment in the next 2 tables.

Group A:

T_1 Recombinant therapeutic proteins		Vs.		**T_2** Recombinant vaccines
T_1 Recombinant therapeutic proteins		Vs.		**T_3** Monoclonal antibody
T_1 Recombinant therapeutic proteins		Vs.		**T_4** Cell and tissue engineering
T_1 Recombinant therapeutic proteins		Vs.		**T_5** Gene therapy
T_1 Recombinant therapeutic proteins		Vs.		**T_6** Antisense therapy
T_1 Recombinant therapeutic proteins		Vs.		**T_7** RNAi
T_2 Recombinant vaccines		Vs.		**T_3** Monoclonal antibody
T_2 Recombinant vaccines		Vs.		**T_4** Cell and tissue engineering
T_2 Recombinant vaccines		Vs.		**T_5** Gene therapy
T_2 Recombinant vaccines		Vs.		**T_6** Antisense therapy
T_2 Recombinant vaccines		Vs.		**T_7** RNAi
T_3 Monoclonal antibody technology		Vs.		**T_4** Cell and tissue engineering
T_3 Monoclonal antibody technology		Vs.		**T_5** Gene therapy
T_3 Monoclonal antibody technology		Vs.		**T_6** Antisense therapy
T_3 Monoclonal antibody technology		Vs.		**T_7** RNAi
T_4 Cell and tissue engineering		Vs.		**T_5** Gene therapy
T_4 Cell and tissue engineering		Vs.		**T_6** Antisense therapy
T_4 Cell and tissue engineering		Vs.		**T_7** RNAi
T_5 Gene therapy		Vs.		**T_6** Antisense therapy
T_5 Gene therapy		Vs.		**T_7** RNAi
T_6 Antisense therapy		Vs.		**T_7** RNAi

Group B:

T_1 Recombinant therapeutic proteins		Vs.		**T_8** Nanobiotechnology
T_1 Recombinant therapeutic proteins		Vs.		**T_9** Synthetic biology
T_1 Recombinant therapeutic proteins		Vs.		**T_{10}** Bioinformatics
T_1 Recombinant therapeutic proteins		Vs.		**T_{11}** Pharmacogenetics
T_1 Recombinant therapeutic proteins		Vs.		**T_{12}** Gene sequencing
T_1 Recombinant therapeutic proteins		Vs.		**T_{13}** Biotechnology Diagnostics
T_8 Nanobiotechnology		Vs.		**T_9** Synthetic biology
T_8 Nanobiotechnology		Vs.		**T_{10}** Bioinformatics
T_8 Nanobiotechnology		Vs.		**T_{11}** Pharmacogenetics
T_8 Nanobiotechnology		Vs.		**T_{12}** Gene sequencing
T_8 Nanobiotechnology		Vs.		**T_{13}** Biotechnology Diagnostics
T_9 Synthetic biology		Vs.		**T_{10}** Bioinformatics
T_9 Synthetic biology		Vs.		**T_{11}** Pharmacogenetics
T_9 Synthetic biology		Vs.		**T_{12}** Gene sequencing
T_9 Synthetic biology		Vs.		**T_{13}** Biotechnology Diagnostics
T_{10} Bioinformatics		Vs.		**T_{11}** Pharmacogenetics
T_{10} Bioinformatics		Vs.		**T_{12}** Gene sequencing
T_{10} Bioinformatics		Vs.		**T_{13}** Biotechnology Diagnostics
T_{11} Pharmacogenetics		Vs.		**T_{12}** Gene sequencing
T_{11} Pharmacogenetics		Vs.		**T_{13}** Biotechnology Diagnostics
T_{12} Gene sequencing		Vs.		**T_{13}** Biotechnology Diagnostics

Overall level of confidence (Please circle the appropriate number):

5: Very high 4: High 3: Medium 2: Low 1: Very Low

Pair-wise Comparison Instrument I B

Prioritization of Technology Development Strategies for the Biopharmaceutical Industry in Emerging Countries

1. Introduction

The technology development strategies describe how new technologies should be realized and implemented. As latecomers in technology development, emerging countries face the decisions of "make or buy", or somewhere in between. This means to develop the technology locally, or import from advanced countries, etc. The following innovation strategies have been identified through literature review and validated by experts. As an expert, you will be asked to make pair-wise comparisons among these strategies for the identified technology areas in the biopharmaceutical industry.

2. Instructions

In the pair-wise comparison tables, please allocate a total of 100 points to represent your perceived judgment about how many times an element is more or less important than the other. Use any number from 1 to 99 to represent your judgment (Exclude 0 or 100). For example, if you think 'sub-criterion1' is 3 times more important than 'sub-criterion2' for the upper level Criterion, then fill "75" in the blank cell on the left, and then "25" (100-75) in the cell on the right. If you believe that one element is completely irrelevant in comparison to the other element of a pair, allocate 1 and 99 respectively. The working process is similar for other pairs, but the judgment values might be very different even for the same pair when under a different upper level criterion. The following 2 tables demonstrate this procedure. For example:

Contribution to upper level Criterion1				
Sub-criterion1	75	Vs.	25	Sub-criterion2

Contribution to upper level Criterion2				
Sub-criterion1	1	Vs.	99	Sub-criterion2

3. Descriptions of Criteria

Technology Development Strategies in China:

Indigenous Innovation – relies on local technology base and available innovation resources to build up indigenous competence

Imitative Innovation – based on imitating, following, and improvement of leading innovators' technology

Collaborative Innovation – cooperates with other innovators, shares resources and develops new technology altogether

International Technology Transfer – technology import and acquisitions, introducing new technology from leaders

4. Prioritization of Strategies for Identified Technologies (T1-T13)

For T_1: Recombinant therapeutic proteins				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

For T_2: Recombinant vaccines				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

For T_3: Monoclonal antibody technology				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

For T_4: Cell and tissue engineering				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

For T_5: Gene therapy				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

For T_6: Antisense therapy				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

For T_7: RNAi (ribonucleic acid interference)				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

For T_8: **Nanobiotechnology**				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

For T_9: **Synthetic biology**				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

For T_{10}: **Bioinformatics**				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

For T_{11}: **Pharmacogenetics**				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

For T_{12}: **Gene sequencing**				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

For T_{13}: **Biotechnology Diagnostics**				
S_1: Indigenous Innovation		Vs.		S_2: Imitative Innovation
S_1: Indigenous Innovation		Vs.		S_3: Collaborative Innovation
S_1: Indigenous Innovation		Vs.		S_4: Int'l Technology Transfer
S_2: Imitative Innovation		Vs.		S_3: Collaborative Innovation
S_2: Imitative Innovation		Vs.		S_4: Int'l Technology Transfer
S_3: Collaborative Innovation		Vs.		S_4: Int'l Technology Transfer

Overall level of confidence (Please circle the appropriate number):

5: Very high 4: High 3: Medium 2: Low 1: Very Low

---------- Thank You ----------

Pair-wise Comparison Instrument I C

Prioritization of Innovation Resources to Support Technology Development Strategies in the Biopharmaceutical Industry

1. Introduction

The Innovation Resources contribute to the implementation of technology development strategies. These are innovators that generate various innovative outputs such as patents, publications, and new products or designs. The innovation resources can include all the entities that develop, implement, or provide support for the realization of prospective technologies. These resources can come from different sources such as public sector, private sector, or even foreign countries. Various types of innovation resources have been extracted through literature review and validated by experts. You will be asked to make pair-wise comparisons among the innovation resources to supportive the technology development strategies.

2. Instructions

In the pair-wise comparison tables, please allocate a total of 100 points to represent your perceived judgment about how many times an element is more or less important than the other. Use any number from 1 to 99 to represent your judgment (Exclude 0 or 100). For example, if you think ‘sub-criterion1’ is 3 times more important than ‘sub-criterion2’ for the upper level Criterion, then fill "75" in the blank cell on the left, and then “25” (100-75) in the cell on the right. If you believe that one element is completely irrelevant in comparison to the other element of a pair, allocate 1 and 99 respectively. The working process is similar for other pairs, but the judgment values might be very different even for the same pair when under a different upper level criterion. The following 2 tables demonstrate this procedure. For example:

Contribution to upper level Criterion1				
Sub-criterion1	75	Vs.	25	Sub-criterion2

Contribution to upper level Criterion2				
Sub-criterion1	1	Vs.	99	Sub-criterion2

3. Contribution of Resource Level to Strategies (S1-S4)

This section contains four tables to prioritize the resources for each of the identified strategies, which include Indigenous Innovation, imitative Innovation, collaborative Innovation and international Technology Transfer

3.1 Contribution to S1: Indigenous Innovation Strategy

R1: University Research Programs
R2: Public Research Institutes
R3: State-owned Enterprises
R4: High-tech Small-to-Medium Enterprises
R5: Equity Joint Ventures
R6: Contract Research/Manufacture Organizations
R7: Foreign R&D Centers
R8: Multinational Companies and Wholly-owned Subsidiaries

For S1: Indigenous Innovation Strategy

R1		Vs.		R2
R1		Vs.		R3
R1		Vs.		R4
R1		Vs.		R5
R1		Vs.		R6
R1		Vs.		R7
R1		Vs.		R8
R2		Vs.		R3
R2		Vs.		R4
R2		Vs.		R5
R2		Vs.		R6
R2		Vs.		R7
R2		Vs.		R8

R3		Vs.		R4
R3		Vs.		R5
R3		Vs.		R6
R3		Vs.		R7
R3		Vs.		R8
R4		Vs.		R5
R4		Vs.		R6
R4		Vs.		R7
R4		Vs.		R8
R5		Vs.		R6
R5		Vs.		R7
R5		Vs.		R8
R6		Vs.		R7
R6		Vs.		R8
R7		Vs.		R8

3.2 Contribution to S2: Imitative Innovation Strategy

R1: University Research Programs

R2: Public Research Institutes

R3: State-owned Enterprises

R4: High-tech Small-to-Medium Enterprises

R5: Equity Joint Ventures

R6: Contract Research/Manufacture Organizations

R7: Foreign R&D Centers

R8: Multinational Companies and Wholly-owned Subsidiaries

For S2: Imitative Innovation Strategy

R1		Vs.		R2
R1		Vs.		R3
R1		Vs.		R4
R1		Vs.		R5
R1		Vs.		R6
R1		Vs.		R7
R1		Vs.		R8
R2		Vs.		R3
R2		Vs.		R4
R2		Vs.		R5
R2		Vs.		R6
R2		Vs.		R7
R2		Vs.		R8

R3		Vs.		R4
R3		Vs.		R5
R3		Vs.		R6
R3		Vs.		R7
R3		Vs.		R8
R4		Vs.		R5
R4		Vs.		R6
R4		Vs.		R7
R4		Vs.		R8
R5		Vs.		R6
R5		Vs.		R7
R5		Vs.		R8
R6		Vs.		R7
R6		Vs.		R8
R7		Vs.		R8

3.3 Contribution to S3: Collaborative Innovation Strategy

R1: University Research Programs

R2: Public Research Institutes

R3: State-owned Enterprises

R4: High-tech Small-to-Medium Enterprises

R5: Equity Joint Ventures

R6: Contract Research/Manufacture Organizations

R7: Foreign R&D Centers

R8: Multinational Companies and Wholly-owned Subsidiaries

For S3: Collaborative Innovation Strategy

R1		Vs.		R2
R1		Vs.		R3
R1		Vs.		R4
R1		Vs.		R5
R1		Vs.		R6
R1		Vs.		R7
R1		Vs.		R8
R2		Vs.		R3
R2		Vs.		R4
R2		Vs.		R5
R2		Vs.		R6
R2		Vs.		R7
R2		Vs.		R8

R3		Vs.		R4
R3		Vs.		R5
R3		Vs.		R6
R3		Vs.		R7
R3		Vs.		R8
R4		Vs.		R5
R4		Vs.		R6
R4		Vs.		R7
R4		Vs.		R8
R5		Vs.		R6
R5		Vs.		R7
R5		Vs.		R8
R6		Vs.		R7
R6		Vs.		R8
R7		Vs.		R8

3.4 Contribution to S4: International Technology Transfer

R1: University Research Programs

R2: Public Research Institutes

R3: State-owned Enterprises

R4: High-tech Small-to-Medium Enterprises

R5: Equity Joint Ventures

R6: Contract Research/Manufacture Organizations

R7: Foreign R&D Centers

R8: Multinational Companies and Wholly-owned Subsidiaries

For S4: International Technology Transfer

R1		Vs.		R2
R1		Vs.		R3
R1		Vs.		R4
R1		Vs.		R5
R1		Vs.		R6
R1		Vs.		R7
R1		Vs.		R8
R2		Vs.		R3
R2		Vs.		R4
R2		Vs.		R5
R2		Vs.		R6
R2		Vs.		R7
R2		Vs.		R8

R3		Vs.		R4
R3		Vs.		R5
R3		Vs.		R6
R3		Vs.		R7
R3		Vs.		R8
R4		Vs.		R5
R4		Vs.		R6
R4		Vs.		R7
R4		Vs.		R8
R5		Vs.		R6
R5		Vs.		R7
R5		Vs.		R8
R6		Vs.		R7
R6		Vs.		R8
R7		Vs.		R8

Overall level of confidence (Please circle the appropriate number):

5: Very high 4: High 3: Medium 2: Low 1: Very Low

---------- Thank You ----------

Appendix E – Disagreement Analysis

Disagreement Analysis - Technology Level

Group A

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.666(b)	.404	.912	18.080	6	54	.000
Average Measures	.952	.872	.990	18.080	6	54	.000

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

Group B

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.565(b)	.294	.874	12.113	6	54	.000
Average Measures	.928	.806	.986	12.113	6	54	.000

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

Disagreement Analysis - Strategy Level

T1: Recombinant Therapeutic Proteins

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.491(b)	.115	.941	6.799	3	21	.002
Average Measures	.885	.510	.992	6.799	3	21	.002

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T2: Recombinant Vaccines

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.465(b)	.094	.935	6.206	3	21	.003
Average Measures	.874	.455	.991	6.206	3	21	.003

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T3: Monoclonal Antibody Technology

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.387(b)	.040	.917	4.785	3	21	.011
Average Measures	.835	.252	.989	4.785	3	21	.011

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T4: Cell and Tissue Engineering

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.204(b)	-.059	.853	2.534	3	21	.084
Average Measures	.672	-.813	.979	2.534	3	21	.084

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T5: Gene Therapy

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.409(b)	.055	.923	5.158	3	21	.008
Average Measures	.847	.319	.990	5.158	3	21	.008

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T6: Antisense Therapy

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.325(b)	.003	.900	3.890	3	21	.023
Average Measures	.794	.025	.986	3.890	3	21	.023

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T7: RNAi

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.362(b)	.025	.911	4.405	3	21	.015
Average Measures	.819	.170	.988	4.405	3	21	.015

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T8: Nanobiotechnology

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.396(b)	.047	.920	4.940	3	21	.009
Average Measures	.840	.281	.989	4.940	3	21	.009

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T9: Synthetic Biology

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.359(b)	.023	.910	4.361	3	21	.015
Average Measures	.818	.159	.988	4.361	3	21	.015

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T10: Bioinformatics

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.308(b)	-.007	.895	3.665	3	21	.029
Average Measures	.780	-.057	.985	3.665	3	21	.029

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T11: Pharmacogenetics

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.330(b)	.006	.902	3.962	3	21	.022
Average Measures	.798	.048	.987	3.962	3	21	.022

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T12: Gene Sequencing

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.242(b)	-.041	.870	2.919	3	21	.058
Average Measures	.719	-.458	.982	2.919	3	21	.058

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T13: Biotechnology Diagnostics

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.329(b)	.005	.901	3.940	3	21	.022
Average Measures	.797	.041	.986	3.940	3	21	.022

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

Disagreement Analysis - Resource Level

S1: Indigenous Innovation

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.333(b)	.108	.718	4.941	7	56	.000
Average Measures	.818	.523	.958	4.941	7	56	.000

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

S2: Imitative Innovation

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.422(b)	.176	.779	6.761	7	56	.000
Average Measures	.868	.657	.969	6.761	7	56	.000

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

S3: Collaborative Innovation

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.154(b)	-.004	.543	2.436	7	56	.030
Average Measures	.621	-.041	.915	2.436	7	56	.030

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

S4: International Technology Transfer

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.407(b)	.163	.769	6.399	7	56	.000
Average Measures	.861	.637	.968	6.399	7	56	.000

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

Subgroup Disagreement Analysis - Technology Level

T4 Cell and Tissue Engineering: Subgroup-G

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.721(b)	.014	.978	6.813	3	6	.023
Average Measures	.886	.042	.993	6.813	3	6	.023

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T4 Cell and Tissue Engineering: Subgroup-F

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.691(b)	-.040	.975	6.034	3	6	.030
Average Measures	.870	-.129	.992	6.034	3	6	.030

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T4 Cell and Tissue Engineering: Subgroup-L

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.861(b)	-.284	.991	10.320	3	3	.043
Average Measures	.926	-.792	.995	10.320	3	3	.043

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T12 Gene Sequencing: Subgroup-G

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.653(b)	-.101	.971	5.241	3	6	.041
Average Measures	.850	-.378	.990	5.241	3	6	.041

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T12 Gene Sequencing: Subgroup-F

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.633(b)	-.131	.969	4.878	3	6	.048
Average Measures	.838	-.533	.990	4.878	3	6	.048

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.

T12 Gene Sequencing: Subgroup-L

Intraclass Correlation Coefficient

	Intraclass Correlation(a)	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.867(b)	-.251	.991	10.788	3	3	.041
Average Measures	.929	-.671	.995	10.788	3	3	.041

Two-way random effects model where both people effects and measures effects are random.
a Type A intraclass correlation coefficients using an absolute agreement definition.
b The estimator is the same, whether the interaction effect is present or not.