GOVERNMENT INTERVENTION IN TECHNOLOGICAL INNOVATION SYSTEM IN CATCHING-UP CONTEXT: COMPARATIVE CASE STUDY

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LIST OF ABBREVIATIONS

3GPP	3^{rd} Generation Partnership Project
AMPS	Advanced Mobile Phone System
ANT	Actor-Network Theory
BRICs	Brazil, Russia, India, China
CAE	Chinese Academy of Engineering
CAS	Chinese Academy of Sciences
CASS	Chinese Academy of Social Science
CATT	China Academy of Telecommunication Technology
CCAC	China Communications Services Corporation
CDMA	Code Division Multiple Access
CNNIC	China Internet Network Information Center
EDGE	Enhanced Data rates in GSM Environment
ETSI	European Telecommunication Standards Institute
EU	European Union
FDD-LTE	Frequency Division Duplexing-Long Term Evolution
FDI	Foreign Direct Investment
FDMA	Frequency Division Multiple Access
GDP	Gross Domestic Product
GPRS	General Packet Radio Service
GSEs	Government Sponsored Enterprises
GSM	Global System for Mobile communication
GSMA	Global System for Mobile Communications Alliance
GTI	Global TD-LTE Initiative
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronic Engineers
ISO	International Organization for Standardization
ITU	International Telecommunication Union
LIS	Local Industrial System
MIIT	Ministry of Industry and Information Technology

MLP	National Medium- and Long-Term Program for S&T Development
MOC	Ministry of Commerce
MOE	Ministry of Education
MOF	Ministry of Finance
MOP	Ministry of Personnel
MOST	Ministry of Science and Technology
MTE	Major Technological Equipment
MTP	Ministry of Posts and Telecommunication
NDRC	National Development and Reform Commission
NIS	National Innovation System
NSFC	National Natural Science Foundation of China
OBM	Own Brand Manufacturing
ODM	Own Design Manufacturing
OECD	Organization for Economic Co-operation and Development
OEM	Own Equipment Manufacturing
OFDM	Orthogonal Frequency Division Multiplexing
PRI	Public Research Institute
R&D	Research and Development
RIS	Regional Innovation System
S&T	Science and Technology
SAIC	State Administration for Industry & Commerce
SARFT	The State Administration of Radio, Film and Television
SASAC	State-owned Assets Supervision and Administration Commission
SCOT	Social Construction of Technology
SIS	Sectorial Innovation System
SME	Small and Medium Enterprise
SMS/MMS	Short Message Services/Multimedia Messages Services
SOE	State-Owned Enterprise
STI	Science, Technology and Innovation
TACS	Total Access Communication System
TDIA	TD-SCDMA Industry Alliance

TD-LTE	Time Division Long Term Evolution
TDMA	Time Division Multiple Access
TD-SCDMA	Time Division-Synchronization Code Division Multiple Access
TIS	Technological Innovation System
TRIP	TD-SCDMA R&D and Industrialization Program
UMTS	Universal Terrestrial Mobile System
VNOs	Virtual Network Operators
WCDMA	Wideband-Code Division Multiple Access
WiMAX	Mobile Worldwide Interoperability for Microwave Access
WTO	World Trade Organization
ZTE	Zhongxing Telecommunications Equipment

ABSTRACT

Recent years have witnessed many significant changes in the global technology landscape. An interesting change we have observed is that some traditional technology late-coming countries such as China and Korea have started to emerge as influential players in the international arena of technology innovation. Historically, developed countries, holding incomparable advantages in financial markets and technologically intensive industries, have naturally taken the lead in technology innovation; while severe deficiencies and challenges are normally faced for developing, or late-coming countries, in innovation. In the literature, strong support from the government has been proven to be crucial for late-coming countries to overcome the deficiencies and to catch up in technology innovation. Based on innovation system perspective, this dissertation aims to understand how the government intervention in technological innovation system (TIS) promotes technology innovation, especially that in the catching-up context.

This dissertation examines two technology innovation cases in China, namely the TD-SCDMA and TD-LTE mobile system innovations. A theoretical framework is developed based on institutional theory to structure the case studies. Qualitative methods including documentary research and semi-structured interviews are applied for data collection. This research concludes that, in the stages of technology development and technology diffusion, different TIS functions need to be achieved and different challenges are faced, which require government intervention. The government could analyse how TIS functions are achieved and how challenges are formed in relation to the TIS structural components, in order to determine the intervention strategy. Government can take both direct intervention on TIS actors, and indirect intervention through impacting TIS institutional environment, with regulative, normative and cognitive instruments. In the catching-up context, government interventions contribute more to path-breaking type technology innovations than path-dependent ones in terms of ensuring the success of innovation. Practical implications for the government to effectively intervene in innovation initiatives are given.

DECLARATION

This dissertation is submitted to The University of Manchester for the degree of PhD in the Faculty of Humanities. I, Guanyu Liu, hereby, declare that no portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institution of learning.

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DEDICATION

To my grandfather and grandmother

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CHAPTER 1 INTRODUCTION

1.1 CATCHING-UP IN TECHNOLOGY INNOVATION

Along with the trend of globalization, recent years have witnessed many significant changes in the global technology landscape. An interesting change we have observed is that some traditional technology late-coming countries have started to emerge as influential players in the international arena of technology innovation (e.g. Mathews, 2005, Bruche, 2009, Yu and Zhang, 2013, Gao et al., 2014). Some late-coming countries like China and Korea have transformed their technology development strategies from initially imitating the technological frontiers to catching-up in terms of technology innovation (Fan, 2006, Cao et al., 2009, Choung et al., 2012, Gao et al., 2014). They are gradually gaining a sustainable capability in technology innovation, and several remarkable accomplishments have already been achieved. For example, so far, Chinese firms have already launched several competitive technologies, both in domestic and overseas markets, such as Linux-based systems, Huawei's mobile base station technology and Galaxy supercomputing (Cao et al., 2009). Similarly, several globally influential technologies from Korea, like WiBro (wireless broadband internet) and HSDPA (high speed downlink packet access), have also been commercialized in global markets (Lee et al., 2009, Kwak et al., 2011).

Throughout history, taking advantage of financial markets and technologically intensive industries, developed countries have naturally occupied the leading position in technology innovation (Freeman, 2002, Nelson, 2004, OECD, 2012, Gao, 2015). Most world changing technological innovations have originated from the developed countries. For example, in the telecommunication field, the world's first telephone was commercialized by *Alexander Graham Bell* in 1892 in Chicago in the US; the first handheld mobile cell phone was produced by *Martin Cooper* of Motorola in 1973 in the US; the first commercial automated cellular network was launched by *NTT* in 1979 in Japan; and the first digital cellular network (GSM) was launched by *Radiolinja* in 1991 in Finland.

For developing countries to catch up in terms of technology innovation, severe deficiencies are normally faced, as they are generally characterized by a weak foundation in technology innovation and a long history of technology imports (Bastian, 2010, Vialle et al., 2012, Gao et al., 2014). For example, in China, it has been observed that indigenous technology innovations are mostly hindered by deficiencies in key resources and capabilities that are required, i.e. R&D infrastructures and skilled human resources (Gao, 2014). Besides, being accustomed to importing foreign technologies, the consciousness for independent innovation and the protection of IPRs were weak in China, which means an innovation friendly environment had not been well established.

Strong support from the government has been proven to be crucial for late-coming countries to overcome the deficiencies faced and to catch up in technology innovation (Wang and Kim, 2007, Kshetri et al., 2011, Kwak et al., 2011, Gao et al., 2014, Levén et al., 2014, Zhu, 2014). For example, in China, the government has emphasised cultivating several domestic high tech industries, the national strategy to promote indigenous innovation has been expressed through several "National Five-year Plans" that have been launched, and many significant innovations in the high-tech area were strongly supported by the Chinese government in particular (Chen and LiHua, 2011, Hu et al., 2012, Yu and Zhang, 2013). Similarly, in Korea, the government also managed the national system of innovation to develop the national innovative capabilities in several key technological areas, and supported several significant indigenous technologies in both development and diffusion (Shin et al., 2006, Wang, 2007, Choung et al., 2012).

Technology innovation has long been recognised as a main driving force for development and growth (Fagerberg, 2005, OECD, 2012). Benefiting from technology innovation, developed countries seek to sustain its development and to maintain competitiveness, while developing countries seek to stimulate growth and catch up with the frontiers of development (Nelson and Nelson, 2002, Fagerberg and Srholec, 2008). Therefore, witnessing late-coming countries' success in technology innovation catching-up, and understanding how government can promote indigenous technology innovation has attracted the common interests of both developed and developing countries.

1.2 INNOVATION STUDY OF GOVERNMENT INTERVENTION IN TECHNOLOGY INNOVATION

In the literature, with the help of a broad range of analytical perspectives, many studies have been conducted to understand the significant roles that government plays in technology innovation. For example, Gao et al. (2014) summarized that government could play the roles of project founder, financial sponsor, risk undertaker, interest moderator, collaboration facilitator and process monitor to promote indigenous innovation. The instruments of government intervention include leveraging public procurement (Edler and Georghiou, 2007), locating and distributing resources (Xia, 2012a, Borrás and Edquist, 2013), mediating market competition and facilitating organizational cooperation (Funk and Methe, 2001, Damsgaard and Lyytinen, 2001).

Nevertheless, we found that, although the roles of government and the instruments of government intervention in technology innovation are recognized, research gaps still exist in the current innovation literature when interpreting the phenomena that observed. On the one hand, the context proves to be significant in understanding innovation activities, as the features of technology innovation and government intervention are varied in relation to different contexts (e.g. Stacy, 2007, Wang and Kim, 2007, Kwak et al., 2011, Gao and Liu, 2012, Chung, 2013). In the current innovation literature, most knowledge is conceptualized based on the context of developed nations, more research efforts directed toward the uniqueness of catching-up context should be taken (Bastian, 2010, Vialle et al., 2012, Gao et al., 2014). On the other hand, the innovation literature has indicated that technology innovation has a system feature in nature (Nelson and Nelson, 2002, Carlsson, 2006). Innovation system perspectives have been widely applied in understanding technology innovations, as well as government in innovations (Fagerberg and Srholec, 2008, Chaminade et al., 2012). Nevertheless, innovation studies that understand the interactions between government and technological innovation system in technology innovation are relatively limited. A holistic view of mechanism of how government intervention in technological innovation system promotes technology innovation is needed.

1.3 RESEARCH AIM AND QUESTION

To address the research gaps that identified, we aim to understand how the government intervention in technological innovation system promotes technology innovation, especially that in the catching-up context. In this dissertation, China's catching-up in technology innovation is particularly focused to achieve the aim of this research. As on the one hand, based on reviewed literature, strong support from the government has been proven to be crucial for late-coming countries especially China to overcome the deficiencies that faced in technology innovation (Wang and Kim, 2007, Kshetri et al., 2011, Kwak et al., 2011, Gao et al., 2014, Levén et al., 2014, Zhu, 2014); on the other hand, it is also witnessed that, with strong government support, a number of technological innovation systems have been built in most of the highlighted industries in China. The government takes interventions in both innovation systems' creation and maintenance. The technological innovation systems with strong government support are also recognized as a key for China to catch up in technology innovation. Therefore, associate China's catching-up cases with the aim of this research, the main research question for this dissertation to answer is:

RQ: How the government intervention in technological innovation system promotes technology innovation in China?

At the operational level, the research question is divided into four sub questions:

SQ1: What are the characteristics of TIS and government intervention in China?

SQ2: How can TIS affect the development and diffusion of a technology?

SQ3: What are the main challenges for the government to address in China's catching-up in technology innovation?

SQ4: What strategies and instruments the government applied to promote technology innovation in China, and how?

1.4 RESEARCH DESIGN

In this dissertation, the critical realism perspective constructed the philosophical standpoint, and qualitative case studies are adopted as the methodology. The research question is answered through examining two innovation case studies in China's telecommunication field, namely the 3G TD-SCDMA (Time Division-Synchronization Code Division Multiple Access) and 4G TD-LTE (Time Division Long Term Evolution) mobile systems, respectively.

To answer the research questions, China's 3G and 4G mobile system innovations are selected as the case studies due to three primary concerns: firstly, the 3G TD-SCDMA and 4G TD-LTE innovations are typical cases that reflect China's catching-up in technology innovation. Historically, China did not participate in the global innovations in the 1G and 2G eras, and the first two generations of mobile systems were mostly developed in the EU and the US. However, China's TD-SCDMA and TD-LTE have been authorised by the International Telecommunication Union (ITU) as international mobile system standards in 3G and 4G era, respectively (Gao and Liu, 2012).

Secondly, the telecommunication industry has long been recognised as one of the key industries for national development in China (Kshetri et al., 2011, Xia, 2012a). Strong government support has proven to be crucial for the success of China's 3G and 4G mobile system innovations (Chen et al., 2014, Gao et al., 2014). The government holds full control of China's telecommunication industry, and the roles played by the government in promoting indigenous technology innovations in telecommunications are extremely prominent and significant (Kwak et al., 2012). Thus, examining the case studies could well exhibit the mechanism of government intervention in innovation.

Lastly, technology innovation in the telecommunication field could well exhibit how the technological innovation system functions to impact innovation. As Lyytinen and King (2002) indicated, the telecommunication industry is generally constituted and shaped by the dynamic interactions among the regulatory regime, the innovation system and the marketplace, while the industry's evolution and technology innovation are both related to the changing interactions between these systems. In China, as the government has full control of the telecommunication industry, it is observed that the interactions between the government and the innovation system of technology are quite frequent and multifarious (Zhang and Liang, 2011, Gao et al., 2014). Thus, examining the innovation cases in China's telecommunication industry could well exhibit how government can interact with the innovation system to promote technology innovation.

Three issues concerning the selection of the 3G and 4G mobile system innovations in China's telecommunication industry as case studies ensure that the research aim could well be achieved and the proposed research questions could be properly answered. Based on the reviewed literature, an analytical framework is developed to structure the case studies. Documentary research and semi-structured interviews are applied for data collection. Resources like archives, websites, reports, and academic papers are adopted, and in-depth interviews are conducted with 44 executives in 16 relevant organisations.

Three rounds of data analysis are conducted based on the strategy Yin (2009) introduced. The narratives of the two case studies are constructed based on the data collection and analysis. After that, the research question is answered through examining the two narrative case studies, and conclusions are made accordingly. To ensure the research quality, a triangulation strategy is applied throughout the whole process of data collection and analysis (Mathison, 1988, Patton, 2002).

1.5 DISSERTATION STRUCTURE

The next two chapters review the literature on technological innovation system (Chapter 2) and government in technology innovation (Chapter 3), respectively. Relevant concepts and studies are introduced, and the catching-up context of technology innovation is particularly emphasized. Based on the reviewed innovation studies, research gaps in the current innovation literature are identified, and the research question of this dissertation is proposed.

Chapter 4 introduces the analytical perspective and develops the framework. A detailed elaboration is given on the adoption of institutional theory as the analytical prospective of this research. Based on institutional theory, a framework is developed for understanding the mechanism of how government intervention in technological innovation system promotes technology innovation, especially that in the catching-up context. The main research question is articulated based on this framework and is divided into four sub-questions at the operational level.

Chapter 5 introduces the research design. Specifically, the selection of critical realism as the philosophical perspective and qualitative case study as the methodology of this research are elaborated in detail. In this work, the proposed research question is answered through examining two mobile system innovation case studies in China. Thus, research settings and case selections are illustrated, and the strategy for data collection and analysis are introduced. Lastly, the research quality is assessed.

Chapter 6 illustrates the background of the case studies. Specifically, the historical evolution of mobile systems from 1G to 4G is reviewed. Furthermore, the telecommunication background in China is illustrated, including the NIS and the national innovation policy for indigenous innovation, the historical transformation of China’s telecommunication industry, the contemporary supervisory architecture and the market competition in China’s telecommunication field.

Chapter 7 and Chapter 8 respectively present the two case studies. The 3G TD-SCDMA and 4G TD-LTE mobile system innovations in China are respectively illustrated in detail. For each case, the chronology, including the critical events in the innovation process, as well as both technology development and diffusion, is generated. The innovation system, including the structural components, functions and performances, is delineated. The challenges that each innovation faced are identified, and the relevant government interventions are exhibited.

Chapter 9 documents the analysis of the case studies. Synthetic analysis is conducted based on the developed theoretical framework. The four sub-divided research questions are discussed in depth and answered through examining the case studies. The mechanism of government intervention into the TIS to promote technology innovation in the catching-up context is exhibited. Through synthetically analysing the conclusions that are made in each case, several findings are also demonstrated and discussed.

Chapter 10 concludes this dissertation. The process of research is reviewed. The proposed research questions are revisited and conclusions are made. The contributions of this dissertation, both analytical and practical, are summarised. Lastly, the limitations of this research and inspirations for future studies are elaborated.

CHAPTER 2: TECHNOLOGICAL INNOVATION AND TECHNOLOGICAL INNOVATION SYSTEM

2.1 INTRODUCTION

This chapter reviews studies about technology innovation, the technological innovation system, as well as the catching-up context for innovation. Specifically, section 2.2 introduces the concepts of technology innovation and related studies. Section 2.3 introduces technological innovation system. Section 2.4 emphasises the catching-up context. Section 2.5 concludes the chapter.

2.2 TECHNOLOGY INNOVATION

2.2.1 Technology management and technology strategy

In the literature, technology is defined differently in different studies. For instance, Karatsu (1990) indicates that Technology represents the combination of human understanding of natural laws and phenomena accumulated since ancient times to make things that fulfil our needs and desires or that perform certain functions. Dean and LeMaster (1991, p. 19) define technology as "firm-specific information concerning characteristics and performance properties of production processes and product design". Miles (1995) defines technology as the means by which we apply our understanding of the natural world to the solution of practical problems. It is a combination of "hardware" (buildings, plant and equipment) and "software" (skills, knowledge, and experience together with suitable organisational and institutional arrangement). Maskus (2004, p. 9) defines technology as "the information necessary to achieve a certain production outcome from a particular mean of combining or processing selected inputs". In this research, we adopt the definition that provided by the UN Conference on Trade and Development (UNCTAD), who defined technology as:

> *"...bought and sold as capital goods including machinery and productive systems, human labor usually skilled manpower, management and specialized scientists. Information of both technical and commercial character, including that which is readily available, and that subject to proprietary rights and restrictions."*

In the literature, technology is normally learnt as consisting of four closely interlinked elements: namely, technique, knowledge, the organization of the production and the product (Chen and LiHua, 2011). Knowledge is increasingly being recognized as a vital organizational resource that gives market leverage and competitive advantage (Nonaka and Taekuchi, 1995; Leonard-Barton, 1995). In general, knowledge consists of two components, namely explicit and tacit. Tacit knowledge is created "here and now" in a specific, practical context, while explicit knowledge is about past events or objects "there and then" (ibid.). Technology transfer does not take place without knowledge transfer, while technology transfer is the prerequisite for technology innovation to happen (Chen and LiHua, 2011).

Apart from understanding the definition and the nature of technology, technology management and strategy are also significant, and have attracted great enthusiasms as a research topic in the literature. According to Khalil (2001), technology management is about getting people and technologies working together to do what people are expecting, which is a collection of systematic methods for managing the process of applying knowledge to extend the human activities and produce defined products. Effective technology management synthesizes the best ideas from all sides: academic, practitioner, generalist or technologist (ibid.). It is argued that there are three major factors strategically in modern organizations that underpin the creation of competitive advantages: leadership ensures that the enterprise will develop itself in the right direction and the production of product will meet the demand of the market; motivation and empowerment are the driving forces of the organization; and proper management of technology, which is important that the company's technology be appropriately and properly managed so as to achieve effective and competitive status (Harrison and Samson, 2003). The advantages in managing technology could also enhance the compatibility for a country in global competition (Blind, 2011).

Technology strategy is no doubt an important but often ignored link in the strategic formulation system. Compared with the position of development and marketing strategy, technology strategy appears to be in a fragmented, piecemeal fashion. A strategy of a nation is a means by which the internal strengths and the weaknesses are linked with the opportunities and threats provided by its environment. Technologies by themselves do not establish the overall strengths of a nation. However, the appropriate and effective technology strategy is a key component and driving force in attaining competitiveness.

Porter (1988) describes "technological strategy" as "a vehicle for pursuing generic competitive strategies aiming at fundamentally different types of competitive advantages" in trying to establish a conceptual link between technological change and the choice of competitive strategy by the individual firm. Rosenbloom (2001) regards "technology strategy" as "the revealed pattern in the technology choices of firms, which involve the commitment of resources for the appropriation, maintenance, deployment, and abandonment of technological capacity. These technological choices determine the character and the extent of the firms' principal technical capacities and the set of available product and process platforms. In this thesis, we adopt the term "technology strategy" to describe the strategically important technology choices made by a state. It is a strategic instrument in achieving sustainable competitive advantage and thereby achieving the catching-up in technology innovation.

2.2.2 Concepts and process of technology innovation

Innovation is not just about "creating new things". According to the general definition from the OECD Oslo Manual (OECD, 2005, p.46), innovation is defined as:

> *"The development and the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations…"*

Specifically, based on how radical the innovations are compared with the existing setup, scholars have also differentiated the radicalistic of innovation, which distinguishes the form of innovation between something that is completely new and something that is improved (Nemet, 2009). Accordingly, innovations that are led by continuous improvements are characterized as *incremental* or *marginal innovation*, while *radical innovations* normally refer to those activities that introduce an entirely new type of machinery or achieve a far-reaching impact (Baregheh et al., 2009).

According to these definitions, five innovation types are identified: namely, introduction of new products, new methods of production, new sources of supply, exploitation of new markets and new ways to organize business. Differentiated by the targets or the outcomes, the five types are categorized into two groups: *non-technology* and *technology innovation*. Specifically, non-technology innovation mainly refers to changes in management areas, like improving ways of doing business (Birkinshaw et al., 2008), while technology innovation mainly consists of producing new products, or improving techniques in terms of production (Fagerberg, 2005).

In this work, technology innovation is emphasized. However, very little effort is made in the innovation literature to specifically define what technology innovation is, and thus the work of Baregheh et al. (2009, p.1333) is referred to; in this work we have our own definition of technology innovation as:

> *A multi-stage process whereby certain groups of stakeholders transform their ideas into new or improved technology products, services or processes with the aim to advance, compete, and differentiate successfully in market competitions.*

Innovation scholars hold varied perspectives on distinguishing stages of the technology innovation process. For instance, McKenney (1994) suggested that technology innovation follows a “cascade” process, which sequentially goes through five stages, namely solution searching, competence building, expanding solutions, enabling changes, as well as strategy evolution. Gopalakrishnan and Damanpour (1997) also identified five stages of innovation, starting from ideation, and then project definition, problem solving, development and finally commercialization. Van de Ven (2005) indicated that successful technology innovation must include both *developing* and *commercializing* the new technology. King et al. (1994) recognized technology innovation as a process of the *production* and *use* of a technology.

In this work, concluding from the literature, we learn that a complete technology innovation is a two-stage process: namely technology development and technology diffusion (David and Greenstein, 1990, Markus et al., 2006, Gao, 2015). In terms of technology development, this stage mainly focuses on "producing" the technology, while in terms of technology diffusion, this stage mainly focuses on "using" the technology (King et al., 1994). In the literature, several separate processes are required to develop a technology, including for instance, basic research, applied research, product development, production research, quality control, as well as commercialization (Hage and Hollingsworth, 2000). To diffuse a technology, separate processes could include, for instance comprehension, adoption, implementation, and assimilation (Swanson and Ramiller, 2004).

The success of a technology innovation initiative means that the technology has not only been developed, but has also been diffused in the market successfully (Gao, 2015). In innovation practice, technology developers normally actively participate in the diffusion of technology in order to profit from their earlier R&D investments. Similarly, technology adopters are often actively involved in technology development, rather than waiting until the technology is ready to use, with the aims of understanding the technology's properties and seeking potential business opportunities (ibid.). In fact, such kinds of "boundary-cross" participation of the innovation actors could significantly contribute to the success of the innovation. This is because technology adopters participating in technology development could provide more accurate information on market demand for the new technology, and technology developers involved in technology diffusion could significantly facilitate converting the new technology into products or services for the market (Funk and Methe, 2001).

Both technology innovation stages present different challenges. Markus et al. (2006) suggest that the high degree of heterogeneity of the interests and resources of innovation participants is normally the primary driving force for different challenges that are faced in different innovation stages. Besides, Markus et al. (2006) called for both stages of the technology innovation process to be looked at jointly, as well as for a focus on their interrelationships. Nevertheless, according to Lyytinen et al. (2008), most existing innovation studies focus either on technology development or diffusion, rather than both. In this work, we also suggest that examining both innovation stages is necessary, as it has been observed in many cases that a well-developed technology might fail in diffusion. For example, in China a massive number of technology patents are granted, but few of them are actually deployed in the market (e.g. Fan, 2006, SIPO, 2015).

2.2.3 Networked nature of technology innovation

Technology innovation, especially on a national level, normally features a networked nature in both development and diffusion stages (Ahrweiler and Keane, 2013). Organization is normally recognized as the basic unit, or the undertakers of technology innovation (see e.g. Lawrence et al., 2002, Tilson and Lyytinen, 2006b, Crossan and Apaydin, 2010). Nevertheless, every organization has its boundaries, which means it is most likely that one alone cannot provide sufficiently required resources and capabilities (Hage and Hollingsworth, 2000). Organization needs to build up relationships, or ties, with external partners when undertaking innovation project. Such partners might include the suppliers, customers, certain institutes, or even competitors in the marketplace (Farrell and Saloner, 1985, Markus et al., 2006).

Linked by the aim of exchanging capabilities or resources, involved the organizations would naturally establish a network for technology innovation (Ahrweiler and Keane, 2013). Actors of the network are heterogeneous in terms of their interests and resources which can have positive or negative, direct or indirect, effects on technology innovation (Lee and Park, 2006, Baregheh et al., 2009, Levén et al., 2014, Samara et al., 2012, Bichler and Schmidkonz, 2012). The established networks are also capable of guiding or constraining the behaviors of the actors involved (Tilson and Lyytinen, 2006b). Within such networks, ideas, resources, skills and capabilities could flow and be exchanged among actors (Carlsson et al., 2002).

Lyytinen and King (2002) categorized the actors in technology innovation into three domains, namely the regulatory regime, the marketplace and the innovation system. Specifically, the regulatory regime is constituted by varied authorities, including industrial, national and even international, who can impact, direct, constrain or prohibit any activity in the innovation system, the marketplace or the regulatory regime itself; the marketplace is constituted by a set of organizational actors providing services, content or technologies; the innovation system includes the actors who undertake the innovation activities (ibid.). In this work, this frame is adopted for two reasons: on the one hand, the frame helps categories the literature regarding the various actors in technology innovation, which gives the work more organization; on the other hand, the frame helps describe the industrial environment in the empirical chapter.

Lyytinen and King (2002), who originally introduced this analytical frame, suggested that this frame is not only applicable in delineating the industrial environment for technology innovation, but also particularly appropriate in analyzing large scale systemic innovation. This is because large scale systemic innovation particularly demands the coordination of multiple independent and heterogeneous actors to ensure compatibility and interoperability across different systems (ibid.). Furthermore, in terms of frame application, Fomin (2008) adopted the frame to investigate the influence of industrial innovation policies in the Danish wireless industry while Tilson and Lyytinen (2006a) used this three domain frame to describe the US telecommunication industry in 3G standardization, and map the changes compared with the industry in the 2G era.

Regulatory regime

In terms of the regulatory regime, current innovation studies mainly emphasize a more powerful force, which can impact the development and diffusion of technological innovation, and which is about policy for technology innovation (e.g. Rothwell, 1982, Teece, 1986, Madden and Savage, 1999, Bar et al., 2000, Tödtling and Trippl, 2005, Kennedy, 2006, Edler and Georghiou, 2007, Eric, 2007, Fomin, 2008, Shin, 2008, Courvisanos, 2009, Nemet, 2009, Yasunaga et al., 2009). Most innovation policy studies focus on the influence of policies on technology innovation, and aim to answer the question of how to promote specific innovations by delivering appropriate policies (Dolfsma and Seo, 2013, OECD, 2015b).

As the key actors in the regulatory regime, the government authorities have attracted most and substantive interest from innovation scholars (e.g. Moon and Bretschneider, 1997, Stacy, 2007, Raus et al., 2009, Fuchs, 2010, Epstein, 2012, Gao et al., 2014, Zhu, 2014). These studies have suggested that the government always plays significant, unique and varied roles in technology innovation, especially for innovations located beyond the industrial level. As mentioned in the introduction, in technology innovation government is emphasized as a core issue in this research; thus, we devote the whole of the following chapter to reviewing studies related to government in technology innovation.

Besides this, a number of case studies from different regions and industries are conducted in the literature, and experiences of stimulating technological innovation are summarized. Nevertheless, it is observed that most of the selected innovation cases are in developed regions or countries, although studies on innovation policies in less developed or developing countries have emerged just in recent years (e.g. Samarajiva, 2000, Mu and Lee, 2005, Steen, 2011, Xia, 2012b, Yu et al., 2012, Borrás and Edquist, 2013, Chung, 2013, Dolfsma and Seo, 2013, Lim et al., 2014, Gao, 2014). Innovation policy is emphasized in this research. Compared with existing studies, especially those works that have emphasized developed regions, this research is designed with the aim of contributing more to innovation practices in less developed or developing nations.

Marketplace

In terms of the market domain, current innovation studies mainly put effort into exploring the influences of competition or market forces on technology innovation. Market forces here might include the impacts from suppliers upstream, from customers downstream, other competitors in the same market and so on. For instance, Robertson et al. (1996) presented an empirical case study in the UK manufacturing sector during late

1980s, with the aim of explaining how suppliers in the market could impact diffusion. By analyzing the cases of three companies, their work revealed that potential adopters of new technology were mostly influenced by an engaged inter-organizational network. Knowledge about new technology was diffused through this network, which they later found to be initiated by the supplier of the new technology. This has also been described as a form of “supply-push” strategy (King et al., 1994).

Similarly, Funk and Methe (2001) presented a case of standardization in the mobile communication industry to show how technology innovation could be influenced by a hybrid system that was founded by influential market participants; Rycroft and Kash (2004) analyzed how vendors in the same market set up a self-organized network for promoting technology innovation in terms of both development and diffusion; and Hansen and Birkinshaw (2007) conducted an analysis based on the value chain of innovation, and described how different actors in the market place could individually participate in and influence the development and diffusion of innovation. In the literature, innovation studies that focus on the market domain’s influences on technology innovation are quite substantial, and are not constrained just to the works listed above.

Innovation system

How different actors in the innovation system affect the development and diffusion of technology is also emphasized in the literature. By distinguishing them from the actors in the regulatory regime and the marketplace, Lyytinen and King (2002) defined actors in the innovation system as the organizations which undertake innovation activities. Such a definition is particularly instrumental for an understanding technology innovation.

Differentiated based on the different roles they play in technology innovation, the actors within the innovation system could also be categorized into different groups, and related studies have been set up to understand the impacts of the actors in the different groups. For example, some of these works attempt to explain how R&D institutes can impact technology innovation, like Hsu (2005) and Lee and Park (2006). In the former work, Hsu built a conceptual model to explain how a research institute, ITRI, in Taiwan helps to set up new industries and contributes toward upgrading existing industries by promoting indigenous technology innovation. Through understanding the mechanism of how ITRI works, he concluded that the key is that R&D institutes like ITRI help to decide the target of innovation, the methods of R&D and commercialization, and further help to form networks by enrolling other key actors to facilitate the technology innovation.

Meanwhile, some studies also focus on the roles of intermediating organizations in technology innovation, like Damsgaard and Lyytinen (2001) and Kapsali (2011). For instance, Damsgaard and Lyytinen (2001) assess three cases of the diffusion of a technology, EDI (*Electronic Data Interchange*), in Hong Kong, Denmark, and Finland. They reveal how intermedia organizations in these regions shape the diffusion of new technology such as EDI. By examining a specific type of intermediating organization – industry associations – in three case studies, they identified six institutional measures that industrial associations applied to facilitate the diffusion of EDI, and developed an analytical matrix. Industrial associations were found to be highly active in using institutional measures. According to their conclusions, intermediating organizations can play significant roles in promoting the diffusion of new technology, especially in knowledge building, knowledge development, and setting standards.

The studies introduced above are not exclusive. Actors in other groups in the innovation system, which have not been elaborated, might also be completely decisive. For example, some other key actors, such as influential enterprises (e.g. Siu et al., 2006, Eric, 2007, Xia, 2012b) and participating universities (e.g. Lee and Park, 2006, OECD, 2007b, Chaminade et al., 2009), have also been emphasized in the literature.

2.2.4 System perspectives of technology innovation

The networked nature of innovation has enlightened innovation scholars to analyze innovation phenomena from a unique perspective – the system perspective of innovation (e.g. Freeman, 1995, Carlsson et al., 2002, Lundvall et al., 2002, Nelson and Nelson, 2002, Hekkert et al., 2007, Fagerberg and Srholec, 2008). Fagerberg (2005) summarized the differences between networks and systems as follows: a system has feedback, and is more structured and enduring than a network. Unlike linear perspectives of innovation, which view innovation as a linear process that starts from the generation ideas and ends up with implementation (e.g. Kash and Rycroft, 2002, Hansen and Birkinshaw, 2007), or multi-level perspectives, which explain technological transitions by the interplay of processes at three different levels (e.g. Geels, 2002, Geels and Schot, 2007, Markard and Truffer, 2008, Tarafdar et al., 2013), system perspectives of innovation mainly highlight the collaboration among participants, and give more credit to the historical evolution of a specific innovation (Nelson, 1992, Carlsson et al., 2002, OECD, 2007b).

The system perspective of innovation attracts significant research attentions. Sharif (2006) highlighted generation and diffusion of new technologies are the basic functions of an innovation system; Hekkert et al. (2007) indicated that understanding technological change from the innovation system perspective is more structured, and the perspective also provides a standard platform to make comparisons between different innovation projects; Bergek et al. (2008) adopted the perspective to develop an analytical framework by identifying structural components, functions and performances of the system, which could contribute to policy-making for promoting innovation. Chang & Shih (2004) introduced a framework to compare the innovation systems of mainland China and Taiwan, revealing that they both have unique characteristics and suggesting a future cooperation between the two innovation systems due to a high degree of similarity; Hekkert et al. (2007) argued that traditional methods of innovation system analysis are insufficient, and introduced a number of processes that are highly important for well operating innovation systems; Chung (2013) applied an innovation system in analyzing the emergence and diffusion of Taiwanese pharmaceutical biotechnology policies, and suggested that the consistency and appropriateness of these policies are highly shaped by the system's components.

In the literature, a general innovation system perspective could be differentiated into distinct divisions, such as national innovation system (NIS) (Freeman, 1987, Lundvall, 1988, Nelson, 1988), sectorial innovation system (SIS) (Malerba, 1999, Pavitt, 2000), regional innovation system (RIS) (Saxenian, 1994, Cooke et al., 1997, Chung, 2002), and technological innovation system (TIS) (Hekkert et al., 2007, Bergek et al., 2008, Markard and Truffer, 2008) etc. Different innovation systems normally focus on different units of analysis. They are distinguished by the scopes, levels, and contexts of innovation or innovation studies, but in general share similar aims and functions (*to pursue innovation processes*) and operating mechanisms (*about how to produce innovations*) (Carlsson, 2006).

As the origin of the other innovation system concepts, the NIS concept is the belief that a complex set of relationships among involved actors, who create, produce, distribute, and apply new knowledge, is highly relevant to innovation (Freeman, 1995). According to the premise of the NIS concept, a nations' innovation performance, to a high degree, rests on the system that is composed by these actors (Freeman, 2002). Informative individuals and organizations, such as public and private firms, research institutes, and universities, can all be recognized as actors in a NIS. Various linkages between these actors may take forms like joint research, cross-patenting, equipment purchasing and so on (Carlsson et al., 2002).

A variety of definitions of NIS are identified in the literature. No single accepted definition exists, but most of them are derived from two early definitions from Freeman (1987) and Lundvall (1988). The following are widely adopted definitions if NIS:

> *"... the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies."* (Freeman, 1987)

> *"… the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge… and are either located within or rooted inside the borders of a nation state."* (Lundvall, 1992)
>
> *"… a set of institutions whose interactions determine the innovative performance… of national firms."* (Nelson, 1988)
>
> *"… the national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change generating activities) in a country."* (Pavitt, 1988)

In fact, apart from the different aspects emphasized, these do not contain too many differences, while the importance of interactions among actors, as well as a web of interactions, are commonly agreed. Next section introduces the concepts and studies of technological innovation system, which is an innovation system concept that particularly focuses on specific technology innovations.

2.3 TECHNOLOGICAL INNOVATION SYSTEM

2.3.1 TIS definition and nature

In literature, technological innovation system is defined in different ways. E.g. Lundvall describes TIS as a combination of interrelated actors, a set of institutions that characterize the routines of behavior, and the knowledge infrastructure that connected to technology innovation (Lundvall, 2007). A more widely accepted definition from Carlsson and Stankiewicz (1991, p.49), introduced TIS as:

> *"A network of agents that interacting in the economic or industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology." (p.49)*

This definition is adopted for this research, as it maintains both general attributes of an innovation system and the primary concerns of an understanding of technology innovation. Specifically, *"a network of agents"* indicates the actors and relationships that are involved in the system, *"economic or industrial area under a particular institutional environment"* exhibits the institutional environment within the system and the contextual considerations for innovation, while *"to generate, diffuse and utilize technology"* reveals both processes of innovation and the functions of TIS.

In the literature, the TIS concept has received sufficient and consistent interest from innovation scholars, and has been developed into varied analytical frameworks for understanding complex technology innovations. For example, a specific TIS frame was applied to analyze technology innovation in the health care sector in Sweden, in which changes were viewed as composed of several technology systems that support technology artifacts that are applicable in the health care sector (Bergek et al., 2008). Similarly, Negro et al. (2007) employed a TIS frame to analyze failures in innovation in Holland's renewable energy technologies, and to conclude that more intervention activities should be undertaken, especially by the government.

In terms of the nature of TIS, as summarized by Carlsson and Stankiewicz (1991), TIS is a concept that is both disaggregated and dynamic. It is disaggregated because a technology system normally crosses the boundaries between nations, regions and industries; it is dynamic since technology systems always evolve over time, such as changes in the number and forms of components, functions and performances (ibid.).

As for technology, the knowledge it embodies, intends to flow across boundaries, especially within the current context of globalization (Mu and Lee, 2005). Thus, TIS by nature can cut through both geographical and sectoral restrictions, and is not embedded in just one country or a specific sector (Hekkert et al., 2007). Addressing the disaggregated nature of TIS, Bergek et al. (2008) suggested that the specific focus and the precise unit of analysis should be clarified at the beginning. Accordingly, a three phase analysis to clarify the focus and units of TIS studies was introduced: firstly, clarify which field the study is focusing on, a product or knowledge; secondly, clarify the breadth and depth of the study; lastly, clarify spatial domain (Bergek et al., 2008).

Besides, since TIS overlaps geographical and sectoral boundaries, TIS activities, including both technology development and diffusion, could also be impacted by the environment where the TIS overlaps (Negro et al., 2008). Therefore, the disaggregated nature indicates that focusing only on how technology innovation can be "produced" by the TIS is insufficient; the external impacts on the TIS should also be considered. Nevertheless, in the literature, TIS studies mostly focus on understanding the structural components, dynamics, functions, and performance of the system (Bergek et al., 2008, Chaminade and Edquist, 2010), while studies set up to understand how TIS can be impacted by external factors are relatively limited.

Further to understanding the disaggregated nature of TIS, Carlsson and Stankiewicz (1991) have also suggested TIS is dynamic, as is the innovation process. Some scholars have suggested focusing on both the present structure of the TIS and significant contemporary activities that take place within the system, and to then learn the dynamics through comparative studies (Hekkert et al., 2007, Walrave and Raven, 2016). Nevertheless, most current studies tend to analyze the innovation system in a static manner, while studies that analyze TIS dynamics are relatively limited (Walrave and Raven, 2016). Similarly to the lack of analyses on external impacts, insufficient studies in understanding TIS dynamics is also identified as a gap in current innovation research.

This needs to be addressed as dynamic analysis would show the process of regulation and improvement, but only focusing on a static system cannot answer questions about how external impacts come about (Hekkert and Negro, 2009).

2.3.2 TIS structural components

Similar to other innovation systems, the structure of TIS is also defined through three dimensions, namely institutions, actors and networks (Carlsson et al., 2002, Hekkert et al., 2007, Negro et al., 2007, Bergek et al., 2008). The three dimensions together comprise the TIS structure. In this section, we illustrate both the concepts associated with each component and the methods of analysis based on the literature.

Institutions as TIS component

In the literature, there are two different kinds of understanding in terms of institutions. Our definition of "TIS institutions" follows that by North (1991) who define institutions as *"… the set of practices, rules and laws that guide or constrain the behavior of actors (who perform the innovation activities in the system)"*. Rather than that of Nelson (1992), who used "institutions" to indicate "real actors" (like research institutes and universities) or a cluster of actors (such as an educational system). By adopting the former understanding, such TIS institutions could also be the guidance of an actor's behavior, as studies related to institutions, such as institutional theory, have suggested that actors within such an "institutional environment" must pursue "legitimacy" for survival. Legitimacy could be achieved if actors take the behaviors that are "favored" by such an institutional environment (Scott, 2001).

As suggested by Freeman (2002), to develop and diffuse a new technology, institutions should be adjusted, or "aligned", to the technology. For TIS, institutions may come in several forms, and the system could also be affected accordingly (Kukk et al., 2016). In fact, a fundamental role of government in innovation is to establish, maintain and adjust institutions, such as the tax system, patent system and legal system, rather than directly mandating the actors, such as by making managerial decisions. Meanwhile, the behavior of government must take into account extant institutionalized norms and beliefs, as well as established practices (Liu and Cheng, 2014).

Actors as TIS component

In general, heterogeneous actors in innovation, with varied interests and resources, could determine the success or not of an innovation (Markus et al., 2006). In the literature, the roles of different actors in innovation have been relatively well investigated (e.g. Damsgaard and Lyytinen, 2001, Eric, 2007, Fuchs, 2010, Mangelsdorf, 2011, Gao et al., 2014). Most studies have concluded that, even a single powerful actor could have a major impact on system dynamics and could be of key significance in creating or mandating the institutions (Kwak et al., 2011, Chung, 2013, Kukk et al., 2016).

With the purpose of categorizing the actors with a more generic view, Liu and White (2001) distinguished actors involved in innovation into *primary actors* and *secondary actors*. Accordingly, primary actors are the organizations which directly undertake the fundamental innovation activities, like conducting research and implementing new technology; secondary actors, in contrast, are the organizations that can affect the behavior of or interactions between primary actors.

Specifically, secondary actors can act directly to mandate primary actors' behavior, such as by dictating plans, setting targets or determining strategies, further to achieving the target of impacting the fundamental innovation activities that the primary actors undertake. Alternatively, they can affect the behavior of primary actors indirectly through institutions that they create or shape. For example, government authorities are categorized as secondary actors from this perspective; they supervise and support innovation, but do not make managerial decisions for primary actors. By using policies, government may change institutions, like the tax regime, to reward or discourage certain investment behaviors by primary actors (Liu and White, 2001).

This generic analytical frame has been widely adopted to define TIS actors, as it is capable of distinguishing the TIS actors from other involved actors, who are also capable of impacting technology innovation, and of understanding how TIS actors are affected in undertaking the fundamental innovation activities. For example, by adopting this analytical frame, Markard and Truffer (2008) defined *TIS actors* as the organizational actors that directly undertake the innovation activities, like research institutes, universities, some GSEs and private firms. In contrast, organizations that are capable of impacting the behaviors of these TIS actors in undertaking innovation activities, like government or public authorities in the regulatory regime, and some GSEs and private firms in the marketplace, are recognized as *external actors*. Furthermore, in terms of the method of identifying TIS actors in empirical studies, several methods such as *analyzing patents* and *"snowball strategy"* are suggested (Jacobsson and Johnson, 2000, Ricken, 2001). The definition of TIS actors introduced here is also adopted in this work.

Networks as TIS component

Both *formal* and *informal* networks are included in the system (Carlsson et al., 2002). These networks are normally established upon the basis of relationships, such as between university and industry, customers and suppliers, and the formation of joint ventures (e.g. Hage and Hollingsworth, 2000, Rycroft and Kash, 2004, Ahrweiler and Keane, 2013, Levén et al., 2014, van Rijnsoever et al., 2015). In the literature, it has been observed that some networks are set up to directly achieve innovation tasks, but some networks are oriented toward impacting the institutions set up within the system. All kinds of networks collectively comprise the TIS by setting the nature and boundaries of the system, determining the actors, activities, interactions and information flows in the system, and gathering and sharing knowledge associated with the innovation (Carlsson et al., 2002).

For example, a problem solving network could define the nature and boundaries of the TIS by answering question like "*where do various actors in the system ask for help* *in solving technical problems*" (Zeng et al., 2010). Buyer-supplier networks determine the *speed*, *direction* and *scope* of the technology information flow (Rycroft and Kash, 2004). Informal networks are the most significant channels for information gathering and sharing, and they are normally established through, for example, professional conferences, meetings and publications (Ahrweiler and Keane, 2013, Montenegro and Bulgacov, 2014). Formal networks like problem solving networks and buyer-supplier networks are comparatively easier to identify, while informal networks normally need to be recognized through further discussions in interviews (Carlsson et al., 2002).

2.3.3 TIS functions and function-based perspective

TIS functions

Understanding how TIS can contribute to technology innovation requires identifying activities that are carried out by the actors in the system. Nevertheless, for a complex technology system, to address all activities is neither feasible nor necessary; only mapping relevant activities would work. According to Hekkert et al. (2007), activities are considered as relevant if they can influence the target of the innovation system which, as mentioned, are to develop and diffuse a new technology (Carlsson and Stankiewicz, 1991, Jacobsson and Johnson, 2000).

In the literature, TIS internal activities that are capable of impacting the target of the innovation system, whether positive or negative, direct or indirect, are defined as the TIS functions (Johnson, 1999). As summarized by Edquist (2001), the overall function of TIS is to pursue innovation processes. Recent works have paid great attention to identifying and assessing the functions of the innovation system. Compared with prior works that were mainly devoted to exploring the components or structures of the system, the "functional perspective" on TIS has put more emphasis on understanding how the system works, or what is does to influence innovations (Bergek et al., 2008).

Besides, understanding TIS functions in terms of only *technology development* and *technology diffusion* is too generic to function as analysis. Thus scholars have proposed several sets of sub-divided TIS functions for analysis based on different points of view. In the literature, these sub-divided TIS functions have jointly formed varied function-based schemes of analysis which have been widely adopted in innovation studies.

For example, at the very beginning of the study of TIS functions, Johnson (2003) suggested eight sub-divided TIS functions, including *supplying incentives, supplying resources, guiding research, recognizing growth potentials, facilitating information exchange, creating or stimulating markets, reducing social uncertainty, and smoothing challenges*. Later, derived from studies of earlier innovation system functions, two typical summaries of TIS sub-functions, Bergek et al. (2005) and Hekkert et al. (2007), have been widely adopted by current innovation studies. A comparison of three typical works that have been introduced is summarized in Table 2.1. Table 2.2 demonstrates the seven functions that introduced by Hekkert et al. (2007).

Table 2.1: Proposed functions of innovation systems**.**

Johnson (2003)	Bergek et al. (2005)	Hekkert et al. (2007)
Supply incentives	Entrepreneurial experimentation	Entrepreneurial activities
Facilitate information exchange	Knowledge development and diffusion	Knowledge development Knowledge diffusion
Research guidance	Influence on the direction of research	Guidance of the research
Recognise growth potentials Create or stimulate markets	Market formation	Market formation
Supply resources	Resource mobilisation	Resource mobilisation
Reduce social uncertainty Smooth challenges	Legitimation	Creation of legitimacy
	Develop positive externalities	

Source: Adapted from Markard & Truffer, 2008.

Table 2.2 Seven TIS functions

TIS functions	Descriptions
Entrepreneurial activities	Entrepreneurs are responsible for changing the potential of new knowledge development, networks and markets into concrete action, and thus create and benefit from business opportunities. Entrepreneurial activities are foundations for creating innovation.
Knowledge development	R&D and knowledge development are prerequisites for innovation; mechanisms of learning are the heart of all innovation processes, thus have been viewed as a foundation of the innovation system.
Knowledge diffusion	Networks contribute to knowledge diffusion because of their function in exchanging information. Network activities are preconditions for systems to learn by interacting and utilising.
Guidance of the research	Activities and components within the system can affect visibility and clarity of demands positively. This can contribute to defining specific foci for mobilising limited resources as an investment. This is also a function that works in guiding the direction of learning.
Market formation	It is normally difficult for a new technology to compete with incumbents, so enough protected space for it is required. System actors like government and other influential agents are capable of creating a temporary niche market, or of adding temporary comparative advantages by favourable public policies for the promotion of innovation.
Resource mobilisation	Resources, such as financial and human, are necessary inputs for activities in the innovation system. Whether the resources are available, or efficiently applied to core actors, can directly determine the success or failure of technological innovation.
Creation of legitimacy	In order to develop well, a new technology has either to overthrow the incumbent regime, or to be part of it. Either approach may face resistance from interest groups in the incumbent regime. System actors like government and influential agents can help to smooth the transition by facilitating cooperation or uniting group interests towards innovation.

Source: Adapted from Hekkert et al., 2007.

Knowledge development is the foundation for an innovation system, since R&D activity is one of the most significant prerequisites for innovation, and learning mechanisms are at the heart of all innovation processes. Besides, ***knowledge diffusion*** within the TIS is normally facilitated by the interactions between enrolled actors and the establishment of both formal and informal networks (Bergek et al., 2008, Walrave and Raven, 2016). In the literature, the knowledge for technology innovation has been distinguished into different types, such as technological, scientific, market, and procedural (Mu and Lee, 2005, Chaminade and Vang, 2008). The sources of knowledge development and diffusion may include, for example, R&D, education and imitation. Indicators for measuring knowledge development and diffusion include, for example, *bibliometric, scale and scope of R&D projects, scientist numbers* and *patents* (Hekkert et al., 2007).

Guiding research is as significant an issue as knowledge, as there must be enough incentives to persuade organizations to participate in innovation (Lee and Oh, 2006, Gao et al., 2014, Yongwoon and Shin, 2015). The research guidance function contributes to innovation success by positively affecting the visibility and clarity of demands, and therefore could help to define the specific foci for mobilizing limited and heterogeneously distributed innovation resources (Bergek et al., 2008). This function normally works through establishing positive expectations towards selected technology (van Rijnsoever et al., 2015). Theoretically, any kind of actors within the system can play the role of persuading others to participate in innovation. Normally, actors such as regulatory departments and key market participants are more likely to play such roles (Tilson and Lyytinen, 2006b, Damsgaard and Lyytinen, 2001). Indicators for measuring to what extent the function is fulfilled may include *beliefs in growth potential, extent of regulatory pressures,* and *articulation of interest by leading customers* (Hekkert et al., 2007).

Entrepreneurial experimentation in technology innovation can significantly contribute to reducing social and technological uncertainty in terms of technologies, applications and markets (Lyytinen and King, 2002, Chaminade et al., 2009, Kukk et al., 2016). Entrepreneurs are responsible for changing the potential of new knowledge development, networks and markets into concrete action, thus creating and benefiting from business opportunities (Kemp, 1994, Bergek et al., 2008). As suggested, TIS without vibrant entrepreneurial activities will stagnate. Indicators for mapping this function include*, number of new entrants, number of different types of applications,* and *the breadth of utilization* (Hekkert et al., 2007).

Resource mobilisation, to some extent, can directly determine whether innovation is successful or not (Hughes, 1987, Lundvall, 1988, Carlsson and Stankiewicz, 1991, Edquist, 2001). Resources like financial and human capital, as well as complementary assets, are necessity inputs for supporting innovation activities in the TIS. The success of innovation is heavily dependent on whether the resources are available, or are efficiently applied to core actors (Hekkert et al., 2007, Sun et al., 2009). Mobilizing the requested resources, such as subsidies and investment, to support the requesting actors is significant for both technology development and diffusion (Carlsson et al., 2002). The indicators for measuring whether resources are well mobilised or not can include, *rising volume of seed and venture capital*, *changing volume and quality of human resources*, and *changes in complementary assets* (Hekkert et al., 2007).

Market formation is particularly significant for technology diffusion. For a new technology, demand by potential customers must be clearly articulated, and comparative advantages, at least temporary ones, must be created (Funk and Methe, 2001, Mu and Lee, 2005, Robertson, 2013). As suggested, for an emerging system, or one in a transformation period, markets might not exist (Carlsson and Stankiewicz, 1991, Nelson, 1992, Bergek et al., 2008). This will significantly obstruct the innovation process as, without market, customers can hardly articulate their demand, which may cause appreciable deficiencies. Three distinct phases of market formation are suggested. The process normally starts from *"nursing markets"*, in which learning space is created and TIS can form; then, along with growth in terms of volume, the market will become a *"bridging market"* to be followed by the *"mass market"* (Kemp, 1994, Jacobsson and Johnson, 2000). Bergek et al. (2008) suggest that both actual market development and driving forces for market formation should be identified. Indicators for tracing market development include *market size*, *timing* and *type*, and qualitative data like *actor strategies* and *purchasing processes* (Hekkert et al., 2007).

Legitimation deals with the problems of social acceptance and compliance in relation to new technologies or change (Hekkert et al., 2007). This function is significant because it influences resource mobilization, market expectations, and thus research direction. According to institution scholars, legitimacy is not given, but created and cultivated through conscious actions by various participants in a process of legitimation

(Suchman, 1995, Hughes, 1987, Deephouse and Suchman, 2008). In the literature, mapping the dynamics of legitimation, both legitimacy recognition and activities that increase or decrease legitimacy need to be addressed (Bergek et al., 2008).

TIS function-based perspective

In fact, these sub-divided TIS functions interact with and influence each other; achieving one specific system function might have further effects on others. For instance, it is suggested that the function of guiding research could contribute to knowledge creation and development; then, after knowledge is created, the market might have expectations regarding the new technology, and eventually might facilitate its diffusion by promoting the function of creating legitimacy (Negro et al., 2008, Walrave and Raven, 2016). In the literature, dynamics and interactions between the sub-divided TIS functions are recognized as the precondition for system change, and thus for "producing" technology innovation (Hekkert et al., 2007, Mekonnen and Sahay, 2008, Samara et al., 2012). As Jacobsson and Johnson (2000) suggested, changes in processes could be achieved by the fulfillment of functions, and changes could strengthen functions and contribute to creating momentum, which is essential for creating a process of creative destruction of the incumbent system.

Therefore, in addition to the elaborated system functions, a TIS function-based perspective has been developed for technology innovation analysis, and varied analytical frameworks based on TIS function analysis have been developed (Hekkert et al., 2007, Negro et al., 2007, Bergek et al., 2008, Hellsmark, 2010). For example: Negro et al. (2007) employed the TIS function-based perspective to analyze failures in innovation in Holland's renewable energy technologies, and suggested that more intervention activities should be undertaken; Bergek et al. (2008) developed a TIS function-based framework to analyze technology innovation in the health care sector in Sweden, with changes being viewed as composed of several technology systems that support technology artifacts that are applicable in the health care sector; Walrave and Raven (2016) adopted the seven TIS functions to map the dynamics of TIS along with the technology innovation; Kukk et al. (2016) employed the function-based perspective to study how a pharmaceutical firm acting as a powerful actor in the TIS could impact the system functions for exploring how actor enabled institutional change evolves in a technology system with the process of innovation.

In the literature, several advantages of adopting the TIS function-based perspective in the study of technology innovation have been summarized. Firstly, function identification sets a standard or a platform, which allows comparison in terms of performance between different innovation systems become possible and more operational; secondly, understanding TIS functions permits a more systematical method for allocating the determinants of technology innovation, and this can greatly increase the analytical power of the innovation system framework; lastly, function analysis could help policymakers enhance the efficiency and effectiveness of intervention (Hekkert et al., 2007, Negro et al., 2008, Markard and Truffer, 2008).

The TIS function-based perspective is also adopted in this work. Nevertheless, we argue that TIS structure and TIS functions are two intertwined concepts that are both related to the nature of the system. On one hand, the structure can determine the activities in the systems which, in the other words, are the system's functions; on the other hand, core activities could also influence the TIS structure. Nevertheless, the relationships between TIS structure and TIS functions are ambiguous to investigate, as it is observed that some structurally different TISs could be similar in function, while some similarly structured TISs are often different in function (Malerba, 1999, Tilson, 2008). In the literature, the studies that set out to understand how TIS functions are determined by TIS structure are limited, which leads to another gap calling out to be bridged in current innovation research.

2.3.4 TIS performance

Assessment of TIS performance

The performance of an innovation system is visible and measurable, reflecting how well the system functions in reality (Samara et al., 2012). According to Carlsson et al. (2002), evaluating the performance of the innovation system means:

> *"…evaluating how each individual part of a system performs (e.g. the firms, the educational system, and the capital market), but the main focus is on the performance of the total system." (p.242)*

It has been suggested that the exact choice of performance measure depends both on the *level of analysis* applied and the *maturity of the system* (Carlsson et al., 2002). Compared with other innovation system concepts, performance of TIS is relatively easier to assess when analysis is located at the level of product, industry, or industrial group, while the performance of an immature system can be intuitively judged through how well the system's targets, such as generation, diffusion and use of knowledge, are achieved (ibid.). Nevertheless, measuring performance via these aggregative targets is not accurate enough and is hard to operate; thus, innovation scholars have introduced a number of indicators to make the measurement more accurate and operable.

Table 2.3 Performance measurement indicators for immature TIS

Indicators of knowledge generation	Indicators of knowledge diffusion	Indicators of knowledge use
Number of patents	Timing/stage of development	Employment
Number of engineers or scientists	Regulatory acceptance	Turnover
Mobility of professionals	Number of partners/licenses	Growth
Technological diversity		Financial assets

Source: Richen, 2001.

For example, as shown in Table 2.3, Richen (2001) introduced several detailed indicators for assessing TIS performance according to the three dimensions that have been introduced. Accordingly, the performance of TIS in generating innovation knowledge could be assessed through measuring the *number of patents*, *number of scientists*, *mobility of professionals*, and *technological fields* (ibid.).

Alternatively, Bergek et al. (2008) introduced two bases for TIS performance assessment, namely *assessing development phase* and *making system comparisons*. In terms of assessing the development phases, the work suggests a distinction between the *formative phase* and the *growth phase* in TIS. Different TIS functions are emphasized in different phases of the system; thus, the performances in these phases are different (Bergek et al., 2008). For example, in formatted systems, the foci or priorities have been shifted to system expansion and large scale technology implementation, when compared with the formative phase. Indicators introduced for assessing the system's functions, such as resource mobilization, entrepreneurial experimentation, and legitimation, could be adopted to assess the TIS performance in this stage. Furthermore, Bergek et al. (2008) also suggested comparing the focal TIS with other similar TISs in different regions or nations. Such comparisons would help address questions like, how or why, some system's functions show different performance in similarly set up systems.

In the literature, many other assessment approaches are also introduced (e.g. Sagar and Holdren, 2002, Markard and Truffer, 2008, Steen, 2011, Samara et al., 2012). In fact, no matter which assessment approach is adopted, none of these conventional indicators alone can reflect the performance of the entire system comprehensively (Carlsson et al., 2002, Bergek et al., 2008). Besides, in this work, we argue that, despite following the standardized indicators or approaches that are introduced in the literature, initiatives associated with the specific technology innovation should also be considered. For example, in Gao et al. (2014), when assessing the complex technology system for the 3G TD-SCDMA mobile technology innovation in China, initiatives such as getting rid of dependencies on foreign technologies as well as cultivating the indigenous telecommunication industry through promoting the innovation, were also identified. In such cases, assessing the innovation performance only through fixed indicators that have been introduced by the literature is obviously improper and insufficient.

In this work, corresponding to the TIS concept that is adopted, we follow the strategy from Markard and Truffer (2008) and assess TIS performance according to two dimensions, namely technology development and technology diffusion. The seven TIS functions are allocated to each dimension and their related indicators are adopted. Moreover, we also suggest that several case-specified indicators should be considered based on the different initiatives in different innovation cases.

Inducement and blocking mechanisms in TIS

Understanding the TIS structure, functions and performance could establish a solid foundation to figure out desirables and challenges that induce or block technology innovation (Carlsson et al., 2002, Bergek et al., 2008). Both internal TIS structural components and the external context of TIS are recognized to be capable of determining the inducement or blocking mechanisms, as Bergek et al. (2008) suggested:

> *"What is being achieved in the TIS is therefore only in part a result of the internal dynamics of the TIS. Exogenous factors also come into play, influencing the internal dynamics." (p.421)*

Therefore, to address the inducement and the blocking mechanisms in specific TIS, understanding the interrelationships between TIS structure, functions and performance could be highly significant. Once such kinds of interrelationships are identified, then policy makers could introduce more targeted and appropriate interventions into the TIS to retarding identified blocking mechanisms, or to strengthen inducement mechanisms, and thereby achieve the aim of stimulating and steering the technology innovation as previously mentioned (Hekkert et al., 2007, Markard and Truffer, 2008, Walrave and Raven, 2016).

To sum up, in this section, we elaborated the fundamentals and reviewed studies of the TIS perspective, including its structure, functions, and performance. Accordingly, some research gaps in current innovation studies were identified, such as insufficient studies in understanding how TIS activities can be impacted by external factors, how TIS dynamics during the innovation process affect matters, as well as how TIS functions are determined in relation to the system's structure.

In addition, despite elaborated TIS functions and dynamics, it is suggested that innovation context is also influential on innovation activities (e.g. Liu and White, 2001, Lee and Oh, 2006, Negro et al., 2008, Bergek et al., 2008, Vialle et al., 2012, Kukk et al., 2016). In the next section, we specifically introduce the catching-up context, including related concepts and studies, as the main contextual focus of this work, with the aim of understanding how innovation and TIS features work in such a context.

2.4 TECHNOLOGY INNOVATION IN CATCHING-UP CONTEXT

2.4.1 Technology innovation catching-up

In recent decades, it has been observed that some late coming countries in terms of technologies have gradually narrowed the divide with countries at the technology frontiers, and some have even surpassed them, through technology innovation. Such a phenomenon has attracted interest from more and more innovation scholars, and has been labeled as technology innovation catching-up (e.g. Mu and Lee, 2005, Wang, 2007, Choung et al., 2012, Vialle et al., 2012, Gao et al., 2014). Nevertheless, as Fagerberg (2005) indicated, most existing knowledge about technology innovation is generated based on the context of developed countries. Innovation studies that particularly focus on the late coming nations who are catching-up with the frontiers in technology, such as China and Korea, are relatively limited.

In the innovation literature, two definitions of technology catching-up are mostly referred to. Gomulka (1987) defined it as a phenomenon in which late comers to industrialization tend to innovate faster than the world's technology frontier, and thus the narrowing of the relative divide in technology between the latecomer and the frontier in technology is named as technology catching-up. Similarly, Fagerberg (2005) understood technology innovation catching-up from a capability perspective as:

> *"(Technology innovation catching-up) relates to the ability of a single country to narrow the gap in productivity and income vis-à-vis a leader country through promoting indigenous technology innovations." (p.514)*

For the latecomers to achieve technology innovation catching-up, changes in both "social technologies" and "physical technologies" are emphasized in innovation studies. As Nelson (2004, p.365) suggested:

> *"catching-up is not a process of exact copying but reflects deliberate and often creative modifications to tailor practice to national conditions, especially those practices associated with the norms within which physical technologies embodied in productive economic activities and their operation are embedded."*

“Physical technologies”, as well as techniques, market demand, manufacturing capability and supply of factors, are relatively easily cultivated and developed in terms of catching-up (Crowston and Myers, 2004). However, the divides between the latecomers and the frontiers in “social technologies”, such as institutions and capabilities in terms of mobilizing resources, legitimizing new technologies, and sustaining innovation, are not that easily bridged (Howcroft et al., 2004, Nelson, 2004, Bastian, 2010). Therefore, the context of technology innovation catching-up is not just about achieving “technological congruence”, but also requires emphasis on enhancing “social capabilities”, as introduced (Lyytinen and Newman, 2008).

In reality, the challenges for latecomers to achieve technology innovation catching-up are quite severe. For example, it is normally complex, iterative, and expensive to develop and adopt a new technology or a new product; even if latecomers have equal resources to the frontier nations, they are more likely to fail due to their initial lack of resources and lack of experience (Pavitt, 1988, Kash and Rycroft, 2002). In addition, in reality, the mechanism is that the “first mover” enters the field, defines the institution, and protects this given position through prototypically. Thus, if a latecomer is willing to enter, it is inevitable it will have to reshape customers’ learning processes and shift buyers’ ideal points to its own position. A latecomer can hardly overcome these severe disadvantages if it lacks enough necessary resources (Gao and Liu, 2012).

Nevertheless, in the literature, some scholars have also indicated that latecomers might be able to enjoy advantages in developing and diffusing new technologies, as others in the leading positions might be reluctant to do so, as this might cannibalize their existing benefits, creating much uncertainty (Mu and Lee, 2005, Kwak et al., 2012). Even if frontier nations are willing to try new things, they still need to cross many barriers in making necessary organizational changes and distributing the necessary resources to support the R&D and adopt the emerging technologies (Gao & Liu 2012). Such kinds of situations happen especially when the new technology is competence-destroying (Hargadon and Douglas, 2001, Kash and Rycroft, 2002), or not wholly alien to current corporate strategies (Lee and Oh, 2006, Birkinshaw et al., 2008).

2.4.2 The catching-up context for technology innovation

In the literature, technology innovation catching-up is mostly investigated in two streams. Some studies treat catching-up as an aim of innovation, by aiming to explore how late-coming nations can catch-up through technology innovation (e.g. Madden and Savage, 1999, Fan, 2006, Gao and Liu, 2012); while others primarily focus on understanding innovation activities in the catching-up context (e.g. Li, 2011, Vialle et al., 2012, Gao et al., 2014). This research belongs to the latter stream which emphasizes the catching-up context of technology innovation.

According to literature, technology innovations can demonstrate different features in different contexts (e.g. Cousins and Robey, 2005, Tödtling and Trippl, 2005, Epstein, 2012, Chaminade et al., 2012, Vialle et al., 2012). Nevertheless, in the literature, innovation studies that set out to understand technology innovation in catching-up contexts are quite limited (Vialle et al., 2012, Gao et al., 2014). Besides, as discussed in section 2.3.1, TIS naturally overlaps geographical and sectoral boundaries. Thus, the external environment could also be decisive in terms of TIS structure, functions and dynamics, which means TIS could also demonstrate different features in different contexts. Nevertheless, few TIS studies focus on the context or the environment in which the innovation system works. Among a limited number of studies, a few have summarized the features of TIS in developing and developed nations, but works that set out to understand the features of TIS, especially in the catching-up context, are rare.

For example, by learning how innovation systems differ between developing and developed nations, Chaminade and Vang (2008) suggested that developing nations are normally perceived as having weak and unstable institutions, a high degree heterogeneity in social, political, and economic structures, low learning capabilities and limited knowledge bases. Thus innovation systems in the developing nations are normally classed as emerging innovation systems, in which inter-sectoral links are weak, learning capability as the core of innovation is weak, and blocks built by firms or research institutes are not formed. Comparatively, in developed nations the systems are relatively mature and face fewer challenges in formation and operation (ibid.).

Besides, as innovation systems are dynamic in nature, they therefore also evolve and an emerging innovation system can transit into a mature innovation system during the process of innovation (Chaminade and Vang, 2008). As Figure 2.1 indicates, in mature innovation systems, blocks are formed, interactions between the blocks are set up, and learning capabilities are enhanced. For developing nations, achieving the transformation from emerging innovation systems to mature innovation systems cannot just rely on market mechanisms, innovation policies, as well as other institutional interventions are encouraged to address market failures in innovation (ibid.).

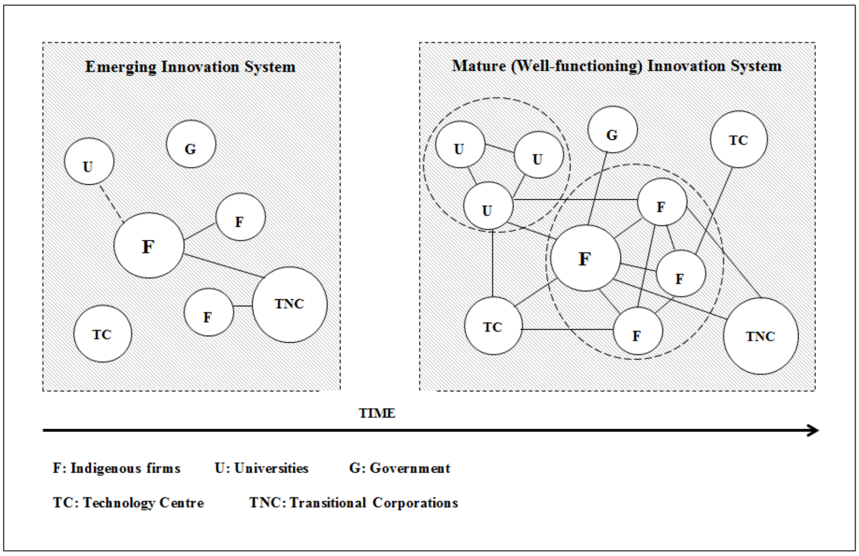

Figure 2.1: Transitions in innovation systems *(source: Chaminade and Vang, 2008).*

To sum up, we suggest that understanding the context in which the innovation system operates is significant for understanding TIS. As Chaminade and Vang (2008) indicated, emerging innovation systems are mostly found in developing nations, while mature systems are mostly observed in developed nations, and the two different innovation systems contain different features. Thus, identifying the innovation context would help illustrate how studying the features of innovation and innovation systems could enable innovation policies to be more targeted and effective. Nevertheless, in the literature, innovation studies that focus especially on the technology innovation and its innovation system in the catching-up context are relatively limited.

2.5 SUMMARY

This chapter has elaborated the studies of technology innovation, technological innovation system (TIS), and the catching-up context for technology innovation. Based on TIS literature, this chapter has set out to understand how a technology innovation is impacted and achieved, and how technology innovation and TIS characteristics, especially in the catching-up context.

Specifically, in terms of technology innovation, we adapted the definition from Baregheh et al. (2009). The innovation process has two stages, namely *technology development* and *technology diffusion* (Markus et al., 2006). Reviewed the studies reviewed emphasized the networked nature of technology innovation, and how it is viewed as the result of interactions among actors in three domains, namely the *regulatory regime*, *marketplace* and *innovation system* (Lyytinen and King, 2002). Associated with the networked nature, the system perspectives of innovation were introduced, the concepts and studies of NIS were particularly illustrated.

Furthermore, the TIS concepts and studies were particularly emphasised. To understanding how technology innovation is achieved and how it impacts in relation to its TIS, concepts like TIS structures, dynamics, functions and performance were discussed. Specifically, *institutions*, *actors* and *networks* were revealed as three structural components of TIS. Within the system, activities of actors that relate to innovation targets, like development and diffusion of technology, were defined as the *TIS functions*. By adopting the work of Hekkert et al. (2007), seven TIS functions were particularly emphasized. We suggested that TIS dynamics during innovation should be mapped and a bridge between TIS functions and TIS structural components should be established. Moreover, by synthesising TIS performances studies, we suggested that TIS performance should be assessed in both the technology development and diffusion stages, and both TIS functions and the specific initiatives of innovation should be considered at each stage. Besides, through assessing TIS performance, inducement and blocking mechanisms for technology innovation could be identified, which could provide valuable political implications.

In the last section, we suggested that the context of technology innovation is also significant, and the catching-up context was especially emphasized due to the aim of this research. In the literature, innovation and the innovation system maintain different features in developing and developed nations, the features of technology innovation and its associated TIS are also different in the catching-up context. Nevertheless, in terms of understanding how technology innovation and the related TIS feature in the catching-up context, it is suggested that more studies need to be conducted.

CHAPTER 3: GOVERNMENT INTERVENTION IN TECHNOLOGY INNOVATION

3.1 INTRODUCTION

This chapter reviews studies about innovation policy and government intervention in technology innovation. Based on the literature, this chapter aims to understand how government intervention can promote technology innovation, especially that in the catching-up context. Specifically, section 3.2 introduces the concepts and related studies of innovation policy, especially emphasizing an understanding of the impacts of rationales, instruments and context. Besides, based on different perspectives, section 3.3 introduces studies on government in technology innovation. After that, associated with the technology innovation studies that were reviewed in the last chapter, section 3.4 summarizes the research gaps that are identified in innovation literature, and proposes the aim and question of this research. Lastly, section 3.5 concludes this chapter.

3.2 INNOVATION POLICY

3.2.1 Rationales for innovation policy

Innovation policies are normally issued with the allusion of enhancing innovation performance. As Lundvall (2007) indicated, innovation policies should target "overall economic performance in terms of innovation", and cover all the issues that may relate to achieving this target. Similarly, OECD (2012) suggested that in order to realise better performance, innovation policies are normally issued and function by crossing different policy domains and overlapping with other public policies. Highlighting public organizations as the main body of policy execution, Borrás and Edquist (2013, p.10) defined innovation policy as:

> *"…all combined actions that are undertaken by public organizations that influence innovation processes."*

Compared with works that view enhancing economic performance as the main target for political intervention, Borrás and Edquist (2013) indicated that the targets could be diverse, and their nature might be economic, social, or environmental and may also relate to security. Therefore, as Chaminade and Edquist (2010) suggested, before considering which kinds of policy instruments could be selected for intervention, the objective of issuing innovation policy, or the rationales, in the other words, must be clarified in advance.

In the literature, addressing failures identified in the innovation process is normally recognised as a generic rationale for issuing innovation policies (Edquist, 2001). In the studies reviewed, it is mostly *market failures* (e.g. Iyer et al., 2006, Robertson, 2013, Tarafdar et al., 2013) and *system failures* (e.g. Negro et al., 2007, Bergek et al., 2008, Chaminade et al., 2012, Walrave and Raven, 2016) that are discussed. Specifically, market failures normally emerge when *"the market cannot by itself allocate resources for innovation efficiently"* (Arrow, 1962, p.14); system failures normally refer to the incapability of the innovation system to support the "*creation, absorption, retention, use and dissemination of economically useful knowledge through interactive learning or in-house R&D investments*" (Chaminade and Edquist, 2010, p.5).

There are different perspectives in examining innovation, which should be the basis for considering innovation policy rationales (e.g. linear model, multi-level perspective, system perspective, etc.). This is because understanding innovation from different perspectives could lead to different understandings of the failures or challenges that are faced in innovation, which further lead to different rationales for issuing innovation policy. As discussed in the previous chapter, system is one feature of technology innovation. In this dissertation, we understand the rationales for issuing innovation policy for a specific technology from the system perspective of innovation, which means the system failures should be focused during innovation.

In the literature, people normally consider two dimensions when analyzing system failures in technology innovation: namely system structure and system functions (Chaminade et al., 2009). In fact, as previously discussed, the structural components of the innovation system could determine the innovation activities, and thereby could impact on the functions of the system (Hekkert et al., 2007, Negro et al., 2008, Bergek et al., 2008). These two dimensions of system failures are interrelated, and system failures could be reflected, or demonstrated, through functions of the innovation system (Bergek et al., 2008, Chaminade et al., 2012). Therefore, system failures could be identified through observing whether the system functions are well achieved or not. However, when aiming to understand how to address the failures identified, the system structure in which the failures are embedded should be particularly focused on.

In the literature, studies of system failures that either focus on the system functions or the system structure can all be categorised into three dimensions relating to the three structural components of the system, namely system actors, networks and institutions. For example: actor failures relate to system actors are caused by deficiencies of imperfect scientific infrastructure, such as universities and research institutions, physical infrastructure and network infrastructure (e.g. Nelson, 2004, Raus et al., 2009, Negro et al., 2007, Chaminade et al., 2009); interaction failures relate to system networks and result from problematic interactions between actors within or across the system (e.g. Lee and Park, 2006, Bruche, 2009, Zeng et al., 2010, Levén et al., 2014); lastly, institutional failures relate to system institutions and are caused by the problematic establishment or functions of institutions, such as lack of formal institutions like laws and regulations, or informal institutions like cognitive and normative factors (e.g. Samarajiva, 2000, Hage and Hollingsworth, 2000, Lawrence et al., 2002, Currie and Guah, 2007, Kukk et al., 2016). It is suggested that innovation policies intervene when system failures are identified (Chaminade and Edquist, 2010).

Furthermore, the studies reviewed have also suggested that the context of innovation should also be considered when understanding the rationales for issuing innovation policy, as the experiences summarized from a given context may be unsuitable for another, and innovation in different contexts could face different challenges (Nemet, 2009, Chaminade and Edquist, 2010, Epstein, 2012). For example, as discussed in the previous chapter, in the developing context, innovation systems are normally described as emergent systems (Chaminade and Vang, 2008). Compared with mature innovation systems in the developed context, systems in the developing context normally face different challenges, as shown in Table 3.1. Nevertheless, in the literature, although innovation context has been identified as a significant impact factor in terms of rationales, few studies have set out to specifically understand how innovation policy rationales vary in different innovation contexts. In terms of catching-up context, such work is even more limited.

Table 3.1 System challenges in different contexts.

System challenges	Mature innovation systems (Developed context)	Emerging innovation systems (Developing context)
Infrastructural challenges	- Lack of research and technological abilities - Lack of close interactions with customers - Lack of large scale research facilities	- Lack of engineering and design abilities - Lack of managerial abilities - Lack of learning organizations
Interaction challenges	- Lack of intensive inter-firm networks - Weak research linkages between universities and industries	- Weak linkages between transnational corporations and indigenous firms - Weak linkages with customers and lack of intermediating organizations - Strong university and rural linkages - Insufficient flow of human capital
Institutional challenges	- Problems relating to IPRs - Problems relating to inappropriate governance	- Linking formal and informal institutions - Lack of innovation friendly regulations - Social inclusion; IPRs; corruption

Source: Adapted from Chaminade & Vang, 2008.

3.2.2 Innovation policy instruments

As Chaminade et al. (2009) suggested, in addition to understanding the rationales for issuing innovation policy, policy-makers should also consider questions like, "for whom, when, where, and how to intervene in the innovation". In the literature, answering such questions is related to understanding the instruments of innovation policy (Chaminade et al., 2012, Borrás and Edquist, 2013).

In the literature, public policy instruments are techniques that are applied by governmental authorities to wield their power in ensuring support for or in preventing social changes (Chaminade and Edquist, 2010). Specifically, Borrás and Edquist (2013, p.14) indicated that policy instruments in innovation are mainly employed to:

> *"Influence innovation processes, and thereby contributes to fulfilling these ultimate political goals by means of achieving the direct objectives formulated in innovation terms."*

Moreover, in innovation studies, both design and implementation of innovation policy instruments are emphasized, as Borrás and Edquist (2013, p.10) in their benchmark work also illustrated:

> *"The choice of policy instruments constitutes a part of the formulation of the policy, and instruments themselves also form part of the actual implementation."*

Obviously, there is no one-size-fits-all policy instrument. It is widely agreed, when designing innovation policy, that the selection of instruments must be done in relation to the "actual problems" that are identified in the process of innovation (Tödtling and Trippl, 2005, OECD, 2008, Edler, 2010, Dolfsma and Seo, 2013, Bergek et al., 2008). Addressing the "actual problems", in the other words, is related to the rationales for issuing innovation policies which are elaborated in the previous section. As the "actual problems" could be identified in different ways if different perspectives are adopted, this is therefore similar to understanding the rationales for issuing innovation policy, so the instrument of innovation policy should also be understood as based on the perspective that is adopted for understanding the innovation.

In the literature, several typologies have been introduced to analyze or establish the instruments of innovation policy. For example, a supply-demand typology distinguishes innovation policy instruments according to both the *supply side* and *demand side*. As King et al. (1994) indicated, innovation policy instruments, including both influential and regulatory types, can drive the innovation by playing different roles based on the "supply-push" and "demand-pull" forces. Supply-push refers to the force for innovation that comes from the production of innovation itself, while the demand-pull force is normally created by the willingness of potential users of innovation (ibid.). Innovation policy instruments focusing on the supply side are suggested to concentrate on stimulating the production factors that are significant for innovating, such as new knowledge and capital for producing innovation (Bar et al., 2000, Chaminade and Vang, 2008, OECD, 2015b). In contrast, on the demand side, policies are suggested to define and articulate demand in terms of potential sources that supply innovation (Edquist and Hommen, 1999, Nemet, 2009, Edler, 2010, Li, 2011). As King et al. (1994) claimed, the instruments on both sides are complementary rather than alternative to one another; the integration and coordination of instruments related to the two forces are significant.

Similarly, a three-fold typology, introduced from general policy studies, has also been widely adopted (e.g. Borrás and Edquist, 2013, Dolfsma and Seo, 2013, Edler, 2013). The typology distinguishes policy instruments into three dimensions, namely *regulatory*, *economic* and *soft instruments*. Regulatory instruments refer to using the law and binding regulations to promote innovations, like issuing regulations for intellectual property rights and rules for competition (Edquist, 2001, Bannister and Wilson, 2011). Economic instruments provide specific pecuniary incentives or disincentives for supporting or preventing specific innovation activities, such as funding research and issuing tax exemptions (Moe, 1990, Kennedy, 2006, Edler, 2013). Soft instruments provide non-coercive instructions, such as forming public-private partnerships and volunteering to set technical standards (Mekonnen and Sahay, 2008, Courvisanos, 2009, Angulo et al., 2011). As Borrás and Edquist (2013) claimed, these three types of policy instrument are normally jointly applied in practice.

Comparatively speaking, the studies reviewed have indicated that the innovation system, to some extent, could provide an ideal frame for policy instrument analysis. The structural figure and functional dynamics of the innovation system could not only provide stepping stones toward where innovation policies really exert influence, but are also capable of revealing the mechanisms by which policy really works (Carlsson et al., 2002, Bergek et al., 2008, Walrave and Raven, 2016). In the literature, many studies set out to understand how innovation policy instruments are designed and implemented based on innovation system perspectives (e.g. Edquist, 2001, Dolfsma and Seo, 2013, Chaminade et al., 2012, Zhang and Liang, 2012, Borrás and Edquist, 2013).

For example, based on the functional dynamics of the innovation system, Bergek et al. (2008) developed an analytical framework to understand how innovation policy instruments are designed and how they function in real innovation practice. The framework includes six steps of analysis, which start by analyzing the structural components of the innovation system, expanding to analyzing system functions and performance, and then figuring out inducement and blocking mechanisms that may facilitate or hinder the system's functions. Lastly, based on the identified inducement and blocking mechanisms, several instruments of innovation policy are suggested, such as increasing user capability, developing standards and supporting advocacy coalitions.

In addition, also through analyzing the functions of the innovation system, Chaminade and Edquist (2010) summarized six systemic problems in relation to innovation system functions, such as unsatisfactory infrastructure provision, hindered knowledge transition and insufficient learning capabilities etc. Instruments for policy intervention were then suggested, based on each systemic problem that is identified, such as building competence centers, supporting technology foresight exercises and inducing cooperation etc.

Similarly, Borrás and Edquist (2013) also investigated instruments of innovation policy based on innovation system functions. As a result, three kinds of instruments, including regulation, economic transformation and soft instructions, were introduced as generic, and a matrix was developed to relate the instruments to the problems that are identified in system functions. Through empirical case studies, they also suggested that to promote a single system function, several policy instruments may be applied at the same time, and any individual instrument may contribute to several system functions.

To sum up, the design and analysis of innovation policy instruments should be related to the innovation system. In the literature, people study innovation policy rationales by focusing on either innovation system structure or functions. However, system functions are determined by the structural components of the system. Understanding how the observed system function problems are embedded in the system structure is the key to understanding how to design and implement more targeted and effective policy instruments for innovation.

3.2.3 Innovation policy in technology innovation catching-up

As discussed in previous sections, the context of innovation should also be considered when seeking to understand innovation policies, as experiences summarized from a given context may be unsuitable for another, and innovation in different contexts could face different challenges, which would impact on both the rationales and instruments of innovation policy (Nemet, 2009, Chaminade and Edquist, 2010, Epstein, 2012, Borrás and Edquist, 2013). In the literature, although innovation context has been identified as a significant impact factor for the design and implementation of innovation policy, some studies have been set up to understand how innovation policy rationales vary in different innovation contexts, especially in the catching-up context.

For example, Vialle et al. (2012) analysed how innovation policies in China help domestic standards compete with the dominant global ones within a catching-up context. Their work suggested three innovation policies for catching-up countries, namely participation in global consortia, indigenous architectural innovation and indigenous modular innovation, and looked at how innovation policies in the three dimensions contributed to China's catching-up in standardization, yet how the suggested policies which were particularly "sharpened" and "characterised" for catching-up were not learnt. In fact, studies which aim to understand innovation policy in the catching-up context have commonly faced the challenge that innovation policies in the catching-up context are difficult to describe; even if conclusions are made, the conclusions of a specific study are normally difficult to be generalise and apply to others (e.g. Madden and Savage, 1999, Liu and White, 2001, Mu and Lee, 2005, Choung et al., 2012).

Further, the reasons for such challenges to exist include the lack of a standard and structured frame for analysis, innovation system could be the key to solving the problem. On the one hand, as discussed in the last chapter, the nature of the innovation system is to maintain competences in providing a standardised platform and systemic scheme of innovation policy analysis. Thus, the innovation system could help structure and standardise innovation policy analysis in different contexts, which enables the generalisation of conclusions. On the other hand, as discussed in section 3.2.1, the challenges that the innovation system faces normally vary in different innovation contexts. In consequence, as determined by the system failures identified in the initial stage, along with the innovation policies issued, including the rationales and the instruments, also demonstrate varied features in different innovation contexts (e.g. Liu and White, 2001, Chaminade and Vang, 2008). Besides, as clearly elaborated in the last chapter, the innovation system in different contexts demonstrates different features, which to a large extent are relevant to the features of that context. Therefore, we suggest that the features of innovation policies in the catching-up context can be summarized through understanding how rationales and instruments are identified and developed, based on the catching-up context featured innovation system.

For example, as Chaminade and Vang (2008) indicated, with the aim of catching up, the emergent innovation system that is normally observed in late-coming nations must be developed to become a mature innovation system. Emergent innovation systems normally feature weak inter-sectoral linkages, insufficient actors and competences, as well as unclearly aligned institutions. Nevertheless, the transformation from emergent system to mature can hardly be achieved by just relying on market mechanisms, so innovation policies must be issued (Chaminade et al., 2009). Thus, through understanding how the innovation system in the catching-up context is impacted by innovation policies, the significance of innovation policies is particularly emphasized in the catching-up context, and it is suggested that policies in the catching-up context should put more emphasis on upgrading the competences and skills of the participants.

In addition, innovation policy as a kind of technology strategy could also determine the process or the procedure about how technology innovation catching-up could be achieved. In the literature, strategies such as indigenous innovation, imitative innovation, and collaborative innovation are generally adopted (Chen and LiHua, 2011). The term “indigenous innovation” is mainly linked to China’s policy in technology innovation in current, which had been transformed from the previous imitative innovation. The promotion of indigenous innovation is the core concept of the future direction of technology innovation in China, which could be translated as “self-organized” or “self-determined” innovation. The US Information Technology Office describes the term indigenous innovation with three adjectives: namely, independent, self-reliant and indigenous (Bijker, 1997). The Chinese Ministry of Science and Technology (MOST) in cooperation with the Chinese National Development and Reform Commission (NDRC) issued a document in 2006 which defines products that are considered as indigenous innovation with the following attributes: namely, developed mainly by domestic companies, domestic ownership of the IPRs, and leap in technology compared to existing products (MIIT, 2015). For late-coming nations to catch up in technology innovation, the innovation policies are normally shifted from imitative innovation to indigenous innovation, like China.

In this section, innovation policy studies were reviewed and elaborated. The rationale and instruments of innovation policy were introduced, and the catching-up context was particularly emphasized as a consideration when understanding innovation policies. Due to the system feature in the nature of technology innovation, the policy for technology innovation could be learnt based on the innovation system perspective, and that the system structure and functions could help to both identify the rationales and to select the instruments, especially when social context is considered.

3.3 THEORETICAL PERSPEECTIVES OF GOVERNMENT IN TECHNOLOGY INNOVATION

Government has played a significant role in technology innovation, and government intervention shapes the process of innovation. For example, government can impact innovation through leveraging public officials' procurement (e.g. Edler and Georghiou, 2007, Edler, 2010, Li, 2011), through conducting or investing in R&D institutes (e.g. Hsu, 2005, Lee and Park, 2006), through locating and distributing resources (e.g. Xia, 2012a, Borrás and Edquist, 2013), through mediating market competition and facilitating cooperation (e.g. Funk and Methe, 2001, Damsgaard and Lyytinen, 2001, Kapsali, 2011) etc. Similarly to innovation policy studies, government in technology innovation is also understood in different ways, based on the different theoretical perspectives that are adopted.

In the literature, the theoretical perspectives for understanding government interventions are mostly underpinned by basic assumptions of the *social shaping of technology*, which explain how technology development and diffusion are impacted by social context (Howcroft et al., 2004, Cousins and Robey, 2005). Government, as the most powerful and influential component of the social context, thus is capable of influencing technology innovation (Howcroft et al., 2004). In the literature, by following the assumption of social shaping of technology, theoretical perspectives, such as stakeholder theory, collective action theory, actor-network theory, institutional theory, as well as innovation system perspective, are normally adopted for understanding government in technology innovation.

The selection of a specific theoretical perspective is suggested to follow the specific context and purposes of the research, as each of them holds both limitations and advantages (Gao et al., 2014). With the aim of understanding how government can promote technology innovation, innovation studies on government intervention are elaborated in the following sections, based on different perspectives to be introduced.

3.3.1 Stakeholder theory

Stakeholder theory is a theory that initially developed to address morals and values in managing an organization (Blind et al., 2010). It helps identify and model the groups which are the stakeholders of an organization, and is capable of developing methods which management can employ to deal with the interests of those identified groups (ibid.). Interpreted by innovation scholars, stakeholder theory regards technology innovation as a socio-technical process that is operated by several stakeholders, including government authorities, and contributes to examination of the stakeholders' roles and interests (Pouloudi, 1999, Papazafeiropoulou, 2002). Taken as the key stakeholder, especially in national level technology innovation, the government might build collective and coordinative relationships among other enrolled stakeholders in order to take advantage of their interests and capabilities in innovation (Choudrie et al., 2003, Shin et al., 2006).

For example, employing stakeholder analysis, Papazafeiropoulou and Pouloudi (2000) examined the role of the government in promoting electronic commerce adoption in European countries, and suggested that governments should have a holistic view of the stakeholders operating in the marketplace and should take actions pro-actively in technology diffusion. Similarly, employing a web of stakeholder analysis, Shin et al. (2006) investigated mobile broadcasting development in South Korea by mapping the interactions between social and technological entities at various development stages. Stakeholder analysis interpreted how diverse groups of stakeholders, with different interests, capabilities and resources, were affected by actions that were taken by the leading stakeholder – the Korean government. Other studies that adopted the stakeholder perspective have drawn similar conclusions, which suggest government could play a leading stakeholder role to coordinate relationships and to mobilize interests and resources for innovation (e.g. Choudrie et al., 2003, Shin, 2008, Levén et al., 2014, Zeng et al., 2010, Ravishankar, 2013).

3.3.2 Collective action theory

Collective action theory was initially introduced by Mancur Olson, and suggested that any group of actors attempting to provide a public good has trouble in doing so efficiently (Markus et al., 2006). The reasons for such “failure” was interpreted as, on the one hand, actors naturally having the incentive to “free-ride” on the efforts of others in certain groups, and on the other hand, the size of a group being of great importance and being difficult to optimally determine (ibid.). By particularly focusing on how different kinds of actors collectively impact the innovation process, collective action theory has been introduced to analyze the different kinds of technology innovation.

For example, adopting collective action theory to analyze technology standardization, Weiss and Cargill (1992) argued that the development of a standard could be problematic, because once a standard exists as a public good, then any firm is free to implement it, regardless of whether it contributed to the development. In addition, they also found that technology standardization exhibits high level of network externalities, which could impact on both standards setting and diffusion. Whether networks - function well or not is greatly determined by the number and type of actors that are needed for successful standards development and diffusion.

Similarly, Foray (1994) indicated that, although free-riding happens, the costs of technology development are reduced if there are more actors to share the costs; thus, potential adopters of technology have a common interest and should band together. Furthermore, he also suggested that, as the number of actors becomes too large, then the costs of coordination would also rise, leading finally to free-riding. Thus, in terms of a successful technology innovation, Foray (1994) emphasized the significance of governance, and concluded that actors enrolled for technology development would take the form of a group with a limited number of members with homogeneous interests.

By extending the previous standardization studies that adopted collective action theory, Markus et al. (2006) investigated the standardization of information systems which is led by various groups with varied interests and resources. They suggested the heterogeneity of enrolled actors and their interests and resources are prone to challenges.

These challenges are varied but interrelated, and the identified challenges must be properly addressed to ensure success of standardization. To identify and address the challenges in standardization, Markus et al. (2006) developed a scheme of analysis, and several tactics were identified. These tactics include governance, GSEs leading, scoping decisions, intellectual property rights (IPR) agreement, and moral persuasion.

In terms of technology innovation, the development and diffusion of the technology needs joint input from a number of participants, such as technology developers, vendors and adopters. Due to different backgrounds, in general these participants maintain varied interests towards technology innovation, and they differ in their resources in controlling the technology and market. For example, in the market, the incumbent stakeholders, especially the dominant ones, would like to retain their established positions, while the new entrants would like to have a share.

When understanding the government in technology innovation, based on collective action theory, government could be recognized as a key actor to take the lead in both technology development and diffusion. To address the challenges that are caused by actors with heterogeneous interests and resources, the tactics proposed by Markus et al. (2006) could be satisfied by the government with the aim of promoting technology innovation. Furthermore, as different challenges are suggested, to be identified in the first step, and then instruments are suggested for development to address these identified challenges, thus, in fact, the work of Markus et al. (2006) has also provided a scheme of analysis for understanding how technology innovation can be promoted.

Nevertheless, based on the aim of this research, we argue that, although collective action theory could help in understanding the government role in innovation and could suggest that targeted instruments be developed, based on the identified challenges, it is incapable of instructing what instruments could be developed and how to develop them. Even though five tactics are suggested by Markus et al. (2006), the suggested tactics for government to support technology innovation are not exclusive. This can be attributed to the limitations embedded in the theory, and combining collective action theory with other literature to generate a new set of solutions is suggested.

3.3.3 Actor-network theory

Actor-network theory (ANT) has been widely adopted in innovation studies (e.g. Gao, 2006, Tilson and Lyytinen, 2006a, Tilson and Lyytinen, 2006b, Kwak et al., 2011, Montenegro and Bulgacov, 2014, Yongwoon and Shin, 2015). It examines the actions and motivations of human actors who align their interests around non-human actors, and understands the world as complex networks of three symmetrical actors, namely natural, social and technical actors (Latour, 2005). The process of building the actor network could be viewed as a process of persuading other actors to participate (Wessells, 2007, Montenegro and Bulgacov, 2014). Nevertheless, even if the actors are enrolled, due to their heterogeneous interests, actors in the network would always intend to align the interests of others with their own (Latour, 2005). Therefore, as Walsham and Sahay (1999, p.42) suggested, *"Successful networks are created through the enrolment of a sufficient body of allies and the translation of their interests"*.

ANT focuses on the network building and formation process, while inscription and translation are the two core concepts of ANT (Callon, 1991). In terms of technology innovation studies, ANT is normally adopted to understand how technology is accepted within a network, and how the networks are formed and sustained (Elder-Vass, 2008, Yongwoon and Shin, 2015). Technology innovation is seen as a process in which an actor network of organizations with varied interests is formed and maintained around the technology (Gao, 2006, Lee and Oh, 2006). Whether the focal actor can enroll other key actors into the actor network and align heterogeneous interests to the technology innovation initiative, is the key for a technology innovation to be successful (Gao, 2007).

Therefore, based on ANT, government is viewed as a focal actor which enrolls actors into the network of a technology innovation, and the innovation is interpreted as a process in which an actor-network of different kinds of organizations is formed and maintained by government (Fomin, 2008). For instance, along with understanding the emergence and evolution of cellular telephony, Lyytinen and King (2002) conceptualized the transformation of the mobile industry as the result of dynamic interactions among heterogeneous actors who were pursuing their own interests.

Government was recognized as the focal actor representing interests from the regulative domain, and its main role was to align its core interests to those of other enrolled actors. Similarly, Lee and Oh (2006) applied ANT to investigate the mobile standard setting process in an international context, and suggested that firms, industrial consortia, and government in each country both collaborated and competed with each other in term of standardization. Countries which aimed to set their own standards as international had to enroll other international actors to align their interests to, and the government in each country explored how to take the lead to facilitate standardization based on their own interests.

Nevertheless, Howcroft et al. (2004) indicated the outcomes of building the network and creating inscriptions are unpredictable, since actors *"might not completely understand the assigned role and the flexible context may lead to re-inscription"*. In contrast, if the actor network is operating with strong and stable ties, then it could be viewed as a package or resource in the later stage of building larger scale networks. ANT scholars have called this a *"black-box"*, and Callon (1991) suggested that the "black-box" is normally irreversible, which means it is not only difficult to undo or cancel the previous translations, but also to confine it in the future.

Despite wide adoption in innovation studies, scholars have also identified several limitations of applying ANT in certain circumstances. For instance, Tilson (2008) suggested ANT cannot systematically address the actual innovation process, both in creation and diffusion, since most ANT analyses are conducted to explore established networks and already introduced innovations, which means the framework is better at historical description but weak in understanding unfinished phenomena. Moreover, ANT is also criticised as lacking enough attention to exploring the network establishment, which means little attention is paid to understanding how actor-networks come to be built from the very beginning (Howcroft et al., 2004, Tilson and Lyytinen, 2006b, Wessells, 2007).

3.3.4 Institutional theory

According to Scott (1995), an institution is a multifaceted, durable social structure that is made up of symbolic elements, social activities, and material resources. Such a social structure "gives organizational actors or individuals lines of action or orientations, but at the same time controls and constrains them" (p.12). To constrain the options that individuals and collectives are likely to exercise, the contracts, insurance, corporations, as well as formal organizations can all be acknowledged as institutions (Jepperson, 1991). Thus a commonly adopted definition in Scott (2001) summarized institution as "comprised of regulative, normative, and cultural-cognitive elements that, together with associated activities and resources, provide stability and meaning to social life" (p. 33).

In innovation studies, there are two different kinds of understanding about institutions. One follows Nelson (1992) who recognized institutions as economic and social entities that set up rules of practice to impact innovation; the other follows North (1991) who viewed institutions as the set of practices, rules and laws that guide or constrain the actors' behaviors towards innovation. For instance, by viewing institution as the "real actor", many innovation studies focus on understanding the function of different institutions involved, such as R&D institutes (Lee and Park, 2006), intermediate organizations (Kapsali, 2011), and government authorities (Lee and Oh, 2006, Stacy, 2007, Chung, 2013, Gao et al., 2014). In comparison, by understanding institutions as "rules", such studies mostly focus on the impacts of institutional influences (e.g. Hsu, 2005, Damsgaard and Lyytinen, 2001, Kshetri et al., 2011, Tsai and Wang, 2011). In order to avoid confusion in understanding what institution normally refers to, we suggest that a clear definition of institution is needed before it is used in the research.

By adopting institutional theory, innovation studies normally emphasize both the roles of government and the instruments of government intervention. Government authorities are normally considered as the most influential public institutions that dominate the regulative domain, and could impact innovation activities through exerting institutional pressures, especially in countries where government controls development (King et al., 1994, Kshetri et al., 2011, Nelson and Nelson, 2002).

For example, Christiaanse and Huigen (1997) adopted institutional theory to explain the success and failure of information system diffusion at a national level. Through comparing two different institutional environments, they concluded that the one with strong government support had provided better conditions for the information system to diffuse than the other one. Similarly, Kshetri et al. (2011) adopted institutional theory to explore the interrelationships between institutions and the third generation of mobile technology standardization in China. The work examined the role of both formal and informal institutions, and concluded that the Chinese government, as the most influential institution supporting the indigenous innovation by demonstrating clear biases, was the key to success. Also emphasizing the institutional environment, Wu and Leung (2012) adopted institutional theory to understand the implementation of the convergence of three networks in China. The research concluded that different government authorities, as influential public institutions, normally conflict, from the ministerial level to the local level, which results in a very complex institutional environment for the three networks to converge. Strong regulative intervention from central government proved to be crucial.

Besides, specifically emphasizing the institutional instrument of government intervention, there exists a cluster of innovation studies in the literature that are conducted based on the benchmark work of King et al. (1994). Initially aimed at exploring the mechanisms by which IT innovation could be impacted by institutional interventions, King et al. (1994) made a breakthrough in theorizing about institutional intervention in the diffusion of technology innovation. The work identified government authorities as a group of core institutions that could influence technology innovation (others include international agencies, research institutes, professional associations, financial institutions etc.), and suggested that institutional interventions can affect technology innovation through the interaction of *influence* and *regulation* along the dimensions of *supply-push* and *demand-pull* forces (King et al., 1994). Specifically, six institutional interventions were summarized, namely *knowledge building*, *knowledge deployment*, *subsidy*, *mobilization*, *standard setting*, and *innovation directive*.

In the literature, the six institutional interventions that King et al. (1994) summarized have been widely adopted to understand government actions in technology innovation (e.g. Montealegre, 1999, Kwak et al., 2011, Damsgaard and Lyytinen, 2001, Mekonnen and Sahay, 2008, Gao, 2015). For example, Montealegre (1999) examined institutional roles in the adoption of the Internet in four less-developed countries in Latin America, and suggested a temporal ordering of the institutional interventions that should have been taken by the local governments. Damsgaard and Lyytinen (2001) examined how an industry association, as significant intermediating institutions, advanced the diffusion of electronic data interchanges (EDI) technology in the grocery sectors of Hong Kong, Denmark and Finland. The work concluded that industrial associations were crucial, especially in knowledge building, deploying and standard setting.

Despite its wide adoption in innovation studies, several limitations embedded in institutional theory have also been identified. For example, some scholars have criticized the fact that little of the literature using the institutional perspective can demonstrate clearly how institutions form, change, operate, stabilize or even dissolve at some point (e.g. Tolbert and Zucker, 1996, Tilson, 2008, Mignerat and Rivard, 2009, Carton et al., 2012, Teo et al., 2014). Besides, some scholars have indicated that applying institutional theory in analysis on the industry level normally faces the challenge of identifying the relevant organizations and their relationships, which leads to the theory being good at interpreting but weak in structuring the analysis (e.g. Williamson, 1999, Hargadon and Douglas, 2001, Siu et al., 2006, Currie and Guah, 2007, Mekonnen and Sahay, 2008). In fact, although institutional theory functions well in understanding how institutional pressures can shape the innovation process, the limitations that are summarized above could lead to two deficiencies: on the one hand, by adopting institutional theory alone it is difficult to understand the innovation process and expose the challenges; on the other hand, the theory itself has difficulty in identifying actors and their interactions, which means it is difficult to understand the overall picture of innovation, and where exactly the identified institutional intervention instruments should actually be exerted to take effect.

3.3.5 Innovation system

Innovation system perspectives, as elaborated in the second chapter, are also widely adopted to investigate government intervention in innovation. In fact, institutional theory, introduced in the previous section, has constructed a significant foundation for innovation system perspectives (Edquist and Hommen, 1999). From the lens of institutional theory, an innovation system could be viewed as a definite "institutional field". Firstly, the innovation system is composed of several organizational actors; secondly, these actors are interdependent or connected by certain relationships; thirdly, all organizational actors and interactions are constrained by common norms, values, and assumptions, which in other words, are institutions (Carlsson et al., 2002).

As underpinned by institutional theory, every single system actor is seeking legitimacy within the given institutional environment in the innovation system. Thus, based on the innovation system perspectives, innovation is normally considered to be the result of collective activities taken by the system actors, while the institutional environment that is enclosed within the innovation system shapes actors' activities and interactions and further initiates, imports, modifies and diffuses the technology innovation (Freeman, 1995). Furthermore, as Freeman (2002) indicated, with the aim of promoting technology innovation, institutions must be adjusted, or "aligned", to a new technology.

In terms of adopting innovation system perspectives in learning about government intervention in technology innovation, among all the innovation system concepts, NIS is generally employed to understand how government authorities impact innovation (e.g. Lundvall, 2007, OECD, 2007b, Fagerberg and Srholec, 2008, Li, 2011, Liu and Cheng, 2014). Government, as the most powerful and influential component of NIS, can play the role of coordinator and guide to compensate for weaknesses in firms in terms of promoting the innovation (Chung, 2013, Gao, 2015). Besides, government could also determine the NIS structure and impact NIS functions in terms of supporting national innovation initiatives (Freeman, 2002, Chaminade et al., 2012, Samara et al., 2012).

As examples of numerous applications of NIS in understanding government in innovation, Freeman (1987) summarized the experiences of how the Japanese government promoted technology innovation by facilitating collaboration between research institutes and industries through establishing a distinguished national innovation system. Negro et al. (2007) demonstrated a comparative case study about how government affected the functionality of national biomass gasification innovation systems differently in the Netherlands and Germany. Similarly, in the context of understanding an evolving national innovation system, Lundvall (2007) suggested government, as a core component of the system, was observed to coordinate and compensate for the weaknesses in other organizations. Other government roles like distributing power and resources, building institutions and controlling system openness are also summarized in related studies.

Nevertheless, based on the reviewed literature, we suggest that more studies need to be conducted to understand government intervention in technology innovation from the TIS perspective. As introduced in the previous chapter, the nature of technology innovation includes a system feature, especially for complex technology innovations at the national level (Nelson and Nelson, 2002, Carlsson, 2006, Markard and Truffer, 2008, Chaminade and Edquist, 2010). In terms of emphasizing the innovation research unit for a specific technology, the concept of TIS proves to be more appropriate than the others (Carlsson et al., 2002, Bergek et al., 2008). For example, as mentioned, a nation's NIS normally includes a number of sub-divided innovation systems (like RIS, SIS, LIS, TIS etc.), but it cannot be adopted to analyze a specific technology innovation (Carlsson, 2006, Bergek et al., 2008).

In the literature, most existing studies conducted to understand government in technology innovation from the innovation system perspective have chosen to adopt the NIS frame for analysis, rather than the TIS (e.g. Nemet, 2009, Samara et al., 2012, Chaminade et al., 2012, Chung, 2013, Liu and Cheng, 2014, Zhu, 2014). As a result, how government, as a key NIS component, is capable of impacting the NIS and thereby influencing the innovation has been relatively well understood, but few studies have been conducted to understand how government, as a significant external actor, can intervene in the TIS to promote technology innovation. Therefore, we suggest that if the innovation system perspective to understand government intervention in technology innovation is adopted, more studies need to be conducted based on the TIS. Furthermore, in terms of application, many scholars have also made the criticism that an innovation system perspective is more like an analytical frame, rather than a theoretical one, as the system perspectives are good at structuring the analysis but weak in interpreting (e.g. Edquist and Hommen, 1999, Nelson and Nelson, 2002).

3.3.6 Conclusion

To sum up, there is a broad range of theoretical perspectives for understanding government in technology innovation, but these are not confined to the five perspectives that are distinguished. Other kinds of theories, such as game theory and social construction of technology, are also used (e.g. Chiang, 1995, Bijker, 1997, Chiasson and Davidson, 2005, Davidson and Chismar, 2007). Table 3.2 summarizes the features and typical works based on the five theoretical perspectives that are illustrated.

As Table 3.2 indicates, each perspective holds different strengths in understanding of the process of innovation and government intervention in technology innovation. For example, stakeholder theory function in identifying innovation actors and challenges that faced relating to various interests, but is weak in understanding the innovation process and identifying instruments for government intervention; ANT and innovation systems are good at structuring the analysis in terms of the innovation process and exposing challenges that are faced in innovation, but are weak in identifying solutions for government to address these challenges; institutional theory focuses on the institutional environment and is good at interpreting how institutional interventions shape technology innovation, but is weak in structuring the analysis in terms of understanding the innovation process and exposing the challenges that are faced in innovation.

Table 3.2: Theoretical perspectives that are adopted for understanding government in innovation. *(Source: author's summary)*

Theoretical perspectives	**Representative literature**	**Interpretation of technology innovation**	**Understanding of government in technology innovation**	**Advantages and limitations in analytical application**
Stakeholder Theory	Pouloudi (1999) Papazafeiropoulou (2002) Shin et al. (2006)	A socio-technical process that is operated by several stakeholders including government authorities.	Government might build collective and coordinative relationships among other enrolled stakeholders in order to take advantage of their interests and capabilities for innovation.	• Good at understanding the roles and interests of stakeholders in innovation • Weak in understanding the innovation process and how instruments are formed and actually work.
Collective Action Theory	Weiss and Cargill (1992) Foray (1994) Markus et al. (2006)	Led by various groups with varied interests and resources. Heterogeneity of enrolled actors and their interests and resources are prone to challenge in both development and diffusion.	Government is a key actor in taking the lead in both technology development and diffusion. Tactics like governance, GSEs leading, scoping decisions, IPR agreement, moral persuasion can be used.	• Good at understanding actors' roles, interests and resources in innovation. • Weak in identifying solutions for government intervention.
Actor-Network Theory	Lyytinen and King (2002) Gao (2006) Tilson and Lyytinen (2006) Fomin (2008) Kwak et al. (2011)	A process in which an actor network of organizations with varied interests is formed and maintained around the technology.	Government is viewed as a focal actor which enrolls other key actors into the actor network and aligns their heterogeneous interests to the innovation initiative.	• Good at understanding actors' roles, interests and describing the innovation process. • Weak in identifying instruments for government intervention.
Innovation System Perspective	Freeman (1995) Liu and White (2001) Lundvall (2007) Fagerberg & Srholec (2008) Chaminade et al. (2012) Chung (2013)	Innovation, including both development and diffusion, is the result of collective activities taken by the system actors who are shaped by the institutional environment of the system.	Government could directly affect the system actors or impact the institutional environment in the system to shape system actors' activities, and further to initiate, import, modify and diffuse the innovation.	• Good at understanding actors' roles, interactions, institutional environment and the process of innovation. • Weak in understanding how government intervention instruments are formed, and how instruments actually impact the innovation process.
Institutional Theory	King et al. (1994) Montealegre (1999) Choudrie et al. (2003) Currie and Guah (2007) Kukk et al. (2016)	Difficult for describing the innovation process and identifying actors unless combined with other frames.	Government is the most important public organization dominating the regulative domain, and able to impact innovation activities through institutional influences.	• Good at understanding government roles and how institutional instruments impact innovation. • Weak in understanding the innovation process and exposing challenges.

3.4 RESEARCH GAPS, AIM AND QUESTION

As demonstrated in the first chapter, this research origins from an interesting phenomenon that technology late-coming nations like China and Korea are gradually catching-up in technology innovation with strong government support. Through reviewing relevant innovation literature on technology innovation and government in technology innovation, research gaps are identified in the present innovation literature.

On the one hand, more studies are needed to understand government intervention in technology innovation based on technological innovation system perspective, especially to uncover how interactions between government and technological innovation system can promote technology innovation. As the nature of technology innovation includes a system feature, especially for complex technology innovations at the national level (Nelson and Nelson, 2002, Carlsson, 2006, Markard and Truffer, 2008, Chaminade and Edquist, 2010). In terms of emphasizing the innovation research unit on a specific technology, the concept of TIS proves to be more appropriate than others (Carlsson et al., 2002, Bergek et al., 2008). Nevertheless, in the literature, most existing studies conducted to understand government in technology innovation from the innovation system perspective chose to adopt the NIS frame for analysis, rather than the TIS (e.g. Nemet, 2009, Samara et al., 2012, Chaminade et al., 2012, Chung, 2013, Liu and Cheng, 2014, Zhu, 2014). As a result, how government as a key NIS component is capable of impacting the NIS and thereby of influencing the innovation has been relatively well studied, but few studies have been conducted to understand how government as a significant external actor can intervene in the TIS to promote technology innovation. Therefore, we suggest that if the innovation system perspective is adopted to understand government intervention in technology innovation, more studies need to be conducted based on the TIS.

On the other hand, the other research gap existing in current innovation literature relates to the context of innovation studies. The innovation context proves to be significant in understanding innovation activities (Fagerberg, 2005, Fan, 2006, Chaminade et al., 2009). The features of technology innovation and government intervention are varied in relation to the different innovation contexts (e.g. Stacy, 2007, Wang and Kim, 2007, Kwak et al., 2011, Gao and Liu, 2012, Chung, 2013). Nevertheless, most knowledge is conceptualised from the context of developed nations, and the uniqueness of technology innovation, TIS and government intervention in the catching-up context are yet to learn, which may lead to unanticipated deviation between conclusions and reality (Bastian, 2010, Vialle et al., 2012, Gao et al., 2014). Therefore, more studies conducted in catching-up context are needed, knowledge of technology innovation and government intervention in such contexts need to be extended.

Therefore, based on innovation system perspective, this dissertation aims to understand how the government intervention in technological innovation system (TIS) promotes technology innovation, especially that in the catching-up context. In this dissertation, China's catching-up in technology innovation is particularly focused to achieve the aim of this research. As on the one hand, based on reviewed literature, strong support from the government has been proven to be crucial for late-coming countries especially China to overcome the deficiencies that faced in technology innovation (Wang and Kim, 2007, Kshetri et al., 2011, Kwak et al., 2011, Gao et al., 2014, Levén et al., 2014, Zhu, 2014); on the other hand, it is also witnessed that, with strong government support, a number of technological innovation systems have been built in most of the highlighted industries in China. The government takes interventions in both innovation systems' creation and maintenance. The technological innovation systems with strong government support are also recognized as a key for China to catch up in technology innovation. Therefore, associate China's catching-up cases with the aim of this research, the main research question for this dissertation to answer is:

RQ: How the government intervention in technological innovation system promotes technology innovation in China?

3.5 SUMMARY

This chapter has elaborated the studies of innovation policy and government intervention in innovation. Based on the literature, this chapter set out to understand how government intervention can promote technology innovation, especially that in the catching-up context. In the above sections, the relevant concepts and studies were introduced. Meanwhile, associated with the conclusions in the second chapter, several research gaps were also identified in current innovation literature.

Specifically, in section 3.2, literature on innovation policy is reviewed. The impacts of the rationales, instruments and contexts of innovation policy are particularly emphasized. Due to the system feature in the nature of technology innovation, we suggest that policy for technology innovation could be investigated based on the innovation system perspective, the system structure and functions, which could help both identify the rationales and select the instruments. Interpreted via the innovation system perspective, as a conclusion, innovation policy is suggested to intervene when system failures are identified (Chaminade and Edquist, 2010). All system failures are related to the system's structural components, and it is suggested that innovation policy instruments must be selected in relation to the actual problems identified in the innovation (Borrás and Edquist, 2013). Furthermore, the context of innovation is also a significant factor which impacts on the rationales and instruments of innovation policy. As the innovation system could feature a context in which it overlaps, we therefore suggested that the features of innovation policies in the catching-up context could be summarized through understanding the catching-up context that features in the innovation system.

In addition, as the most powerful public organization, literature on government intervention in technology innovation is reviewed in section 3.3. As indicated by the literature reviewed, government has played a significant role in technology innovation, and government intervention shapes the process of innovation (Pavitt, 2000, Markus et al., 2006, Gao, 2015). In the literature, there exists a broad range of theoretical perspectives for understanding government in technology innovation. The five most widely adopted perspectives, including stakeholder theory, collective action theory, actor-network theory, institutional theory and the innovation system perspective, are introduced. Through reviewing relevant studies, we revealed that each perspective holds a different understanding about technology innovation and government intervention in innovation, and each contains both advantages and limitations in analytical application. Therefore, we suggested that the theoretical perspectives must be selected or further developed to serve the specific research aims, and the mechanism by which technology innovation can be promoted by government interventions should be emphasized. As shown in the literature, from one particular perspective, one piece of research normally understands a few government instruments specifically developed from or applicable to the studied cases.

Lastly, in section 3.4, based on the reviewed literature in both chapter 2 and chapter 3, we summarized two research gaps that are identified in the present innovation literature. The research gaps suggested the necessity of conducting more studies to focus on the TIS for understanding government intervention, especially in catching-up context. To fill the identified research gaps, the aim of this research was expressed, and the research question was proposed.

So far, relevant literature about government intervention in technology innovation has been elaborated. Relevant concepts and studies were introduced and many conclusions were made. In this work, the reviewed studies not only exhibited the research gaps in the present innovation literature, but also provided us a solid foundation on which to achieve the aim of this research. In the next chapter, institutional theory as the particular theoretical perspective of this research is introduced, the theoretical framework for structuring this research is developed, and the research questions based on the theoretical framework are specifically articulated.

CHAPTER 4: ANALYTICAL FRAMEWORK

4.1 INTRODUCTION

As discussed in chapter 3, there exists a broad range of analytical perspectives for understanding government intervention in technology innovation, and the understandings gained form these perspectives are varied, based on the different analytical perspectives that are adopted. Institutional theory suits our research aim and thus will serve as the theoretical base. Associated with TIS, in this chapter we draw on TIS to develop the analytical framework.

4.2 THEORETICAL PERSPECTIVE

4.2.1 Why institutional theory

To fulfill the aim of this research, we need an analytical basis that functions well, not only in understanding the innovation process, mapping innovation actors and exposing the challenges that are faced in innovation, but also in identifying the instruments for government intervention and interpreting how these identified instruments actually affect innovation. Through considering the advantages and limitations of each analytical perspective, we select institutional theory, which had advanced in innovation studies, as our analytical lens for three primary reasons.

Firstly, TIS is recognized as one of the major research focuses in this research, which means we can take the advantages of the innovation system perspective to complement the deficiencies of institutional theory in structuring analysis, and at the same time, to exploit the advantages of institutional theory in interpreting.

Secondly, government intervention is also a major focus in this research. In the literature, government authorities have long been viewed as significant institutions in innovation (King et al., 1994, Edquist, 2001). Government authorities dominate the regulatory regime, and intervention instruments are mostly developed, based on institutional pressures, especially regulative ones (King et al., 1994, Lyytinen and King, 2002). Compared with other analytical perspectives, institutional theory works well in interpreting how the instruments of government intervention are identified and how these intervention instruments shape technology innovation in actual application.

Thirdly, institutional theory, as the underpinning analytical foundation of innovation system perspectives, is another significant reason impacting our selection. On the one hand, actors, networks and institutions are introduced as three structural components of a complete TIS (Carlsson et al., 2002). Adopting institutional theory could properly address the TIS institutions as, compared with other theories, institutional theory is the only one that focuses on the institutional environment (Gao et al., 2014). On the other hand, institutional theory could interpret how TIS functions in technology development and diffusion are achieved in relation to the TIS actors, as it theorizes how system actors are guided or constrained to pursue "legitimation" in such an "institutional field".

4.2.2 Institutional theory

Institutional theory suggests that *"organizations are suspended in a web of values, norms, beliefs, and taken-for-granted assumptions that guide and confine their actions over time"* (Barley and Tolbert, 1997). The central underlying assumption of institutional theory is that organizations and organizational actors seek to gain legitimacy in their environment in order to be accepted, and thus ensure their long-term survival (Meyer and Rowan, 1977). "Legitimacy" is located at the center of institutional theory. Scholars use "institutional field" to describe the environment within which legitimacy must be acquired, repaired, or maintained by organizational actors (Suchman, 1995, Mignerat and Rivard, 2009). The norms, values and assumptions that determine the "institutional field" for organizational actors to survive, all emerge because of the existence of institutions (Barley and Tolbert, 1997).

Besides, in an "institutional field", each organizational actor should at least be connected or similar to one of the other actors (Deephouse and Suchman, 2008). The connections between different organizational actors in the field represent the existence of exchange relationships or communications between them (DiMaggio and Powell, 1983). Thus, depending on the connections, Scott (1995) suggested that the focal organization in an institutional field *"may be more influenced by the behavior of others with which it has connections, and so does reversely"*. Therefore, according to institutional theory, organization-based activities could then be interpreted as the process of interlinked but heterogeneous organizational actors pursuing legitimacies within the specific institutional field (Mignerat and Rivard, 2009). Such an understanding not only helps the roles of different organizational actors in an institutional field to be interpreted, but also contributes to exhibiting the mechanism of how institutional pressures form and take effect.

Based on a systematic literature review, Mignerat and Rivard (2009) summarized all the studies applying institutional theory into two distinct categorizations. One concerns learning institutional effects or pressures (e.g. Jepperson, 1991, Oliver, 1991, King et al., 1994, Lawrence et al., 2002, Silva and Figueroa B, 2002, Cousins and Robey, 2005); the other concerns understanding institutionalization (e.g. Tolbert and Zucker, 1996, Deephouse and Suchman, 2008, Kukk et al., 2016). Institutional effects pertain to processes in which institutions affect other organizations (Jepperson, 1991), while institutionalization refers to stages the institutions consist of (Tolbert and Zucker, 1996).

The most obvious difference is that, in the analysis of institutional effects, an institution is normally considered as an independent variable, while in the analyzes of institutionalization, the institution is normally viewed as the object of analysis (Mignerat and Rivard, 2009). In innovation literature, most existing studies belong to the former category, as institutional theory is normally adopted to understand how institutions and institutional influences can shape innovation activities (e.g. King et al., 1994, Montealegre, 1999, Cousins and Robey, 2005, Siu et al., 2006, Mekonnen and Sahay, 2008, Mignerat and Rivard, 2009, Tsai and Wang, 2011, Carton et al., 2012).

According to DiMaggio and Powell (1983), institutions could exert three kinds of institutional pressures on organizational actors, coercive, normative and mimetic pressures. *Coercive pressures* normally emerge from the legal environment and the existence of standards; *normative pressures* arise from professionalization, such as inter-organizational networks, similar educational backgrounds and mimetic behaviors; *mimetic pressures* normally emerge when the degree of uncertainty is high, which leads to organizational actors tending to model themselves on other organizations in their field that are perceived to be more legitimate or successful (DiMaggio and Powell, 1983). With the notion of three institutional pressures, the concept of three institutional pillars was proposed by Scott (1995), namely *regulative*, *normative* and *cultural-cognitive* pillars, representing the three analytical components of institutional pressures. These three pillars operate in combination, but are distinguished within mechanisms (Scott, 2001).

In the regulative pillar, coercive pressure explains how the institutions constrain and regularize the organizational actors' behaviors (Scott, 2001). Almost all scholars underscore the regulative aspects of institutions by figuring out the capacity of institutions to influence future behaviors by establishing the rules, inspecting others' conformity, and manipulating sanctions (Williamson, 1985). These processes can be operated both through informal mechanisms, like shaming or shunning activities, and highly formalized and assigned means, like the police and courts (Jepperson, 1991).

In the normative pillar, normative pressure explains how social obligations of the organizational actors constrain and shape their behaviors (Scott, 2001). Institutional pressures in the normative pillar are normally introduced as surveillance and sanctioning powers that are accompanied by feelings of guilt or innocence or incorruptibility (Lawrence et al., 2002, Bannister and Wilson, 2011). It is suggested that a normative conception of institutions emphasizes that the stabilizing influence of social values and norms could be both internalized and imposed by external factors (Mignerat and Rivard, 2009).

In the cultural-cognitive pillar, mimetic pressure explains why organizations, in a context of uncertainty, tend to copy other organizations who they consider as leaders or models (Scott, 2001). Culture-cognitive elements of institutions are defined as the shared conceptions that constitute the nature of social reality and the frames through which meaning is made (Zucker, 1987, Nemet, 2009, Lizardo, 2010, Zeng et al., 2010). In summary, coercive, normative and mimetic pressures are the mechanisms exerted by regulative, normative and cognitive influences on organizational actors to guide and constrain their behaviors (Mignerat and Rivard, 2009, Bannister and Wilson, 2011).

4.3 Theoretical framework

Therefore, based on the three reasons that are summarized, institutional theory is selected as the analytical basis for this research. A Theoretical framework is developed to exhibit the mechanism of government intervention in innovation. Our framework is composed of three components, which establish the argument that in each stage of technology development and diffusion, TIS presents specific features and has specific functions, but at the same time faces specific challenges, which need to be addressed by appropriate government interventions. The framework is illustrated in Figure 4.1, with the core components, relations, and the key points of research are demonstrated.

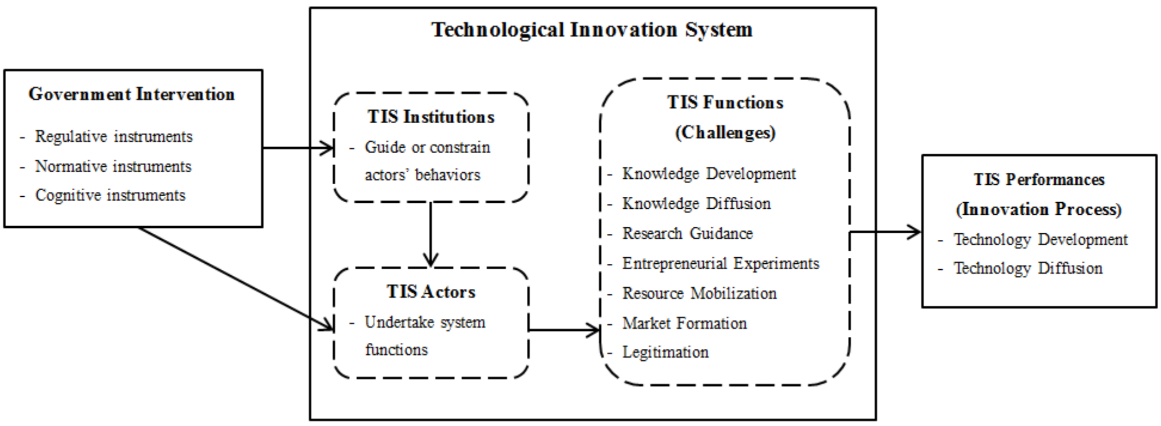

Figure 4.1: Framework of government intervention in TIS promotes technology innovation.

4.3.1 The innovation process and TIS performance

The innovation process

The literature reviewed in the second chapter indicated that innovation scholars hold varied perspectives on distinguishing stages of the technology innovation process (e.g. McKenney, 1994King et al., 1994, Gopalakrishnan and Damanpour, 1997, Van de Ven, 2005, Markus et al., 2006, Gao, 2015). By adopting the categorization of Gao (2015), in this research we study a complete technology innovation as a two-stage process, namely *technology development* and *technology diffusion*. The success of a technology innovation initiative means that the technology is not only developed but is also diffused in the market successfully (Gao, 2015). Specifically, the development stage mainly focuses on "producing" the technology, while the diffusion stage mainly focuses on "using" the technology. In the literature, several separate processes are required to develop a technology, including for instance, basic research, applied research, product development, production research, quality control, as well as commercialization (Hage and Hollingsworth, 2000). To diffuse a technology, separate processes could include for instance, comprehension, adoption, implementation, and assimilation (Swanson and Ramiller, 2004).

TIS performance

The performance of an innovation system is visible and measurable, reflecting how well the system functions in practice (Bergek et al., 2008, Markard and Truffer, 2008, Samara et al., 2012). In the literature, TIS performance is related to the effectiveness and efficiency of the system in introducing, diffusing and exploiting the new innovation. Therefore, TIS performance is normally assessed based on the process of innovation, as technology development and technology diffusion on the one hand are stages of the innovation process, yet on the other hand are also the basic targets of technology innovation (Carlsson et al., 2002). In this research, we follow the strategy of Markard and Truffer (2008) who studied TIS performance based on the stages of technology development and technology diffusion.

As introduced in the literature review chapter, innovation scholars have summarized a number of detailed indicators for assessing TIS performances at each stage. For example, the performance of TIS in the technology development stage could be assessed through measuring the *number of patent, number of scientists, mobility of professionals,* and *technological diversities*; in the diffusion stage, TIS performance can be examined through measuring indicators such as *license numbers, employment, turnover* and *financial assets* (e.g. Richen, 2001Negro et al., 2008, Hekkert and Negro, 2009). These indicators are suggested to be selectively adopted in specific cases. Furthermore, we also suggest that several cases specified indicators should be considered, based on the different initiatives in different innovation cases.

4.3.2 TIS structure, TIS functions and innovation challenges

TIS structural components

As introduced in chapter 2, the actors, networks and institutions are three TIS structural components (Carlsson et al., 2002, Bergek et al., 2008). *TIS actors* are defined as the organizational actors that directly undertake the innovation activities, like research institutes, universities, some GSEs and private firms (Markard and Truffer, 2008). *TIS networks* are established upon the interactions between varied system actors (Carlsson et al., 2002). *TIS institutions* are defined as *"the set of practices, rules and laws that constrain the behavior of system actors"* (Liu and White, 2001, p.1095).

As Freeman (2002) indicated, for developing and diffusing a new technology, institutions must be "aligned" to the technology. TIS institutions could guide and constrain the behaviors of TIS actors since, as interpreted by institutional theory, actors within such an "institutional environment" must pursue "legitimacy" for their survival (Mignerat and Rivard, 2009). In the TIS, the institutional environment might be established and influenced in several ways, and the system could also be affected accordingly (Kukk et al., 2016). Therefore, as shown in the framework, TIS institutions impact TIS actors through institutional influences, and TIS actors undertake innovation activities.

Besides, although networks are also recognized as one of three basic TIS structural components, the framework did not delineate the TIS networks when drawing up the system structure for two reasons. On the one hand, in a national level technology innovation program, so many actors from different fields are involved that they cannot be exhaustively addressed, which means summarizing their interactions could hardly be achieved in a comprehensive manner; on the other hand, the interactions themselves are not static, but are dynamic and keep evolving within the different stages of innovation, which means they can only be addressed in a certain time period. Therefore, we suggest that making the effort to summarize interactions between actors is not only unrealistic but also meaningless. The networks should be addressed when analyzing how TIS functions are achieved by networked system actors in practice.

TIS functions

Another core component of the framework includes TIS functions and innovation challenges. In the literature, the internal system activities undertaken by the TIS actors that are capable of impacting the target of the innovation system, whether positively or negatively, directly or indirectly, are defined as the *TIS functions* (Johnson, 1999). It is suggested that there are varied TIS functions which need to be positively achieved to "produce" the innovation (Edquist, 2001, Hekkert et al., 2007, Kukk et al., 2016).

As introduced in chapter 2, Hekkert et al. (2007) summarized seven TIS functions, including *entrepreneurial activities, knowledge development, knowledge diffusion, research guidance, market formation, resource mobilization* and *legitimacy creation*. The specific explanations and indicators of each function can be found in Table 2.2 in section 2.3.3, and are not repeats here. Besides, in the different stages of technology innovation, the TIS functions are differently emphasized. Some functions may particularly contribute in the development stage, i.e. knowledge development and guidance of research; some functions may take more effect in the diffusion stage, i.e. market formation and legitimation. Also, some functions may be significant throughout the whole innovation process, i.e. knowledge diffusion, resource mobilization and entrepreneurial activities (Bergek et al., 2008, Walrave and Raven, 2016).

Innovation challenges

Achieving the functions of the innovation system needs the use and coordination of a variety of resources and capabilities (Hekkert et al., 2007, Chaminade et al., 2009, Samara et al., 2012). For example, in terms of developing new knowledge, the capabilities and resources needed might include R&D capability and infrastructures, professionals, financial support etc. Therefore, TIS actors, as the carriers of resources and capabilities and undertakers of innovation, must be well mobilized to think and further act in a positive way with respect to the system's functions (Hekkert et al., 2007, Markard and Truffer, 2008, Walrave and Raven, 2016).

Nevertheless, the different system actors normally hold different interests in relation to innovation, and control different resources and capabilities (Chaminade and Edquist, 2010, Samara et al., 2012). The heterogeneity of TIS actors in terms of interests, capabilities and resources could be a *challenge* to the achievement of TIS functions, thereby hindering the success of innovation (Bergek et al., 2008). Furthermore, as indicated by the literature reviewed, an innovation project normally bears specific *deficiencies* in resources or capabilities that are insufficient to support innovation activities (Samara et al., 2012, Georghiou et al., 2014). These deficiencies could give rise to challenges, and further hinder the success of innovation (Gao, 2015).

As mentioned, for a specific innovation project to succeed, seven TIS functions in different stages of innovation must be well achieved (Hekkert et al., 2007). In addition, the fulfillment of different TIS functions requires different resources and capabilities (Bergek et al., 2008). Therefore, the challenges faced are normally different in the different stages of innovation. In a specific innovation project, in the different stages, the challenges to different TIS functions must be specifically identified, targeted and addressed to achieve success for the innovation (Bergek et al., 2008). Nevertheless, TIS itself might not always be able to address the identified challenges, for example when deficiencies arise or TIS institutions cannot align system actors' interests, resources and capabilities with respect to the innovation. System failure is then evident, and external interventions are needed (Chaminade and Edquist, 2010, Epstein, 2012).

4.3.3 Government intervention in TIS

System failures hinder the fulfillment of system functions and cannot be solved by the innovation system itself. Thus, in order to ensure the achievement of the TIS functions, appropriate government interventions must be made to address the deficiencies and challenges that caused the system failures. This indicates the rationales concerning *why* government should take intervention (OECD, 2007a, Chaminade and Edquist, 2010). Moreover, *when* to take intervention is important, as appropriate instruments for the intervention must be applied at the proper time so as to efficiently ensure the success of innovation (Montealegre, 1999, Choudrie et al., 2003, Gao, 2015). In the literature, some innovation cases are initiated by government; thus, government intervention starts at the beginning of such innovation projects (e.g. Smith, 2007, Chen et al., 2012b, Kukk et al., 2016). Also, some innovations are not government organized, in which case government intervention emerges in the middle of the innovation process (e.g. Raus et al., 2009, Foster and Heeks, 2013, Ahrweiler and Keane, 2013).

Besides, understanding *where* exactly the government could intervene is also significant. Based on the reviewed literature, TIS functions are undertaken by the TIS actors. TIS actors are organized in the system and a single TIS actor may undertake more than one TIS function (Liu and White, 2001, Carlsson et al., 2002, Bergek et al., 2008). Thus, for the government, TIS actors compose the fundamental layer on which the intervention instruments should be exerted. Furthermore, as introduced, TIS institutions include a set of practices, rules, laws and values to guide or constrain the behaviors of TIS actors (Liu and White, 2001, Fagerberg, 2005). Thus, the institutional environment in TIS is the other place where the government could intervene. Therefore, as shown in the framework, two modes of government intervention are distinguished. The government could act directly to manipulate the TIS actors through, for example, dictating operational plans, setting organizational targets and funding or subsidizing; alternatively, the government could affect the TIS actors through the TIS institutions that it creates or shapes (King et al., 1994, Liu and White, 2001, Kshetri et al., 2011, Kukk et al., 2016).

Lastly, the most significant issue is to understand the instruments of government intervention, which also relates to the question of *how* to intervene. As discussed in the third chapter, government interventions are studied from different perspectives, and one piece of research normally focuses on a few intervention instruments. A comprehensive list of intervention instruments is neither available nor realistic (Gao, 2015). According to institutional theory, government authorities, as the most powerful institutions can exert institutional effects to affect the actors' behaviors (Scott, 1995). In this research, we also study intervention through different *regulative*, *normative* and *cognitive* instruments.

As elaborated in section 3.3.4, a regulative instrument is established based on the mechanism of coercive pressure (DiMaggio and Powell, 1983, Scott, 1995). A regulative instrument could be presented in the form of laws, rules, sanctions, directives etc. Thus, the government could restrict or stimulate the development and the diffusion of a specific technology through creating or shaping the institutional environment in the TIS (e.g. Chaminade et al., 2009, Blind et al., 2010, Kshetri et al., 2011), or by mandating the TIS actors according to directives, especially those government controlled or sponsored organizations, such as the GSEs, public R&D institutes and national universities (e.g. Hsu, 2005, Markus et al., 2006, Xia, 2012b).

In addition, a normative instrument functions based on the mechanism of normative pressure, which primarily emphasizes social values and norms (DiMaggio and Powell, 1983, Scott, 1995). A normative instrument could be in the form of certifications, accreditations, licenses etc. Thus, the government could adopt normative instruments mainly to affect the institutional environment in the TIS, and thereby to affect the process of innovation (e.g. Kennedy, 2006, Kshetri et al., 2011, Kukk et al., 2016).

A cognitive instrument takes effect based on the mechanism of mimetic pressure (DiMaggio and Powell, 1983, Scott, 1995). It enables TIS actors to copy others who are recognized as leaders or models (Scott, 2001). A cognitive instrument could be in the form of shared common beliefs and shared action logics. Thus, the government could use cognitive instruments to affect the institutional environment in the TIS.

4.4 RESEARCH QUESTIONS

This framework will guide our research to answer the main research question, as:

RQ: How the government intervention in technological innovation system promotes technology innovation in China?

At the operational level, this main research question could be answered through addressing four sub-questions, as shown in figure 4.2:

SQ1: What are the characteristics of TIS and government intervention in China?

SQ2: How can TIS affect the development and diffusion of a technology?

SQ3: What are the main challenges for the government to address in China's catching-up in technology innovation?

SQ4: What strategies and instruments the government applied to promote technology innovation in China, and how?

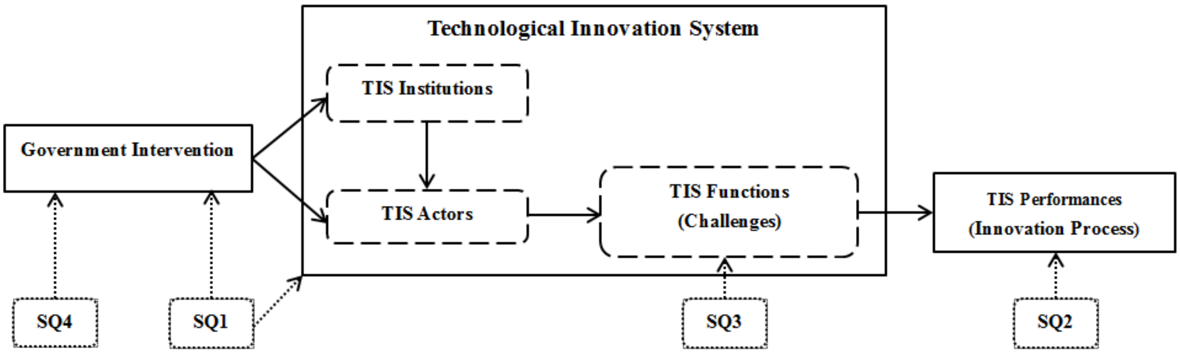

Figure 4.2: Articulating the main research question based on the framework.

4.5 SUMMARY

This chapter developed a theoretical framework for understanding how government intervention in TIS could promote technology innovation, especially that in the catching-up context. Institutional theory was selected as the analytical basis to construct the framework. Based on institutional theory, government authorities were recognized as powerful and influential institutions in the regulatory regime that could impact the innovation process through issuing regulative, normative and cognitive interventions. In addition, institutional theory also contributes to unpacking how the institutional environment in the TIS shapes the behaviors of TIS actors, and to interpreting how TIS functions in technology development and diffusion are achieved in relation to the TIS actors. Although institutional theory was criticized as weak in structuring analysis in actual use, in this work, we have found that the frame of TIS could well complement the deficiencies of institutional theory and thereby exploit the advantages of institutional theory in interpreting. Therefore, we suggested that adding TIS as the analytical lens, to some extent, might extend the application of institutional theory in innovation research.

Besides, the framework was composed of three components, including government intervention, technological innovation system and the process of technology innovation. Through the framework, we established the argument that in each stage of technology development and diffusion, TIS presents specific features and has specific functions, but at same time faces specific challenges, which need to be addressed by appropriate government interventions. Two modes of government intervention are distinguished: the government could act directly to manipulate the TIS actors, or affect the TIS actors through the TIS institutions that it creates or shapes. Specifically, regulative, normative and cognitive instruments were uncovered as three kinds of instruments for government intervention in innovation. The framework developed can shape the data collection and analysis, and thereby guide us to answer the proposed research questions. In the next chapter, the design of this research is elaborated in detail.

CHAPTER 5 RESEARCH DESIGN

5.1 INTRODUCTION

This chapter elaborates the research design, which builds up the links from data collection and analysis to the answers of the proposed research questions. In this research, qualitative research methodology is adopted, and the research questions are answered through examining two innovation case studies in China. Specifically, the philosophical perspective and the methodological design of this research are elaborated in section 5.2 and section 5.3, respectively. The research quality is assessed in section 5.4. Section 5.5 concludes the chapter.

5.2 PHILOSOPHICAL PERSPECTIVE

5.2.1 Positivism, interpretivism and critical realism

Every single piece of research is underpinned by a certain assumption, and such an assumption is highly related to the validity and methodology of the research (Myers, 1997). Various philosophical assumptions may lead to distinctions in how we understand the nature of things *(ontology)*, how to explain the nature of knowledge and what counts as knowledge *(epistemology)*, and in the methods that are chosen for acquiring knowledge *(methodology)*. Thus the results and findings of studies, even on the same topic, might be varied due to the different philosophical assumptions (Mingers and Willcocks, 2004). There are several following Orlikowski and Baroudi (1991) philosophical assumptions include *positivism*, *interpretivism* and *critical realism*. A comparison of the differences in ontological, epistemological, and methodological assumptions between three perspectives is summarized in the Table 5.1.

Positivism assumes that reality is given objectively, and could be described by measurable attributes which exist independently and which the researcher has no control over. Positivist research generally attempts to increase the predictive understanding of phenomena by testing proposed theories (Orlikowski and Baroudi, 1991). In other words, positivist study can be described as research that adopts a hypothetico-deductive approach, by aiming to build up relationships among a set of variables which might have predictive power (Tsang, 2014). Quantitative methods, like questionnaire surveys, generally tend to be used by positivist studies, and statistical methods in data collection and analysis are relied on to set up the relationships between identified variables (Yin, 2009). As Orlikowski and Baroudi (1991) indicated, research could be classified as positivist if *"there was evidence of formal propositions, quantifiable measures of variables, hypothesis testing, and the drawing of inferences about a phenomenon from the sample to a stated population"*.

Interpretivism normally assumes that reality cannot be reflected properly if social constructions like language and shared meanings are neglected (Orlikowski and Baroudi, 1991). By viewing reality as socially constructed, interpretivism believes that diverse meanings could exist with different social constructions, and these meanings can influence how the objective world is understood, and how people respond (Tsang, 2014). Therefore, with the aim to understand *"the meanings and actions of actors according to their own subjective frame of reference"*, interpretivist study generally attempts to explore the phenomenon through the meanings that are assigned by human beings (Mingers and Willcocks, 2004). Thus, methods like intensive interviews, participation and observations are usually adopted in order to uncover such intentional phenomena, and in contrast with positivism research, qualitative methodologies like ethnographies and case studies are preferred (Tsang, 2014).

Critical realism was initially developed in opposition to both the empiricist view of positivism and the idealist view of interpretivism (Mingers, 2002). It was designed to describe the interface between society and nature, as the perspective was developed through combining transcendental realism (a general philosophy in natural science) and critical naturalism (a philosophy in social science) (Archer et al., 1998). Thus, the critical realism perspective admits that reality is objective, but it indicates the layers of reality, and suggests the events that are observed are generated by the structures and mechanisms of which these layers are comprised (Tsang, 2014).

Critical realism scholars assume that *"social reality is historically constituted and that it is produced and reproduced by people"* (Orlikowski and Baroudi, 1991). It argues that, although people who produce social reality are capable of changing social circumstances consciously, their ability to change is constrained by various forms of environment, such as social, political, and cultural domination. Therefore, unlike positivist and interpretivist studies, critical realism research not only favours the predictive power of exploring structures and mechanisms, but also cherishes adequate explanations of past events (Tsang, 2014). Besides, according to Orlikowski and Baroudi (1991), it highlights the conflicts and contradictions in contemporary society, and maintains no specific preference for quantitative or qualitative methods of research.

Table 5.1: Comparison of positivism, interpretivism, and critical realism.

	Positivism	Interpretivism	Critical realism
Ontology	Reality is objective. Events are constrained by the human conception of causality.	Reality is socially constructed by people. Multiple realities of an event are possible.	Reality is objective but stratified, consisting of structures, mechanisms and events.
Epistemology	A hypothetico-deductive approach is applied to discover law-like relationships that can predict.	Generating knowledge by interpreting the subjective meanings and actions of subjects and events.	Retroduction is applied to create theories concerning the structures and mechanisms that generate the observable events.
Methodology	Quantitative methods based on strategies like surveys.	Qualitative methods based on strategies like case studies.	No preference; sometimes a mixed method is also used.

Source: Adapted from Tsang, 2014.

5.2.2 Critical realism as the philosophical standpoint of this research

As Myers (1997) suggested, the philosophical perspective of a piece of research is normally determined by both the researcher's preference and the aim of that research. As introduced in the first chapter, this study originally started from the perception of an interesting phenomenon in which late-coming nations in terms of technology are catching up in terms of technology innovation through government support. Based on the literature reviewed, government intervention in technology was investigated, and several research gaps were identified in the current innovation literature. To fill the identified research gaps, more studies are suggested to extend the present understanding of the mechanism of government intervention in technology innovation through the technological innovation system, especially that in the catching-up context.

According to the author's personal preference (*a realist*), and the aim of this research (*exploration of mechanisms*), the perspective of ***critical realism*** is believed to be the most appropriate philosophical standpoint for this research in three dimensions. Firstly, ontologically we follow the assumption that reality is objective, and believe reality to consist of events that are generated by structures and mechanisms (Bhaskar, 1978). Secondly, the object of this work is to develop a framework regarding the mechanisms which is generated from the observed events, and which reveals government interventions in technology innovation. Epistemologically, the mode of retroduction is appropriate for the exploration of mechanisms (Mingers, 2002). Lastly, compared with the positivist and interpretivist perspectives, "*causality*" is more emphasised by critical realism, which is crucial not only for generating the inherent order of events, but also for understanding in what conditions the mechanism could be activated (Tsang, 2014).

According to Bhaskar (1978), the critical realism perspective is underlain by two basic philosophical assumptions. One is the admission of the existence of reality as independent of human perception and cognition; the other is the recognition of the fact that reality has its own inherent order. Besides, he also summarised the terms of scientific concepts, laws, and theories as the *transitive objects of knowledge*, and coined the structures and mechanisms of the world to which our theories aim to refer as the *intransitive objects of knowledge*. The norm of intransitive objects of knowledge describes how these structures and mechanisms exist independently from our knowledge. The word structure is applied to describe a set of internally linked objects, and the word mechanism describes the ways in which they act. These internally related objects within a structure are identified based on their relationships with other components in the structure. The mechanisms are inherent to the structures, and function in *"enabling or limiting what can happen within a given context"* (Tsang, 2014, p.176).

As Bhaskar (1978) indicates, the *events* are generated as the result of the combined effects of such *mechanisms* and *structures*. Reality takes place independently, and does not rely on whether or not it has been observed or detected by human beings. The events might be observed, or might not be, but unobserved events do not necessarily mean the absence of structures and mechanisms. Accordingly, three domains of reality have been summarised, namely the domains of the *real*, *actual*, and *empirical* (Figure 5.1). Specifically, the *empirical domain* consists of experienced events, which are observed both directly and indirectly; the *actual domain* is made up of events whether they are observed or not; while the *real domain* maintains the structures and mechanisms that produce the patterns of referred events (Tsang, 2014).

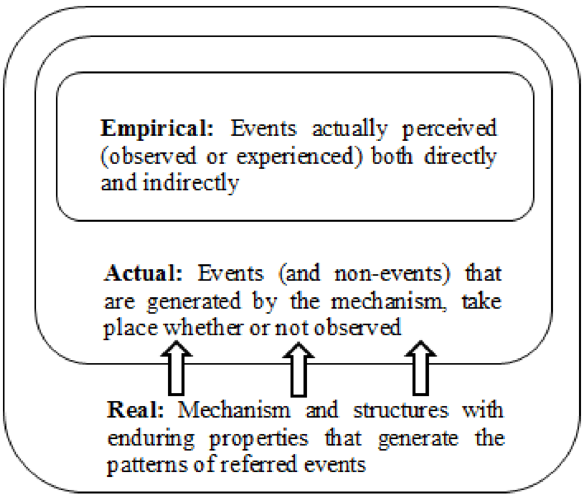

Figure 5.1: Three domains of reality in the critical perspective *(adapted from Mingers 2002).*

Furthermore, critical realism also emphasises the *"causality"* in reality, and exhibits an ontological distinction between causal laws and the events associated with them (Archer et al., 1998). As suggested, the underlying structures and mechanisms residing in the real domain can *"generate the patterns of events, and then subsequently lead to the establishment of causal laws"* (Tsang, 2014, p.176). In addition, the priority concern about causality is the *"causal powers of objects"*, but not the actual relationships between observed events. As Tsang (2014) explains, the power of an object is how it describes something about *"what it will or can do in the appropriate conditions in virtue of its intrinsic nature"*. Whether or not a causal power is activated actually mainly depends on the conditions within which the object resides.

Bhaskar (1978) distinguished contingent conditions as *intrinsic* or *extrinsic*. *Intrinsic conditions* mean the nature of an object that is able to operate a mechanism consistently, while *extrinsic conditions* affect the mechanism operation of an objective externally. Accordingly, when causal powers are exercised, the effects of mechanisms will be activated, and are then based on the events that are generated. However, their effects are not fixed due to contingent conditions in the actual world, which means even if two events are generated by the same mechanism, due to different contingent conditions, the observed results would be likely to be different. As a summary, the relationships between structure, mechanism, and events are shown in Figure 5.2.

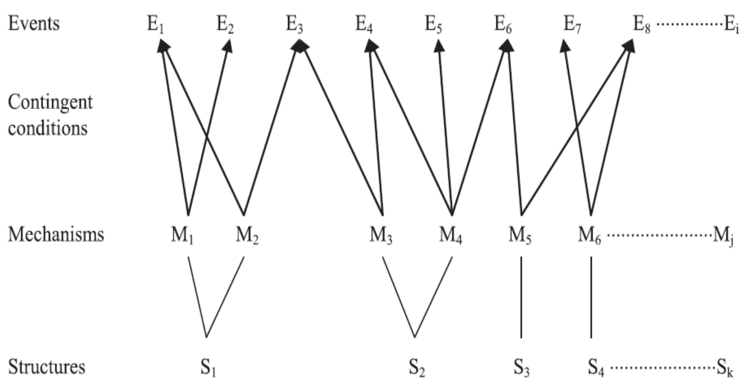

Figure 5.2: Relationships between structure, mechanism and events *(adapted from Sayer 1992).*

According to the figure, depending on contingent conditions, different events are sometimes generated by the same mechanism, and more than one mechanism can be associated with one structure. Based on the understanding of relationships between structure, mechanism, events, causality, and contingent conditions, Bhaskar (1978, p.70) introduces a concept of the closed system as *"one in which a constant conjunction of events obtains: i.e. in which an event of type A is invariably accompanied by an event of type B"*. In other words, a closed system is achieved if both intrinsic and extrinsic conditions are satisfied, since within these conditions, the regularities of events are generated. Therefore, in critical realism study, the regular sequence or mechanisms of events could then be exhibited by providing ideal conditions for certain experiments (Tsang, 2014).

The acknowledgement of exploring mechanisms and structures through establishing a closed system, in fact, has led to the philosophical basis for the epistemology of *retroduction*. As introduced by Mingers and Willcocks (2004, p.95), by employing retroduction, *"we take some unexplained phenomenon and propose hypothetical mechanisms that, if they existed, would generate or cause that which is to be explained"*. Thus, the core of retroduction is to explore the mechanism by providing a logically sound explanation about what properties, like contingent conditions, must exist as prerequisites for the phenomenon of interest to exist and exist in the way it is observed (Mingers, 2002).

Unlike deductive epistemology for interpretivist research, but similar to the inductive mode for positivist study, the mode of retroduction also entails *"the addition of new knowledge beyond what the premises contain that can hardly be assessed with certainty"* (Tsang, 2014, p.181). Compared with the inductive mode, retroduction is more creative and its structure is more flexible.

5.3 RESEARCH METHODOLOGY

In this section, following the perspective of critical realism and the epistemology of retroduction that discussed, the methodology for this research is detailed elaborated.

5.3.1 The case study method based on the critical realism perspective

As Myers (1997, p.6) defined, a research method is *"the strategy of inquiry which moves from the underlying philosophical assumptions to research design and data collection"*. In the literature, two methodologies are mostly applied, namely *qualitative* and *quantitative methodology* (Baxter and Jack, 2008). Underlain by different philosophical perspectives, quantitative methods are normally adopted when answering *"what"* and *"when"* questions, while qualitative methods are mainly applied when *"why"* and *"how"* questions are asked (Yin, 2009). Considering that the research question is to understand "how" technology innovation could be promoted by government interventions in the TIS, qualitative methodology is thus adopted for this research.

Furthermore, several specific research strategies that serve qualitative methodology are suggested, such as *experiments*, *archival analysis* and *case studies* (Yin, 2009). To determine which strategy is appropriate for a specific type of research, Yin (2009) summarised three considerations: firstly, the type of research questions posed; secondly, the extent of actual control the investigator has; and lastly, the degree of focus on the contemporary as opposed to the historical.

For example, in terms of case studies, Yin (2009, p.29) suggested that this strategy could be applied when *"how and why questions are being asked, about a contemporary set of events over which investigators have little control"*. Furthermore, the case study strategy is also suggested if the *"contextual conditions"* are covered in the research, as the strategy believes that *"the contextual conditions might be highly pertinent to the observed phenomenon of study"*. Considering the aim of this research, the strategy of case studies was adopted. As introduced in previous chapters, the context of catching-up is a significant consideration, so "how" research questions are asked, and there is no doubt that the author clearly has no control on the contemporary phenomena that are observed.

Referring to the concept of a “closed system” that Bhaskar (1978) introduced, social science scholars hold that most social phenomena are investigated in an “open-system” environment, so the idea of creating a closed system for retroduction in social science study is unlikely to be possible. There are two reasons for the openness of the social system. Firstly, the extrinsic conditions are violated because the social structures are sometime affected by human actions; secondly, the intrinsic conditions are violated due to the limitations of learning capacity, self-reflection, and change (Tsang, 2014). In consequence, it has been suggested that the mechanisms generated by the retroductive mode in social science case studies are more suitable for the explanatory type of study like this one.

By adopting the mode of retroduction in this research, we employed the case study strategy with the purpose of creating a relatively closed social system, within which we attempted to testify whether or not the postulated explanatory mechanisms for interpreting the observed events can function well (Jefferies, 2011). Nevertheless, as Tsang (2014) suggests, the cases selected for retroductive study should satisfy two criteria at least. Firstly, the cases should reflect the observed events properly and accurately; secondly, the contingent conditions, including both intrinsic and extrinsic, should be easy to clarify. By employing retroduction, the explanatory mechanism can only be testified when the events can be properly reflected by the case, while the “relatively closed system” can only be built up when the intrinsic and extrinsic conditions are clear and difficult to violate (Kemp, 2005). As the strategy of qualitative case studies for answering the questions of this research has been determined, in the next section the settings of this research and the reasons for the specific cases selected are detailed.

5.3.2 Research settings and case selection

As introduced, with the aim of exploring the mechanism based on retroduction, cases should be selected properly, based on the events (Kemp, 2005). Considering the aim of this research, to satisfy the requirements, the case studies in this research are suggested to be established in a typical industry in which significant technology innovations are normally driven by the government, and in which the interactions between the government and the TIS should have a prominent relevance to the outcomes of technology innovation.

Besides, in terms of designing the case study, Yin (2009) distinguished between *single case* and *multiple case* study designs. Accordingly, single a case study is normally applied when the case is extreme or unique and it can represent a significant contribution to knowledge and theory building. Multiple case studies are normally capable of helping in understanding the similarities and differences between the cases. Benefiting from replication, the logic underlying the multiple case study design could create more robust and reliable evidence (Baxter and Jack, 2008). Considering all the suggestions for selecting research settings and case studies, a comparative case study based on the 3G TD-SCDMA and 4G TD-LTE mobile system innovations in China's telecommunication industry are believed to be the most appropriate selection for this research.

In terms of research settings, among all eligible industries, the telecommunication industry in China is believed to be an appropriate selection for this research. Firstly, understanding indigenous technology innovation in China's telecommunication industry could achieve the target of understanding innovation in the catching-up context. Secondly, in China the telecommunication industry has long been recognised as one of the key industries for national development, and the roles played by the government and the TIS in promoting indigenous technology innovations are extremely prominent and significant (Kwak et al., 2012). Thirdly, as Lyytinen and King (2002) indicated, the telecommunication industry is generally constituted and shaped by dynamic interactions among the regulatory regime, the innovation system and the marketplace, while the industry's evolution and technology innovation are all related to the changing interactions between these systems. Lastly, the government in China controls the overall national economy, and the interactions between the government and the TIS are comparatively frequent and multifarious (Gao et al., 2014). Thus technology innovation in China's telecommunication industry is believed to be an ideal setting for this research.

Furthermore, in terms of case selection, the government driven 3G TD-SCDMA and 4G TD-LTE mobile system innovations in China's telecommunication industry have provided ideal case studies for this research. Historically, the first generation mobile system was launched around the 1970s, when only voice communication was possible. Then in the early 1990s, the 2G system was introduced. In this era, Global System for Mobile communication (GSM) and narrowband CDMA were applied as the two main international standards. GSM was initiated in Europe and CDMA was issued in the US (Yan, 2007). In 1999, the International Telecommunication Union (ITU) approved three 3G international standards, known as WCDMA, CDMA2000, and TD-SCDMA. CDMA2000 and WCDMA were based on the CDMA and GSM networks, and were mainly commercialized in the EU and US, respectively. TD-SCDMA was introduced by China, requiring completely new supporting networks. TD-LTE and FDD-LTE are authorized as two international 4G mobile system standards by the ITU. The TD-LTE system is partially derived from TD-SCDMA, and FDD-LTE is backward compatible to WDMA and CDMA2000 (Wang and Kim, 2007).

Following the philosophical standpoint and the qualitative case study methodology in this research, the two innovation cases could well serve the aim of this research, at least according to three aspects. Firstly, as retroduction is applied for mechanism exploration, multiple case studies can create more robust and reliable evidence for testifying the postulated mechanism. The cases of TD-SCDMA and TD-LTE provide a similar context, or contingent conditions, and thus similar observed events could grant the validity of the posed mechanism (for SQ2, SQ3 and SQ4). Secondly, since the case of the TD-LTE innovation is basically derived from the TD-SCDMA innovation, then the features and changes in terms of government intervention and innovation system, especially in the catching-up context, could be highlighted through comparing these two cases (for SQ1). Lastly, the data accessibility is also a significant concern in selecting these two cases. Since the supervisor of this study worked in China's telecommunication sector for a few years, and has expertise in technology innovation especially in China's telecommunication industry as a scholar, his close connection within the industry therefore promises accessibility of data for the case studies. Therefore, due to these considerations, a comparative case study based on the government driven TD-SCDMA and TD-LTE mobile system innovations in China was adopted as the research methodology to answer the research question in this work.

5.3.3 Data collection: documentary research and semi-structured interviews

In this research, we followed the strategy of a longitudinal case study for data collection and analysis (Holland et al., 2006, Tengblad and Ohlsson, 2009). Documentary research and semi-structured interviews were applied as two primary methods to collect data for this research, since using multiple sources for data collection for the same findings can significantly enhance the validity of case study research (Myers, 1997, Zucker, 2009). The case studies have drawn heavily upon many sources. To delineate the overall picture, resources like archives, websites, reports, and academic papers were employed; to acquire in-depth views of the cases, interviews were also conducted with a total of 44 management level executives in 16 relevant agencies, firms and organisations that participated in China's TD-SCDMA and TD-LTE innovations.

Documentary Research

For policy related studies, it is suggested that documentary research is essential and especially instrumental, as government polies and reports are normally given through the form of documentation (Li, 2011). The data sources for documentary research include websites both of organizations' officials and of the mainstream media, reports from both organizations and analysts, and also relevant academic articles. The data that we collected from documentary research was mainly applied in delineating the overall picture of the case studies of the TD-SCDMA and TD-LTE innovations in China.

Through analyzing the data that was collected, two detailed chronologies of key events regarding China's 3G TD-SCDMA and 4G TD-LTE mobile system innovations were generated at first. The chronologies enabled us to clarify questions like *"when and where, who is involved, and what has been done or changed"*, and to set the foundation for innovation process based analysis (Tilson, 2008). Besides, data collected from documentary research also helped to roughly figure out the structure of the innovation systems, and to trace the dynamics of specific events and of the government interventions that were associated with the process of TD-SCDMA and TD-LTE.

The TD-SCDMA and TD-LTE innovations have been at the top of the agenda in China's national development, not only through achieving the strategy of catching-up via indigenous technology innovation, but also through attracting tremendous public interest (Xia, 2012a, Gao et al., 2014). In China, public agencies and organizations are normally encouraged to keep updating the basic information and the dynamics of organization on the internet, including their structures, situations, plans, projects, announcements etc. For listed enterprises, publications of managerial and financial performances are generally strict requirements of laws and regulations. Therefore, numerous archival data about their participation in the TD-SCDMA and TD-LTE innovation projects were published and easily accessed on official websites without obvious barriers.

For example, in terms of public government agencies, official websites such as those of the Ministry of Industry and Information Technology (http://www.miit.gov.cn), the State-owned Assets Supervision and Administration Commission (http://www.sasac.gov.cn), and the National Development and Reform Commission (http://www.ndrc.gov.cn) were all visited. For relevant firms and organizations, websites like China Unicom (http://www.10010.com), China Mobile (http://www.10086.com), China Telecom (http://www.chinatelecom.com.cn), Datang Telecom (http://www.datanggroup.cn/), and Huawei (http://www.huawei.com) were also visited and their news and reports relating to the two cases were collected.

Nevertheless, in terms of some specific details like invisible barriers that might hinder the innovation project, the data are very limited on these official websites. To deal with this contradiction, several mainstream media are referred to in order to collect detailed data about the TD-SCDMA and TD-LTE innovation in China. For example, the IT sections on the internet portals of mainstream media, such as Sina (http://tech.sina.com.cn), Sohu (http://it.sohu.com), Tencent (http://tech.qq.com), and People's Daily in China (http://www.people.com.cn/) were accessed and reviewed. These media have special blogs and discussion areas for the TD-SCDMA and TD-LTE innovations, where up-to-date information was gathered.

Apart from collecting data from internet portals, analysts' reports and the annual reports of related organizations were also reviewed for documentary data collection. For example, the monthly reports from TDIA were reviewed, since they provided very detailed information and valuable insights about the TD innovation. Moreover, most of key actors in TD innovation are listed enterprises and their reports are published yearly. Thus, according to their annual reports, many details of the TD-SCDMA and TD-LTE innovations from their perspectives were found, such as their roles in these projects, their networks, and even their investments in the projects.

Lastly, we also collected data through reviewing the academic publications, in Chinese and English, related to both the two mobile systems and the telecommunication industry in China. For example: Kwak et al. (2012) reviewed the evolution of the alliance structure in China's mobile telecommunication industry along with the TD-SCDMA innovation; by reviewing the case of TD-SCDMA innovation, Gao and Liu (2012) analyzed China's development strategy for catching up through developing technology standards; Gao et al. (2014) conducted an empirical case study based on China's TD-SCDMA standardization to analyses the roles of the government in promoting innovation; Yongwoon and Shin (2015) provided an in-depth analysis of the process of TD-LTE innovation in China. These articles generally held different ideas and illustrated issues from different angles and perspectives.

In order to enable the tracing back to original documents for this research, we have established a database on a cloud server, and digital documents were carefully saved. Visiting official and mainstream media websites mainly contributed to summarizing the related policies and news, while reviewing reports and academic articles mainly helped to provide details and insights about the innovations. Accordingly, Appendix 2 has summarized all TD-SCDMA and TD-LTE innovation related policies that were identified and reviewed. Appendix 3 has demonstrated an example of news about China's TD innovation that is specifically summarized from the Sina website. Lastly, Appendix 4 has included reviewed reports and academic articles that are related to China's TD innovations.

Semi-structured Interviews

Based on documentary research and the developed framework, the overall picture of China's TD-SCDMA and TD-LTE innovations, such as the context of innovation, government interventions and innovation systems, were roughly delineated. However, in order to acquire an in-depth view of the case studies, only collecting data based on documentary research was not sufficient, especially in terms of understanding complicated innovation system dynamics and diverse government interventions. Thus in additions to documentary research, semi-structured interviews were adopted.

Semi-structured interviews were conducted with key persons who had been involved in or held valuable insights into China's TD-SCDMA and TD-LTE innovations. Most of them were in the management level and performing as core executives in related organizations. As Myers (1997) indicated, semi-structured interviews can help the informants to identify and describe their own situations, and express what they have seen and have been involved in. In this research, semi-structured interviews offered us an opportunity to learn from the interviewees and gain close access to their meanings and interpretations. The interviews in this research were designed according to an inflexible set of questions in order to provide the interviewees with more flexibility and the ability to broaden the points of interest that they regarded or perceived as relevant.

The first step was to identify the potential interviewees. An integrated strategy suggested by Richne (2001) and Carlsson et al. (2002) was adopted. To be specific, firstly based on documentary research, we categorized identified organizations into different groups according to their roles in innovation, and then figured out key actors within each group. Secondly, we conducted pilot interviews with the accessible organisations in each group, and encouraged them to point out further related actors in the innovation projects, and then attempted to contact them with their references. Lastly, we listed all interviewed organizations and made a comparison with the map of initially identified actors and the dictionary of TD technology patents, to make sure at least one key organization in each group was interviewed. In most cases, we conducted interviews of several key organizations in each group (Table 5.2).

Table 5.2: List of key organizations interviewed.

Organizations	Categorization	Description
MIIT	Government Authorities	Ministry of Industry and Information Technology. A state agency responsible for regulation and development of postal services, telecommunication etc.
SASAC	Government Authorities	The State-owned Assets Supervision and Administration Commission of the State Council. A special commission directly under the State Council. Responsible for managing SOEs, including appointing executives and drafting laws.
NDRC	Government Authorities	The National Development and Reform Commission. A special commission directly under the State Council. Responsible for studying and formulating policies for economic and social development, and guiding restructuring of the economic system.
China Mobile	Mobile Operators	One of three dominant service operators in China. A State-Owned-Enterprise, a listed company. Mainly invests in TD-SCDMA in the 3G era and in TD-LTE in the 4G era.
China Telecom	Mobile Operators	One of three dominant service operators in China. A State-Owned-Enterprise, a listed company. Mainly invests in CDMA2000 in the 3G era and FDD-LTE in the 4G era.
China Unicom	Mobile Operators	One of three dominant service operators in China. A State-Owned-Enterprise, a listed company. Mainly invests in WCDMA in the 3G era and in FDD-LTE in the 4G era.
DaTang	Technology Vendors	Datang Telecom Technology & Industry Group, founded by CATT. A key domestic technology vendor managed by SASAC. Expertise in electronics and telecommunication.
HuaWei	Technology Vendors	HuaWei Technologies Co., Ltd. A key domestic technology vendor. Distinguished in network switching, antenna and signals.
ZTE	Technology Vendors	Zhongxing Telecommunication Equipment Co., Ltd. A key domestic technology vendor managed by SASAC. Distinguished in network equipment, terminals, and telecommunication services.
Siemens	Technology Vendors	Including a former JV, Nokia Siemens Networks (NSN), which is a technology vendor jointly formed by Nokia and Siemens. Specialized in telecommunication solutions.
Ericsson	Technology Vendors	Including a former JV, ST-Ericsson, which is a technology vendor jointly formed by Ericsson and STMicroelectronics. Specialized in manufacturing wireless products and mobile devices
CATR	R&D Institutes	China Academy of Telecommunication Research, administered by MIIT. Mainly responsible for scientific research and innovation in terms of China's telecommunication.
CAS	R&D Institutes	China Academy of Sciences. Mainly responsible for scientific research and providing references for policies.
BUPT	Universities	The Beijing University of Posts and Telecommunications. A key national university distinguished in the field of telecommunication.
UIBE	Universities	The University of International Business and Economics. The Law School in UIBE performs research in technology standards and IPRs.
TDIA	Industrial Alliance	TD Industrial Alliance. Jointly formed by key organizations in the TD field, aiming to promote progress in TD industrialization.

Source: author illustrated.

In terms of data collection, we interviewed several government officials, enterprise executives and scholars from the organizations listed in Table 5.2, who have experience or valuable insights into the TD-SCDMA and TD-LTE innovations. To ensure a comprehensive view and to conduct the work in a more organized manner, all interviewees were also categorized into six groups and assigned by a different code based on the roles their organizations played in the case studies. Since the snowball sampling strategy is employed in identifying and accessing the interviewees, in order to not be excessive and to avoid duplication, the initial sample is constrained at 55 and is distributed as follows: 10 *government agencies*, 15 *mobile operators*, 15 *technology vendors*, 8 from *R&D institutes*, 4 from *universities* and 3 from *alliances*.

During the pilot and the formal fieldwork, 55 potential eligible interviewees were identified and the same numbers of pre-interview questionnaires were sent out. Of these 55 pre-sent questionnaires 47 were collected, with three of the interviewees being unable to attend interview, and five of them recommending replacements. The rest of them gave positive feedback. Lastly, in fact 44 interviews were conducted, and each interview lasted at least 60, but no more than 90 minutes. Later on, 15 follow up telephone calls were also made to interviewees, in order to confirm or clarify some information in the drafts of the interviews. The protocols for interviews were designed based on the research sub-questions, on issues implied by the reviewed literature, and on some of the interviewees' feedback in the pilot fieldwork. Different protocols were designed and applied to interviewees from different groups. Core questions that were asked of the six groups are briefly summarized in Table 5.3 and the primary data collected are briefly summarised in Table 5.4.

For more details about data collection from the interviews: the pre-sent documents, including *information pages* and *consent forms*, are enclosed in Appendix 5, while *pre-interview questionnaires* are presented in Appendix 6; the *formal interview questionnaires* are shown in Appendix 7; an *example of an interviewee's answers* is enclosed in Appendix 8; and lastly, the *overview of the interviews* are all briefly summarized in Appendix 9.

Table 5.3: Key questions covered in the interviews.

Group of interviewees	Key questions posed in the interview
Government authorities	- How TD innovation is related policy made and implemented in your department, or your organisation? - What are your opinions or experiences regarding the TD cases?
Mobile operators	- Why and how you and your company were related to the TD cases? - How did government affect your company regarding TD cases? - What are your opinions or experiences regarding the TD cases?
Technology vendors	- Why and how you and your company were related to the TD cases? - How did government affect your company regarding TD cases? - What are your opinions or experiences regarding the TD cases?
Research institutes	- Why and how you and your institute were related to the TD cases? - What are your opinions or experiences regarding the TD cases?
Universities	- Why and how you and your university were related to the TD cases? - What are your opinions or experiences regarding the TD cases?
Industrial alliances	- How was this industrial alliance established initially? - How did you and your institute contribute in the TD cases? - What are your opinions or experiences regarding the TD cases?

Source: author illustrated.

Table 5.4: Summary of interview approaches.

Approach	Quantity	Detailed information
Pre-interview questionnaires	55	- Sent out pre-interview questionnaires and information sheets to 55 eligible and accessible potential Chinese interviewees. - Information sheets included the basic information about this research and the researcher, as well as the procedure for the interview. - Pre-interview questionnaires covered issues such as background and experiences of the interviewee regarding the TD cases, basic background of the interviewee's unit or organisation, the agreement for arranging an interview, and any other recommendations. - 47 questionnaires were collected, 45 agreed to be interviewed.
Semi-structured interviews	44	- 37 interviews were semi-structured, 8 interviews were unstructured. - All interviews were conducted in Chinese. - 6 interviews were conducted in pilot fieldwork in April 2014; the rest of the interviews were concentrated during June-October 2014. - 37 interviews were conducted in Beijing, 4 in Shanghai, 4 in Fuxin. - 10 interviewees from government authorities, 13 from mobile operators, 12 from technology vendors, 4 from R&D institutes, 3 from universities, 2 from industrial alliances.
Follow-up telephone feedback	15	- Mainly conducted in late 2014 and early 2015, aimed at checking the accuracy of data and understanding. - TD-LTE as the 4G technology is still not terminated in diffusion terms and policies continue to be updated; follow-up telephone interviews contributed to continuously gathering complementary information. - Text messages were sent to 20 interviewees who kept in touch, 15 of them were available and happy to make phone calls.

Source: author illustrated.

5.3.4 Data analysis: approaches and techniques

In terms of analyzing the data in this study, we took the strategy of *"relying on the theoretical propositions which perform as a guidance that led to the case study"* (Yin, 2009, p.130). The analysis of data and the narrative of the case studies were all inherent and based on the theoretical propositions, which include the main research question and sub-questions, the developed theoretical framework, as well as the qualitative case study strategy that has been elaborated. Accordingly, a total of three rounds of data analysis, from shallower to deeper, were implemented in this work in a retroductive manner, as previously mentioned (Mingers et al., 2013).

Firstly, some "early steps in analysis" were taken, mostly based on the data collected from documentary research. As previously elaborated, this part of the data collection and analysis was mainly implemented to draw the overall picture of the background to the innovations (*e.g. China's innovation policy, telecommunication industry and mobile system evolution*) and of the specific case studies in this research (*e.g. government intervention, and mobile system innovations*). Based on the overall picture that was delineated, the interviews and further case narratives were structured, detailed information that was required to be collected was figured out, and the potential eligible interviewees were identified.

Secondly, based on data collected from the interviews, the previously delineated overall pictures of the selected cases were refined from rough to precise versions. Particularly, the innovation system actors, their formal and informal interactions, as well as formally dominant and unapparent institutions were figured out and clarified; the government roles as well as the intervention measures that were taken were also identified. Then, based on this round of analysis, descriptive sections about government intervention and the TD-SCDMA and TD-LTE innovation systems were delineated.

Lastly, based on the previous two rounds of analysis, we moved further to seek the answers to the proposed research questions. Specifically, two types of analysis based on the case studies were conducted. By adopting the *duplication* strategy, the mechanisms and the patterns of government intervention in the TIS to promote innovation were explored (SQ2, SQ3, SQ4); by adopting the *comparison* strategy, the evolution and the characteristics of government intervention and the innovation system in the catching-up context were summarized (SQ1) (Cavaye, 1996).

Furthermore, to ensure the quality of data collection and analysis, the strategy of triangulation was adopted in both stages of this research. As Mathison (1988) indicated, "*triangulation is to control bias and establishing valid propositions*". In practice, triangulation normally refers to the application and combination of several methodologies in one study to facilitate the trustworthiness and validation of data through cross verification from more than one source, such as by combining multiple observers, theories, methods, materials and even researchers (e.g. Kaplan and Maxwell, 1994, Seale, 1999, Baxter and Jack, 2008).

5.3.5 Ethical considerations of this research

As Baxter and Jack (2008) indicated, ethics are a significant issue that all researchers need to take into account when conducting "real world studies", especially for researchers doing qualitative studies and applying case studies as the methods of research. Normally two issues should be addressed, firstly to make sure that any study that we are undertaking is designed in a way that is cognizant of the rights of participants, and secondly that in undertaking studies involving participants we conduct the research in an ethical manner. This study has taken every effort to meet the standard of ethical practice and to protect both the data and informants.

Several measures were taken before and during the data collection. For instance, before the pilot and formal fieldwork, the form named "*Research information pages*" was sent to the interviewees (Appendix 5). This aimed to give participants overall knowledge about the background of our research and answers to question dealing with data and informant protection. Then, before the interviews, the "*Consent form*" was presented and explained, and was signed by the interviewees (Appendix 6). After the interviews, all interviewees were anonymized in transcribing, analyzing and writing up.

5.4 ASSURENCE OF RESEARCH QUALITY

5.4.1 Internal validity and data analysis

The notion of validity has different interpretations across different disciplines and for the different methodologies that have been used (Golafshani, 2003). Within the context of social science, especially for qualitative empirical studies, validity normally refers to the extent to which a concept, conclusion or measurement is well explored and corresponds accurately with the real world (Stenbacka, 2001). To be straight forward, validity means accuracy throughout data collection, data analysis, and the formation of conclusions. In terms of controlling validity in social science research, Yin (2009) suggested three types of validity, namely construct validity, internal validity and external validity.

Construct validity

Construct validity refers to whether the researcher develops a *"sufficiently operational set of measures*" and whether data are gathered without subjective bias from the researcher (Yin, 2009). In terms of designing sufficient operational measures, as illustrated in the previous chapter, we have broken down the four proposed research sub-questions into several grounded questions, which were easily understood and more feasible in terms of being answered. Moreover, guided by the framework that was developed, we have resolved the process of answering these questions into three distinct but progressive stages as elaborated in section 5.3, which to a large extent have enhanced the degree of feasibility and operability of measurements in this research.

Besides, by keeping the strategy of triangulation in mind, this work has taken every effort to avoid subjective bias throughout the research. For example, initially this work was designed to adopt multiple sources of evidence when gathering the data. Furthermore, the same strategy was also adopted both in cross-checking the content provided by different informants, and in comparing the similarity and accuracy between the information collected from the documentary research and that collected from the interviews.

Internal validity

Internal validity refers to an inductive estimate of the extent to which conclusions about causal relationships can be made (Yin, 2009). In other words, to acquire a high degree of internal validity, the results for correlation between dependent variables and independent variables should be accurate and highly controlled. In this work, internal validity was properly controlled mainly in three aspects. Firstly, as previously elaborated, the methodology was adopted based on critical realism which underpins this research as the philosophical standpoint. By following the given paradigm, as shown in Figure 5.2, the mechanism as the main aim of this research was explored within the given context, which in other words, was a closed social system as required for retroduction. The duplicative analyses of two observed events in such a context, therefore, to a large extent could ensure the high degree of causality required for internal validity.

Secondly, the internal validity of this research has also been secured by the highly logical design throughout the work. As elaborated, this research originated from an interesting phenomenon whereby some late-coming countries, with government support, are catching up in terms of technology innovation. To interpret the phenomenon, relevant literature was reviewed. Meanwhile, three research gaps were identified in the present innovation study. Aimed at bridging the identified gaps, the research objective was introduced and the main research question was proposed. After that, based on the reviewed literature, a theoretical framework was developed to address the research questions that were proposed. Based on the framework, we articulated the main question and divided it into four sub-questions at the operational level. The framework was adopted to guide the research, as the data was collected based on documentary research and semi-structured interviews, which were inherently designed based on the theoretical framework that was developed. Lastly, research questions were answered based on the data analysis that was structured by the framework.

Thirdly, in addition to illustrating the logicality of the overall research, causality was also ensured by the technical data collection and rigorous analysis that followed. For example, the transcripts of the semi-structured interviews were systematically coded to describe the following issues in a temporal manner, as follows:

- The background of China's national innovation policy;
- The background of China's telecommunication industry, including its historical transformation, contemporary supervisory architecture and market competition;
- Identifying the TIS actors, including their interests and resources;
- Figuring out networks between involved actors;
- Capturing the institutional environment of the innovation system, as well as the system functions and performance;
- Summarizing the challenges that prohibit TIS functions in each innovation stage'
- Mapping relevant intervention instruments from government authorities;
- Mapping the features of both TIS and government interventions in catching-up.

Such a systematic approach of coding not only provided a reliable way for gathering data from the case studies, but also helped construct the analysis of two innovation systems rigorously. Figuring out the TIS structure, functions and government interventions in such a standardised process also enabled comparisons between the different systems and the government interventions. For each case, we built up a chronology of relevant events in terms of the development and diffusion of the technology, and also mapped the intervention practices of the government authorities in each innovation stage. This was mostly based on the documentary research and has been cross checked during the interviews. The chronology of events has provided the empirical foundation upon which to elaborate according to the conceptual framework. The result of analysis then helped to answer the questions about how TIS impacts innovation and how government interventions impact the TIS in terms of promoting indigenous technology innovation. The three summarized approaches that were taken throughout the research, from designing to concluding, have jointly ensured the internal validity that is required.

5.4.2 External validity and Reliability

External validity

According to Yin (2009), external validity concerns the degree to which the results of a piece of research can apply to other cases. In other words, it refers to whether the findings of a specific research could be generalised or not (Zucker, 2009). Generally, external validity is very difficult to measure and control for a case study, because most case studies are usually chosen for their uniqueness as well as their representativeness. For instance, the innovation of the TD-SCDMA mobile system would be unlikely discussed if removed from the unique context of China's catching-up in technology innovation.

To address this contradiction, Yin (2009) also suggested that the generalisability of a case study should be considered differently in comparison with survey research due to the different natures these types of research contain. Accordingly, generalisation cannot be complete until the theory is tested by replicating the findings obtained for other cases. Nevertheless, in this research, external validity has been concerned from the initial research design through to implementation. For instance, as stated in the very beginning, this research originated from the phenomenon of the catching-up of indigenous technology innovation, and the research questions were asked in the context of catching-up, rather than being constrained to any specific industry in any specific country. China was selected just as a representative for countries in a similar context. Therefore, the mechanism that has been explored in China could also be generalised well for other countries in a similar situation, or even in other industries which share a similar context with telecommunication in China.

Besides, despite context issues, an understanding of the mechanisms involved was elaborated as the core aim of this research. By adopting methodology with a critical realist viewpoint, the mechanisms were summarized from two observed events in the same given context, which also confirms that the structure and the casual power of objects were fixed in reality. In other words, in a similar context, similar events could also be observed if the incentive powers are properly exerted based on the mechanism that is summarized, which means the generalization is not only feasible but is also operable.

Reliability

Reliability is introduced as the extent to which the results are consistent over time and their degree of trustworthiness (Seale, 1999). In other words, reliability deals with whether the quality of research is reliable, dependable and trustworthy. In empirical studies, reliability is not just the standard for justifying the data that has been collected, but also requires the testing of the measurements that are used for collecting and analysing the data (Golafshani, 2003).

In order to control the reliability of collected data and the measurements, we have initiated a couple of schemes with multiple modes for collecting and analysing the data by following the triangulation paradigm (Yin, 2009). First of all, as mentioned, data were collected from both documentary research and semi-structured interviews. This has secured the reliability of collected data in at least two aspects. On the one hand, the interviews was structured based on data collected from documentary research; on the other hand, documentary research data was also referred to, to confirm, test and cross-check the information that was provided by interviewees. Besides, the questions in the interviews were mostly open-ended and the interviewees were often asked various questions on the same topic based on the developed framework, in order to test the consistency of the answers. Accordingly, the results from multiple interviewees were cross-checked to ensure the reliability of data collection.

Furthermore, both documentary research and semi-structured interviews were underpinned by the theoretical framework, which has also contributed to the reliability of both collected data and measurements. For example, all the data were collected and analysed with structural guidance and clear targets. Specific approaches that were adopted in practice were all testified by many published studies, such as the strategy of identifying components in TIS that was introduced by Carlsson et al. (2002), as well as the strategy of generating results from data analysis that was introduced by Yin (2009). Therefore, based on multiple well testified measurements in both data collection and data analysis, the reliability of this work was doubly secured. Table 5.5 summarises how data collection and data analysis are aligned with the research questions.

Table 5.5: Alignment of research questions, data collection, sources, and analysis.

Research Question	Data Collection	Data Sources	Data Analysis
SQ1: How are TIS and government intervention characterised in China?	**Capture the background and intervention** - Historical background of technology - The generic national innovation policy - The industry background, including history, supervisory architecture and market **Capture TIS structural components** - TIS actors and their networks - Institutional environment in the system - Dynamics regarding the two stages	**Mainly documentary research & partially semi-structured interviews** - Official websites (e.g. www.miit.gov.cn; www.sasac.gov.cn; www.huawei.com;) - Mainstream media (e.g. tech.sina.com; www.people.com.cn) - Academic publications (e.g. Stewart et al., 2011; Chen et al., 2012; Xia 2012; Gao 2013) - Industrial reports and firm reports	**Summaries government intervention and TIS characteristics** - Analyze China's national innovation policy in high-tech - Analyze the telecommunication industry including historical evolution and the contemporary supervisory and market structure regarding the 3G and 4G innovations - Summaries the similarities in each case including the TIS and the intervention characteristics especially in catching-up - Compare the two cases in order to map the evolutions of TIS and government intervention in the 3G and 4G cases
SQ2: How can TIS affect the development and diffusion of a technology?	**Generate the overall innovation process** - Identify and summaries milestones and key events in the innovation process - Identify main undertakers and their activities **Address TIS functions** - Identify TIS functions in each stage - Identify expectations of each function		**Address interrelationships between innovation and TIS** - Create chronology for the TD-SCDMA and TD-LTE innovations - Distinguish the innovations into development and diffusion - Map the seven TIS functions with the two stages - Summaries key actors that undertake the TIS functions - Analyze the activities of key actors regarding the TD-SCDMA and TD-LTE innovations
SQ3: What are the main challenges for the government to address in China's catching-up in technology innovation?	**Identify innovation challenges** - Identify required resources and capabilities in each innovation stage - Identify key actors, their interests, resources and capabilities in each innovation stage	**Partially documentary research** - Academic publications (e.g. Stewart et al., 2011; Chen et al., 2012; Xia 2012; Gao 2013) - Press releases - Industrial reports and firm reports **Semi-structured interviews** - Government authorities (e.g. MIIT, SASAC, PTRI) - Mobile operators (e.g. China Unicom, China Mobile) - Technology vendors (e.g. Datang, Huawei, Siemens, ZTE) - Research Institutes (e.g. CMRA; CTRA; CAS) - Universities (e.g. BUPT) - Industrial Alliances (e.g. TDIA)	**Address challenges that hinder the TIS functions** - Assess the performance of TIS from development to diffusion - Map the challenges for each TIS functions in innovation - Build up the linkages between the challenges for TIS functions and the TIS structural components - Understand whether the challenges are caused by deficiencies in actors (resources and capabilities), or by a not well structured TIS
SQ4: What strategies and instruments the government applied to promote technology innovation in China, and how?	**Identify intervention instruments** - Participating government authorities & roles - Identify government interventions in relation to the innovation		**Address government intervention instruments** - Summaries all the government interventions in relation to the TD-SCDMA and TD-LTE innovations - Map summarized government interventions with the process of innovation based on the chronology that is developed - In different stages of innovation, map government intervention with challenges that are identified for different TIS functions - Analyze the intervention instruments based on regulative, normative and cognitive dimensions - Distinguish whether the instruments exert pressure on TIS actors directly, or affect the TIS institutional environment

5.5 SUMMARY

In this chapter, we elaborated approaches and techniques that were adopted to answer the proposed research questions. Three dimensions were primarily considered when designing this research, namely the philosophical perspective relied on, the research methodology adopted, and the strategy to ensure research quality.

Specifically, in section 5.2, we firstly compared positivism, interpretivism and critical realism as the three most widely adopted philosophical perspectives, and selected critical realism as the philosophical standpoint of this research due to the research aims. Then, underpinned by the critical realist perspective, in section 5.3 we introduced the qualitative case study as the methodology that was adopted as a grounded strategy for data collection and analysis in this research.

Following the strategy of qualitative case study, as mentioned, the research settings and case selection were then elaborated. Specifically, the 3G TD-SCDMA and 4G TD-LTE mobile system innovations in China were selected as case studies in this work. To answer the proposed research questions with case studies, documentary research and semi-structured interviews for data collection, and the analysis strategy introduced by Yin (2009) for data analysis were adopted. The developed conceptual framework which has structured both the data collection and analysis, and the ethical considerations of this work were also detailed in section 5.3.

Lastly, in section 5.4, the assessment of research quality was illustrated, along with an elaboration on how triangulation strategy was applied in both data collection and data analysis to ensure quality. Accordingly, constructive validity, internal validity and external validity were all considered and ensured throughout the overall research, including the research design, data collection, data analysis and conclusion. With the aim of elaborating clearly on how these processes were designed and implemented in regards to answering the proposed questions, we summarised the key points in Table 5.5. Next, in the following chapters (6, 7, 8), the results of data collection and analysis are expressed for the two innovation case studies in China.

CHAPTER 6: MOBILE SYSTEM EVOLUTION AND TELECOMMUNICATION INDUSTRY IN CHINA

6.1 INTRODUCTION

Before understanding the case studies about TD-SCDMA and TD-LTE mobile system innovations in China, this chapter introduces the backgrounds for understanding the selected cases. The contents of this chapter are based on the collected data. Specifically, section 6.2 reviews the historical evolution of mobile systems from the first generation (1G) to the current adopted fourth generation (4G), which helps understand the technological background of 3G TD-SCDMA and 4G TD-LTE mobile system. Furthermore, section 6.3 introduces the telecommunication background in China, which helps understand the social background of 3G TD-SCDMA and 4G TD-LTE innovations. In this section, the national innovation policy in China at the contemporary, and the supervisory architecture and market competitions in China's telecommunication field are briefly introduced. Section 6.4 concludes chapter at last.

6.2 THE EVOLUTION OF MOBILE SYSTEMS

Before understanding the case studies about 3G TD-SCDMA and 4G TD-LTE mobile system innovations in China, a review about the historical evolution of mobile systems from 1G to 4G are elaborated in this section. Understanding the evolution of mobile systems not only contributes in figuring out the key technical features of mobile systems in each era, but also helps delineate an overall picture of the international competition in the mobile system field. Before specifically introducing mobile system in each generation, we first summarize the result of features comparison between the four generations in the Table 6.1, and also delineate the path of mobile systems evolution from 1G to 4G in the Figure 6.1 as followed.

Table 6.1 Evolution of mobile systems from 1G to 4G

	1G	2G	3G	4G
Year	1970-1980	1980-1990	1990-2000	2000-2010s
Speed	2.4Kbps	64Kbps	2Mbps	200Mbps-1Gbps
Technology	Analog Cellular	Digital Cellular	Broadband CDMA, IP	Unified IP & LAN, WAN, PAN
Standard	TACS; AMPS	GSM, CDMA One, EDGE, GPRS	WCDMA, CDMA 2000, TD-SCDMA	WiMAX, FDD LTE, TDD LTE
Multiplexing	FDMA	TDMA, CDMA	CDMA	OFDM
Switching	Circuit	Circuit & Packet	Packet expect circuit for air	Packet
Core Network	PSTN	PSTN & Packet network	Packet network	Internet
Handoff	Horizontal	Horizontal	Horizontal & Vertical	Horizontal & Vertical
Services	Only voice	Digital voice, short message, packet data	Integrated high quality audio, video	Dynamic information access

Source: author summarized based on ITU 2013, TDIA 2014

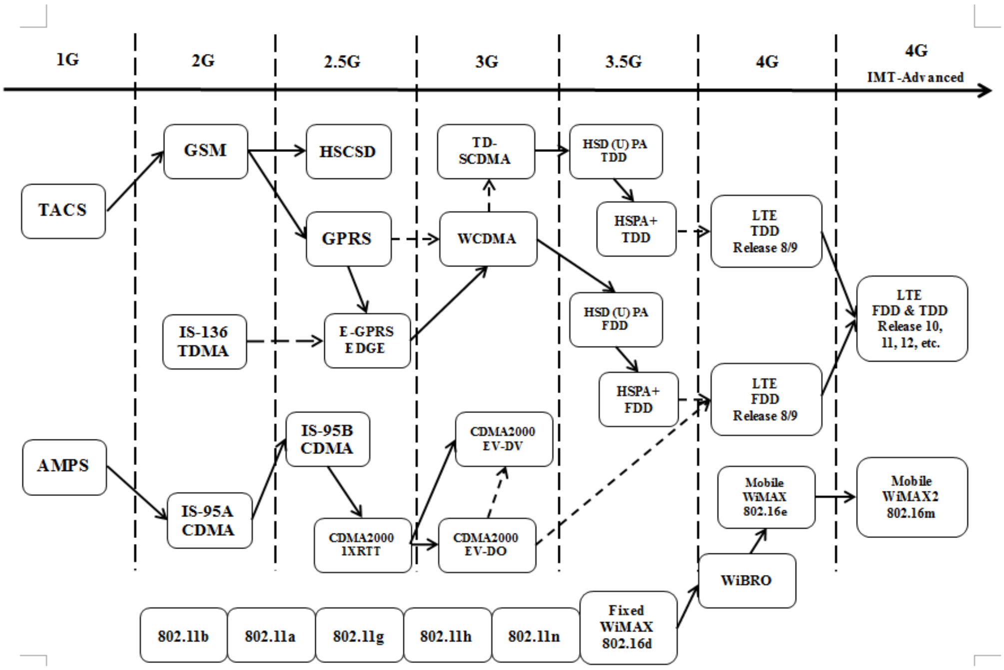

Figure 6.1 Path of mobile wireless technology evolution from 1G to 4G (*source: author illustrated*)

6.2.1 The first generation of mobile wireless system: analog cellular era

In 1947, the conception of cellular communication was first introduced by AT&T's Bell Labs[1]. The technical details could be simply understood as to increase the mobile system's capacity through reusing frequencies and restricting the range of base station. The small divided coverages were named as "cell". The cell required higher frequencies, and because of limited coverage, if mobile user moved between different cells the phone call should been handover from one station to another. Basically, the main components of the system include base and mobile stations, subscriber database for authentication and tracking location, reusable ratio frequencies, and switching equipment for accessing to the fixed line (Qualcomm, 2014).

All 1G systems were operating based on analog signals. The technology of frequency modulation (FM) was adopted for communication, and radio spectrum was shared among subscribers. During a phone call, subscribers were allocated with a pair of 25 kHz or 30 kHz radio channels for supporting the call. For selecting radio channels in a more effective way, multi-channel FM transceivers were normally integrated in mobile terminals and channels were selected by the cellular system rather than the subscribers. Such strategy of sharing limited ratio spectrum was the later known *Frequency Division Multiple Access (FDMA)*[2] (ITU, 2008, Qualcomm, 2014).

The diffusion of mobile cellular started from 1980s, when the world's first cellular system launched in Tokyo by *Nippon Telephone and Telegraph (NTT)* in 1979, then in Europe in 1981. Then the most adopted systems were *Nordic Mobile Telephones (NMT)* and *Total Access Communication Systems (TACs)*. All systems were capable to handover and roam, but could not interoperate between countries. Later in 1982, the *Advanced Mobile Phone System (AMPS)* was launched in the US and commercialized in Chicago in 1988. The AMPS system adopted FDMA with 30 kHz channel capacity, took 824-894mHz as frequency band, and then the speed was up to 2.4 kbps (Kumar et al., 2010).

[1] AT&T is telecommunication service provider in the US, providing both domestic and universal telephony service. Its domination position was established in 1913 when freed from anti-trust prosecution.
[2] FDMA provides multiple users to access by separating the used frequencies, which was mainly used in GSM to separate cells, and later used in TDMA to separate users within the cell.

6.2.2 The second generation of mobile wireless system: digital cellular era

The second-generation mobile wireless systems were developed based on the digital cellular technology in late 1980s. Digital multiple access technologies including *Time Division Multiple Access (TDMA)* and *Code Division Multiple Access (CDMA)* were adopted[3]. Compared with 1G system, 2G systems had higher spectrum efficiency and better data services. The speed was up to 64 kbps and the bandwidth was 30-200 kHz. The 2G systems could offer services like *Short Message Services (SMS)* and *Multimedia Messages Services (MMS)*. Driven by varied considerations, two distinct systems were developed in the Europe and in the US, known as GSM and CDMA One, respectively. In Europe, the mean consideration of developing a second generation digital cellular mobile system was to satisfy the need for European level communication and national coordination. Thus the GSM system was a joint effort from the European and national level telecommunication regulators, the equipment manufacturers, and the telecommunication service operators. While in the US, the main incentive was to increase speed and capacity of telecommunication in urban areas (Kumar et al., 2010).

Global System for Mobile Communication (GSM) as the most widely adopted system in the 2G era was introduced by the *European Telecommunication Standards Institute (ETSI).* The development of GSM started from 1982, when the *European Conference of Postal and Telecommunications Administration (CEPT)* created the *Groupe Spécial Mobile* committee (former ETSI) to develop a European 2G standard. In 1987, 13 European nations signed a memorandum of understanding in Copenhagen for developing and diffusing a common cellular system across Europe, and passed EU rules to make GSM as a mandatory standard. GSM was first commercially launched in Finland by Radiolinja[4] in 1991. GSM was the first technology that enables international roaming and took over 85% market shares by operating in more than 219 countries. With continuously improvement, GSM then shifted from circuit switched network to

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[3]TDMA technology divides signals into time slots, including GSM, PDC, iDEN, IS-136; CDMA provides each user with a special code to communicate over a multiplex channel, like IS-95 (CDMA One).

[4] Radiolinjia was a Finnish GSM operator founded in 1988. The world's first GSM phone call was made on Radiolinjia's network on March 27, 1991.

packet switched[5] network, and enhanced data rate to 144 kbps. *General Packet Radio Services (GPRS)* and *Enhanced Data rates in GSM Environment (EDGE)* were two mainly adopted protocols for packet switching. GPRS and EDGE enabled flexible data transmission rates and continuous connection to network (ITU, 2010).

CdmaOne (IS-95) was another 2G system, which was developed by Qualcomm, a San Diego based firm, in 1995. Initially, IS-54, based on digital AMPS (TDMA), was accepted as the first version of 2G system in the US in 1990. It could have become the first and single 2G system standard in the US if Qualcomm did not purpose the other alternative based on CDMA, which was a radical different multiple access approach. It was different with previous approaches that shared limited radio spectrum by either adopting FDMA (allocating users with a pair of frequencies), or TDMA (allocating users with a pair of frequencies and timeslots). In CDMA system, all communications were transmitted on the same pair of frequencies and also at the same time. The signal was combined with a higher rate bit stream, which could distinguish the signals and also differentiated with the signal that transmitted. This higher rate bit stream was known as the chip code, which was what the “C” in CDMA stands for. The phone call was then digitalized because receivers who know the chip code could then reversely recover the original signal that been transmitted. Although the CDMA system was untried for commercializing use, the technology had already been well adopted for the US military due to its resistance to interception and jamming (Qualcomm, 2014, Gawas, 2015).

CDMA in the 2G era was widely recognized as a huge success for Qualcomm, and one of the most significant successes was Korea adopted CDMA as its national standard for mobile wireless services in 1993. Korean government issued its industrial policy to provide domestic manufactures and operators a chance to establish themselves in mobile technology (Lee et al., 2009). Qualcomm then worked with other manufactures and operators in both US and Korea to further develop the technology, and formed a group named as CDMA Development Group (CDG) in December 1993. This group had taken a leading role in promoting the diffusion of CDMA all around the world.

[5] Packet switching is a technique that breaks information (voice & data) into packets for sending.

6.2.3 The third generation of mobile wireless system: all-round upgrading

Facing the need of higher speed and quality of data transmission, the third generation mobile system was first introduced in 2000. Compared with former systems, the target of 3G systems was to enhance data rates up to 384 kbps in wide coverage areas and 2 Mbps in local. Apart from providing better voice communications, multiple data services were enabled by 3G systems, such as video calls, broadband wireless data, etc.

Initially, the idea of developing 3G mobile system was first purposed by the *International Telecommunication Union (ITU)* in 1986, which targeted to create a single air interface that could allow pocket-size mobile terminals to access the system at anywhere around the world. This idea was conceptualized as the *Future Public Land Mobile Telecommunications Services (FPLMTS)*, and this unified 3G system was leaded by ITU-R[6] Task Group 8/1. This simple idea of "terminal mobility" did not survive, and also the vision of a single global 3G system was not realized (ITU, 2008).

However, from now on, ITU then always keep the vision of creating a global unified mobile system in the later development. In 1995, then the FPLMTS was renamed as *International Mobile Telecommunication 2000 (IMT-2000)*[7], and still responsible to define the demands for 3G mobile system. Learnt from the failure of conceptualizing global unified 3G system, ITU had recognized that it is unfeasible to align the ideal concept with heterogeneous existing 2G systems, cordless telephony systems and other undefined systems. As several major 2G systems like GSM, cdmaOne, PDC and D-AMPS were deployed in the 1990s, when considering about transitioning into the third generation system, contemporary manufactures and operators of these standards would like to select the path with economic and technological attractiveness. This is current acknowledged as path-dependency for standardization, and existing air-interface and established industrial networks had set the starting point for 3G system development.

[6] The ITU Radio-communication Sector (ITU-R) is one of the three divisions of ITU that responsible for radio communications. Roles of ITU-R including manage international radio frequency spectrum and satellite orbit resources, and to develop standards.
[7] The International Mobile Telecommunications-2000 (IMT-2000) includes a set of standards used for mobile devices and services that meet the application requirements for the 3G mobile system.

Therefore, since 1995, ITU has adopted the current operation model that several mobile system standards could be accepted by the ITU, like IMT-2000 family composed by three international 3G mobile system standards. As GSM and cdmaOne was developed by the EU and the US respectively in the 2G era, thus initial 3G systems were also purposed and developed in these two regions based on the technologies derived from the former developed 2G system.

In Europe, developing 3G system had been regarded as a significant interest for the European Community, since the positive influences of GSM development and diffusion. In Europe the development of 3G system was driven by *ETSI* and named as *Universal Terrestrial Mobile System (UMTS)*. *3rd Generation Partnership Project (3GPP)* was the organization established by the ETSI to work on defining the 3G mobile systems to meet the IMT-2000 standard (ITU, 2008). First commercialized in 2001, European developed *WCDMA (Wideband-CDMA)* is the typical air-interface of UMTS with most widely deployment all over the world. By sharing the same infrastructure, *TD-SCDMA* as another air-interface of UMTS is developed by China and commercialized in 2009 (Kumar et al., 2010). Derived from cdmaOne, *CDMA2000* is the name of US 3G variant which was first commercialized in 2003 (Kshetri et al., 2011, ITU, 2013). The figure 6.2 and figure 6.3 illustrate the paths of migration from 2G to 3G. At last, a comparison among the three most branded international 3G systems is summarized in the Table 6.2.

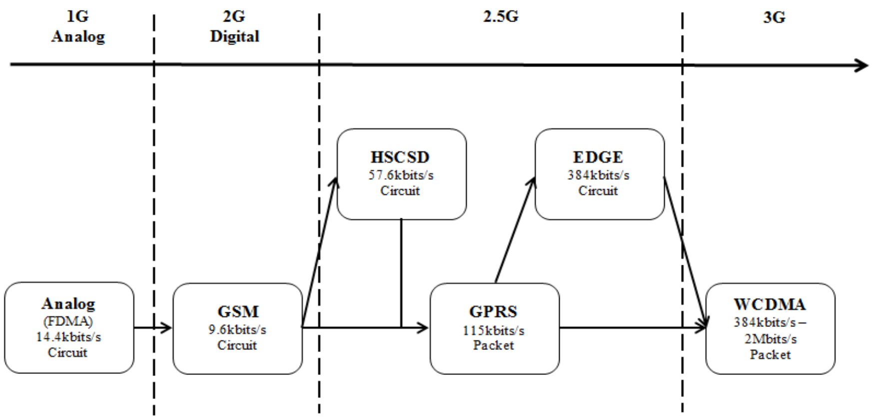

Figure 6.2 The migration path for GSM operators towards WCDMA (*source: author illustrated*)

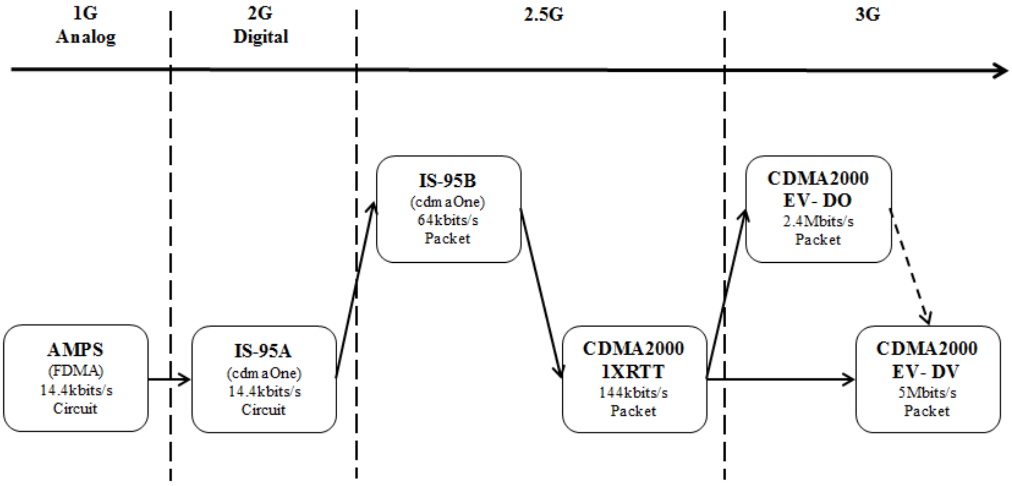

Figure 6.3 The migration path for cdmaOne towards CDMA2000 (*source: author illustrated*)

Table 6.2 A comparison between 3G mobile systems

	WCDMA	**CDMA2000**	**TD-SCDMA**
Developed by	Nokia, Ericsson, Alcatel (Europe-based)	Qualcomm Inc. (US-based)	CATT/Datang, Siemens (China-based)
First operator, country, year	NTT DoCoMo's FOMA, Japan, October 2001	SK Telecom, South Korea, October 2000	China Mobile, April 2008
2G version	GSM	cdmaOne	None
Duplexing scheme used	Frequency Division Duplex (FDD)	Frequency Division Duplex (FDD)	Time Division Duplex (TDD)
Multiplexing	CDMA	CDMA	CDMA
Standardized	3GPP	3GPP2	3GPP
Where adopted	162 networks in 72 countries, takes nearly 70% shares of overall market	166 operators in 73 countries, 275m subscribers	1 operator (China Mobile) in one country
Major markets	EU & Japan	US	China

Source: author adapted from Kshetri et al. 2011 & ITU 2013

6.2.4 The fourth generation of mobile wireless system: All-IP technology

Targeting for faster data transmission, enhanced roaming abilities, unified messaging and broadband multimedia, the demand of the fourth generation mobile system was initiated by ITU-R with issuing IMT-Advanced[8] in late 2000s. 4G systems are designed as All-IP based network, and the reason for transiting to the All-IP is to establish a common platform to integrate all the technologies that been developed so far (ITU, 2015). As pointed out in last section, to establish a global unified mobile system has always been viewed as the ultimate target for ITU. Compared with former systems, IMT-Advanced requires 4G systems to fulfill specific requirements such as based on All-IP packet switched network; have peak data rates up to 200 Mbps for high mobility and 1 Gbps for low mobility; have smooth handovers across heterogeneous networks and so on (Rumney, 2008). Accordingly, potential applications may include such as IP-based telephony, HD mobile television and high performance gaming (ITU, 2013).

Initially, two candidate 4G systems were submitted to the ITU: the *Mobile WiMAX*[9] which was standardized by the IEEE[10] and the *LTE* which was standardized by 3GPP. However, since the first version of *LTE (3GPP Release 8)* and *WiMAX (IEEE 802.16e)* supported much less than 1Gbps peak bit rate, which was initially required by IMT-Advanced, thus they were not completely IMT-Advanced compliant (ITU, 2013). In September 2009, upgraded from former released versions, *LTE-Advanced (3GPP Release 10)* and *WiMAX-Advanced (IEEE 802.16m)* were officially submitted to ITU as two 4G candidates for commercial adoption. Considering contemporary 4G techniques are based on these two candidates, thus ITU-R still recognized them as international 4G standards by the end of 2009 (3GPP, 2012).

Later in 2010, since Intel announced to drop out the *WiMAX*, the technology then was gradually given up by most mainstream mobile service operators at that time. Operators

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[8] IMT-Advanced: International Mobile Telecommunications advanced, defined a set of requirements for 4G mobile wireless system standards, like IMT-2000 in the 3G era.
[9] Mobile Worldwide Interoperability for Microwave Access (IEEE 802.16m)
[10] IEEE: Institute of Electrical and Electronics Engineers, a professional association objective to advance the educational and technical disciplines in electrical, electronics, telecommunications and computing.

that former invested in *WiMAX* then turned their interests into TD-LTE (CCM, 2007). The exit of *WiMAX* then made *LTE-Advanced* to became the only mainstream 4G standard de facto (CENA, 2012). *LTE-Advanced* has peak data rates up to 1 Gbps for downloading and 500 Mbps for uploading, which could definitely fulfill the initial requirements that raised by IMT-Advanced (SRRC, 2013).

LTE FDD[11] and *LTE TDD* are two variants in *LTE-Advanced*. In fact, LTE is the natural upgrade path for carriers with both *UMTS (WCDMA and TD-SCDMA)* and *CDMA2000* networks (3GPP, 2012). Since the duplexing technique for *WCDMA and CDMA2000* are based on FDD, thus *LTE FDD* is the natural upgrade path for most *WCDMA* and *CDMA2000* networks. Similarly, *LTE TDD* is the path for *TD-SCDMA* because of employing TDD as the duplexing technology.

However, despite of duplexing techniques, the inheritances for both *LTE FDD* and *LTE TDD* from 3G standards are quite limited. This is because multiplexing for 3G systems are mostly based on *CDMA* technology, and all the 3G systems are established based on packet-transmission networks. In contrast, 4G systems are All-IP technology which developed based on *OFDM*[12]. Besides, since two variants of 4G system both adopted LTE technique, thus the contact ratio for these two systems are quite high (ITU, 2013, SRRC, 2013). Figure 6.4 illustrates the migration paths for 3G system operators towards 4G, and comparisons between *LTE TDD* and *LTE FDD* mobile wireless systems are briefly elaborated in Table 6.3.

Through reviewing the evolution of mobile wireless systems from the first to the fourth generation, it has been acknowledged that, network convergence as the ultimate target of ITU is definitely an irreversible trend for telecommunication development in future. High degree of overlap in terms of patents and technologies in FDD LTE and TDD LTE, and the adoption of All-IP technology have both confirmed such trend. Furthermore, traditional technology late-coming nations like China and Korea are playing more and more significant roles in international collaboration and competition.

[11] FDD (Frequency-Division Duplex); TDD (Time-Division Duplex)
[12] OFDM (Orthogonal Frequency Division Multiplexing), contrast with CDMA.

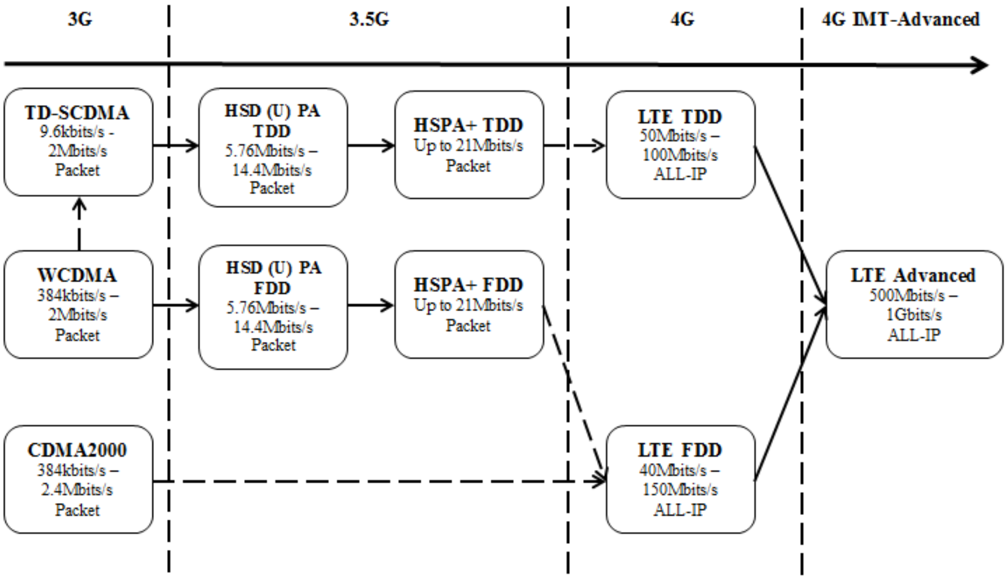

Figure 6.4 The migration path for 3G system operators towards LTE

Table 6.3 A comparison between 4G mobile systems

	LTE FDD	**LTE TDD**
Developed by	Collaboration including ST-Ericsson, Alcatel, Nokia-Siemens, NTT DoCoMo, Huawei, ZTE and other members in ETSI (Europe-based)	Collaboration including China Mobile, CATT/Datang, ZTE, Huawei, Nokia-Siemens, ST-Ericsson, Qualcomm (China-based, GTI promoted)
First launched, country, year	Sweden and Norway, December 2009	India, September 2010; China, December 2012
3G version	WCDMA, CDMA2000	TD-SCDMA
Duplexing	Frequency Division Duplex (FDD)	Frequency Division Duplex (FDD)
Multiplexing	OFDM	OFDM
Standardized	3GPP	3GPP
Where adopted	154 networks in 94 countries, over 90% market shares	39 networks in 26 countries, over 5 million subscribers
Major markets	EU, US	China, Japan, Korea, US, SA
Main devices vendors	Huawei, ZTE, Ericsson, Alcatel, Nokia-Siemens	Huawei, ZTE, Ericsson, Alcatel, Nokia-Siemens
Main terminal vendors	Apple, Samsung, Blackberry, Nokia, Motorola	Apple, Samsung, HTC, Huawei, ZTE, Lenovo, Hisense

Source: author adapted from ITU 2013 & TDIA 2014

6.3 TELECOMMUNICATION INDUSTRY IN CHINA

In this section, being recognized as the cradle for 3G TD-SCDMA and 4G TD-LTE mobile system innovations, the telecommunication background in China is illustrated associating with China's national innovation environment before the case studies.

In the literature, three characteristics of the telecommunication industry in China are mostly summarized. Firstly, the industry develops accompany with the strong national will, which aims to advance the industry through indigenous technology innovation, to lead the development of domestic economy, and also in further to compete with foreign players (e.g. Eric, 2007, Kshetri et al., 2011, Zhang and Liang, 2011, Yu et al., 2012, Lim et al., 2014). Secondly, the intense confliction of bureaucratic interests among various government authorities and interests groups resulting in an asymmetric and complex environment for China's telecommunication industry, affecting both activities in the industry and interactions with other domains (e.g. De Bijl and Huigen, 2008, Marukawa, 2010, Xia, 2012b, Lim et al., 2014). At last, the telecommunication market in China has been exponentially expanded, and the industry never stops reconsolidation and evolution in the development (e.g. Gao and Lyytinen, 2000, Mu and Lee, 2005, Hu et al., 2012, Kwak et al., 2012, Xia, 2012a, Xia, 2012b, Gao et al., 2013).

Therefore, following the three identified characteristics, in this section we first briefly introduce China's NIS and national innovation policy at the contemporary of TD-SCDMA and TD-LTE innovations. Then we elaborate historical transformations of telecommunication industry and industrial policies in China, which helps understand how the contemporary industry structure and policies are formed. At last, by specifically focusing on the periods of TD-SCDMA and TD-LTE innovations, the contemporary telecommunication industry in China are introduced mainly from two dimensions: the supervisory architecture and the market competitions in this field. After then, as the primary focus in this research, another significant dimension that introduced by Lyytinen and King (2002) – the innovation systems for TD-SCDMA and TD-LTE, are specifically discussed associating with government interventions in the next chapter.

6.3.1 China’s NIS and national policy for indigenous technology innovation

As Freeman (1995) indicated, by enclosing a serious of political, economic, technological and other factors, a nation’s NIS could largely conclude a society’s capability for development and the institutional environment for national level innovations. Moreover, determined by the NIS, the national policy for innovation could set the bases for understanding the innovation policies in specific areas in a nation (Borrás and Edquist, 2013). Therefore, as a key industry in China, before specially introducing the telecommunication background, we suggest that the NIS and the contemporary national policy for technology innovation are also significant for understanding the background of China’s mobile system innovations.

China’s science and technology policy

Through reviewing the national innovation policy in China, OECD (2008) indicated that the overall history of science and technology (S&T) development in modem China is throughout determined by the evolution of national S&T policy. Based on four times of the *strategic national S&T conferences* that held in 1978, 1985 and 2006, five phases of China’ S&T policy evolution are distinguished. Facing different challenges, China’s S&T policy exhibited obvious differences in terms of features and emphases at different phase, thus the NIS and the nation innovation policy evolved synchronously with the evolution of S&T policy in China (Motohashi and Yun, 2007). In this work, we only focus on the last phase (*indigenous innovation*), in which TD-SCDMA and TD-LTE innovations happened. More details about other phases are summarized in Appendix 10.

As the most significant signals for the starting of indigenous innovation phase, in 2006, the *National Science and Innovation Conference* was held and the *National Medium- and Long-Term Program for Science and Technology Development 2006-2020* was launched. They seek to upgrade the contemporary growth model to be more sustainable. State Council emphasized promoting indigenous innovation was as the primary approach for enhancing further economic growth (State Council, 2006).

The MLP has represented most of the fundamental ideas about contemporary S&T policy in China: firstly, an innovation-based economy is planned to be built through continuously fostering indigenous innovation capabilities; secondly, to establish a firm-centered innovation system and to enhance domestic firms' capabilities in innovation; at last, to achieve significant breakthroughs in targeted fields for both economic development and basic research (OECD, 2009). The process of China's S&T policy evolutions are summarized in Table 6.4 as followed.

Table 6.4 Process of S&T policy evolutions in China

S&T evolution	Context	Policy emphasis	Policy learning	Funding approach
Phase 1: Incubation (1975-1978)	Cultural Revolution terminated; Economic development is urgent and imperative	Remove barriers set by ideologies that prohibiting S&T development	Learning from self-reflection and criticism	Direct public institutional support
Phase 2: Experimentation (1978-1985)	Reform and opening up policy launched Started experimental economic and education reforms	Change Soviet S&T system model and link science and industry Initial reform in universities system	Learning by bottom-up experimental reforms	Initial experimental changes in funding approaches Partially releasing funding channels
Phase 3: S&T system Structural reform (1985-1995)	Strength international cooperation in both S&T and economic Economic system reform expand in S&T	Start reform in PRIs including university systems, and put certain PRIs into business entities	Learning by designing and adopting top-down systemic reforms in institutions	Reduce direct public funding in applied research in PRIs. Launch national programs
Phase 4: Deepening S&T system reform (1995-2005)	Extremely rapid economic growth Pressures from technology-based competitions in global market	Enhance firms' capabilities for innovation Enhance PRIs' capabilities for commercialization	Learning from other countries conducted distinctive practices in S&T development	Further polarization of PRIs through launching new programs Introduce venture capitals
Phase 5: Indigenous innovation[13] (2006-)	Highlight the sustainability of national development Willing to maintain the sustainability of current growth trend	Finish shift from PRIs-centred system to firms-centred Improvement in mobilizing S&T for sustainable develop	Toward endogenous institutional learning and evidence-based policy making	Improve mix policies in supporting more efficiently both market-led and institutions-led S&T development

Source: author summarized from State Council 2006, Motohashi & Yun 2007, and OECD 2008

[13] Indigenous innovation stands for "*original innovation, integrated innovation, and re-innovation based on assimilation and absorption of imported technology*" (State Council, 2006, Section II, Article 1).

Policy for indigenous innovation in China

Determined by the NIS, innovation policy in China has also demonstrated different features in different phase of NIS evolution. Same as NIS analysis in former sections, the indigenous innovation phase (*2006- now*) is the targeted time period in this research. As the contemporary S&T policy put the primary emphasis on sustaining the fast growth trajectory, thus promoting indigenous technology innovation, which was recognized as the best solution for achieving this development target, is particularly emphasized by innovation policy in this phase (OECD, 2015b). Associating with the NIS challenges that identified, the rationales of innovation policy in this phase were to satisfy the expectations of indigenous innovation and address the NIS challenges.

Despite of distinct rationales, the design and implementation of innovation policy are also featured differently for promoting indigenous innovation. For example, innovation policies are not just designed and implemented throughout by a top-bottom approach, more influences are made by private sector stakeholders, and the biases in favor of state-own enterprises are observed to decrease (Liu and Cheng, 2014). Moreover, the evaluation and award mechanisms in terms of fostering innovations have been systematically reestablished. For example, picking-up scholar talents is favored as much as enhancing quality and mobility of existing human capitals, and the competences in R&D have receive as much emphases as managerial capabilities (Liu and Cheng, 2014, Zhu, 2014, OECD, 2015a).

Besides, soft environment for innovation are gradually considered as significant as building the physical R&D infrastructures, as more efforts in establishing the innovation friendly environment and cultivating the social capabilities for innovation are taken (Kwak et al., 2012, Vialle et al., 2012, OECD, 2015b). Similarly, the diversified R&D programs that introduced not just focus basic research and R&D selected high technologies any more, they also start to emphasize the construction and strengthening the infrastructures for S&T development (Bichler and Schmidkonz, 2012). In Appendix 11, a table is drawn to summarize how diversified R&D programs, such as *The Spark* and *The Torch* help promote the indigenous technology innovations in China.

6.3.2 Transformation of China’s telecommunication industry

Based on the overall innovation environment in China that delineated, from this section, we specifically illustrate China’s telecommunication background. We start from elaborating the historical transformation of China’s telecommunication industry. After then, by specifically focusing on the phase in which the two selected cases took places, we particularly introduce the supervisory architecture and the market competitions of the contemporary telecommunication industry in details.

A series of structural reforms has constituted the main thread of telecommunication industry development in China (Xia, 2011, Kwak et al., 2012). Since the inceptive telecom reform took place in 1994, the telecommunication industry in China has gone through in total five times of significant restructuring (*1994, 1998, 2002, 2008 and 2014*). The government not only triggered each round of structural reforms in telecommunication industry, but also steered and manipulated the transformations in terms of the targets, process and paces. As a result, Gao et al. (2013) indicated that the regulatory regime of China’s telecommunication has shifted from *fragmented* and *centralized* towards *coherent* and *decentralized*; meanwhile, the marketplace have shifted from *monopoly* to *competition*.

As a core industry for the state economy development, both ideological and political system in China favors the government intervention in this field (Gao et al., 2013). It has been witnessed, reforms in the regulatory regime are normally conducted by institutional changes, which are mostly concurrent with upper-level government reforms; but reforms in the marketplace are normally achieved by continuously introducing new competitors and establishing the environment that friendly to market competitions (Tan, 1999, Mu and Lee, 2005, Hu et al., 2012, Gao et al., 2013). As a summary, we figured out the key events and milestones of the historical transformations of China’s telecommunication industry in Table 6.5 as followed. The historical overview has clearly demonstrated how the industry evolved towards decentralization and full-competition after a serious of transformations.

Table 6.5 Historical overview of China's telecommunication industry

Reforms	**Key events**
Stage 1: Separate Post & Telecom (1994;1998)	- **1994.07** China Unicom, jointly founded by 13 ministries and commissions, was introduced as a new competitor to the telecommunication industry - **1995.04** The then *Post and Telecommunications Administration* transferred its government functions to other Ministries, and registered as an SOE - **1998.03** The then *Ministry of Posts and Telecommunications (MTP)* was separated into the new *Ministry of Information Industry (MII)* and the *Post Bureau*. Meanwhile, China Telecom separated from MII and became SOE
Stage 2: Separate Mobile & Telecom (1999;2000)	- **1999.02** MII restructured China Telecom's business into three parts: fixed-line, mobile and satellite. China Mobile and China Satcom were created. - **2000.09** The State Council approved the proposal about regional telecom governance reform, which was initiated by MII - **2000.12** Regional telecom governance reform completed. China Railcom was created. China Railcom, China GBnet, China Netcom were granted licenses
Stage 3: Separate North & South of China Telecom (2001;2002)	- **2001.10** The proposal of China Telecom North-South Separation was initiated - **2001.11** China officially join the WTO, and State Council approved the plan of the next round telecom reform for addressing potential challenges - **2002.05** China Telecom was geographically separated into north and south: China Telecom-North kept 30% network resources and formed new China Netcom; the South kept 70% of the resources and became the new China Telecom.
Stage 4: Reorganize Three Telecom Giants (2008)	- **2008.03** The *Ministry of Industry and Information Technology (MIIT)* was established to replace the former MII, mainly responsible for regulation and development of the internet, wireless, broadcasting and communications. - **2008.05** MIIT, NDRC and MOF announced the third restructuring proposal: China Telecom acquired China Unicom's CDMA network; China Telecom acquired basic telecom business from China Satcom; China Unicom retained GSM network and merged with China Netcom, formed new China Unicom; China Railcom (Tietong) merged into China Mobile.
Stage 5: Introduce Private Capital (2013;2014)	- **2013.05** MIIT officially gave the first batch of mobile telecommunication resale licenses to 11 enterprises, which herald the private capital from Virtual Network Operators (VNO) is welcomed in the telecommunication industry - **2014.07** MIIT announced that the China Telecommunication Infrastructure Services Co., LTD was formally set up. This enterprise is jointly holding by China Mobile (40% stock rights), China Unicom (30.1%), China Telecom (29.9%) according to initial investments.

Source: author summarized based on Kwak et al., 2012, Xia 2012 and Gao et al., 2013

As Table 6.5 indicated, government retained strong national will to promote development of domestic telecommunication industry, and positive to intervene. The telecommunication service operators in China are all GSEs, who not only align their own interests with the government will for development, but also keep reconsolidating by following government orders. The government steers and stimulates domestic telecommunication to develop through both launching institutional reforms and manipulating leading GSEs (Gao et al., 2014).

Besides, Table 6.5 also confirmed the trend that Gao et al. (2013) concluded: in the regulatory regime, the industry transformed from fragmented and centralized towards coherent and decentralized; and in the marketplace, it evolved from monopoly to competition. For example, in the first phase, the main target for industry transformation was identified as to separate the functions between/from government and/to enterprise; and in phase 2 and phase 3, the government intended to break the monopoly in industry by splitting China Telecom into separate enterprises and introducing more competitors to the market, such as China Mobile, China Railcom, and Satcom.

This "spirit" of industry transformation has been implemented throughout the whole history of telecom development in China, even today. The most recent reform that started from 2013, has demonstrated sufficient interests in introducing private capitals into the industry. As a result, three GSEs that running telecom services now have to compete with the VNOs, like Dixintong, Jingdong, and Alibaba in the same market. In following sections, the contemporary telecommunication industry in China, including both supervisory architecture and market competitions, are briefly illustrated.

6.3.3 Supervisory architecture for China's telecommunication field

As introduced, both regulatory regime and marketplace of telecommunication industry in China were reconsolidated after the fourth industry restructuring in 2008: major industry players reduced from six to three *(China Mobile, China Unicom, and China Telecom)*; and the former industry key regulator MII was merged into the newly established MIIT (StateCouncil, 2008). After the reconsolidation, three 3G mobile systems, namely TD-SCDMA, WCDMA and CDMA2000, were officially launched in the beginning of 2009 (Kshetri et al., 2011, Gao and Liu, 2012). Until 4G mobile systems launched from early 2013, no significant structural change was observed in the industry. In the figure 6.5, we briefly delineated the supervisory architecture of the telecommunication industry in China.

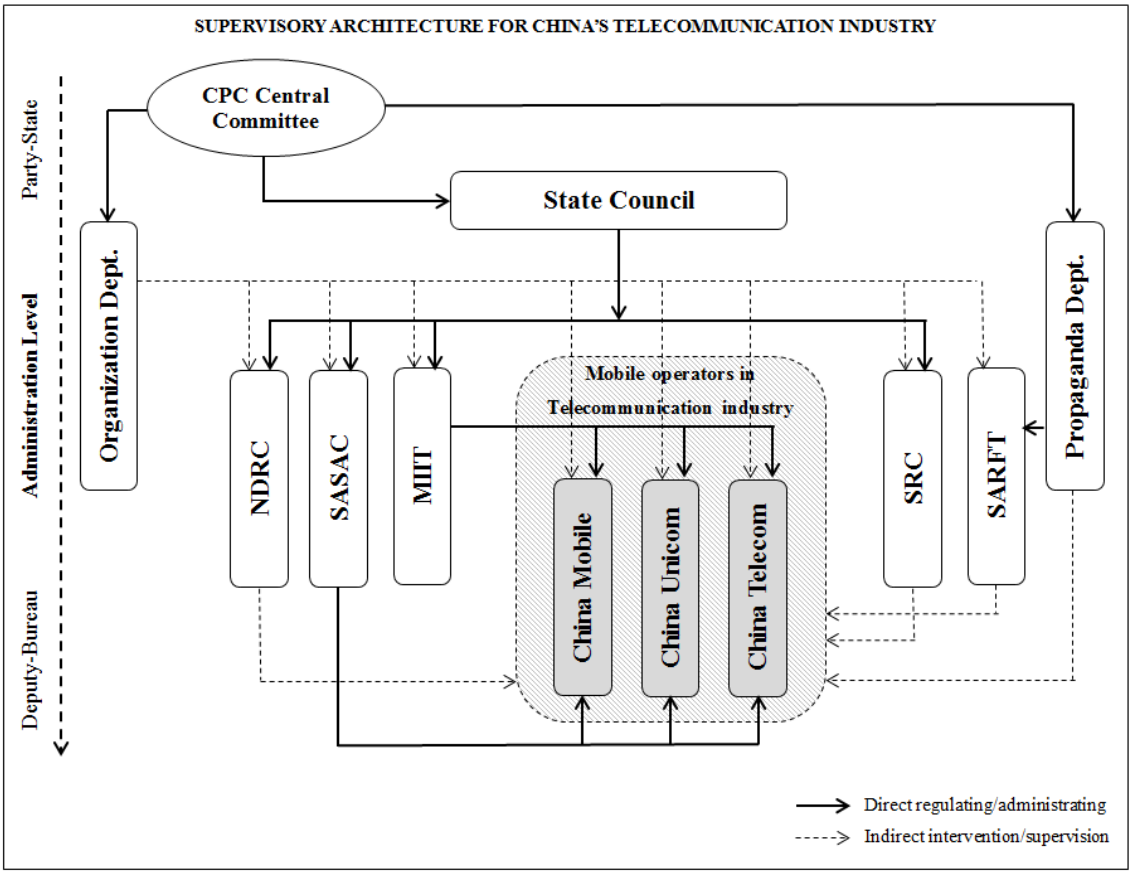

Figure 6.5 Supervisory architecture for the telecommunication industry in China *(source: author adapted from Xia 2012a)*

In the figure we especially delineated how operators as the hub of other industry participators are impacted by the government authorities in regulatory regime. How other participators like vendors, dealers and content providers plays within such supervisory architecture are particularly elaborated in the next section, which is specifically set to understand market competitions in China's telecommunication field.

Besides, in the Table 6.6, we briefly summarized the functions and roles of the government authorities that impact the telecommunication industry. Some of them have been introduced in the section 6.3.1 when introducing the political system in China's NIS, yet in Table 6.6 we mainly emphasized on the roles that the government authorities play particularly in the telecommunication field.

Table 6.6 Government authorities in China's telecommunication industry

Authorities	Roles and Functions
CPC's Organization Department	**Cadre organizer:** officially appoints and evaluates senior executives for GSEs in telecommunication
CPC's Propaganda Department	**Ideological guardian:** exercises ideological censorship on contents transmission and the manufacturing
SASAC	**State-asset guardian:** nominates and evaluates senior executives of telecom GSEs, approves their mergers and sales, and oversees return on the state asset
NDRC	**Macro-economic planner:** ensures economic stability and growth, issues policies for economic development, and maintain the balance of economy
MIIT	**Industry regulator:** regulates and promotes telecommunication development; comparatively, SARFT regulates the content for transmission.
SRC	**Capital market regulator:** sets and enforces regulations of public securities trading and promoting corporate financial information transparency.

Source: author adapted from Xia 2012

As introduced, major players in telecommunication fields are GSEs, which in law are all regulated and supervised by the SASAC. MIIT cooperating with SASAC is the regulating administrator in the telecommunication fields. In addition, MIIT also comply with ideological guidance from the CPC Propaganda Department, and personal scheduling from the Organization Department. Besides, as the NDRC functions as the administrator for macro-economic, thus the tariff policies that executed by the MIIT are also under its supervision. At last, including the NDRC (*in pricing*), the other two government authorities, namely as the Ministry of Commerce (*in market concentration*) and the State Administration for Industry & Commerce (*SAIC: dealing with unfair competition and administrative monopoly*) are collaboratively responsible for enforcing the *Anti-Monopoly Law* in their respective fields (Xia, 2012b, OECD, 2015a).

The supervisory architecture for China's telecommunication industry retains both advantages and deficiencies for industry development. On the one hand, direct government orders to GSEs in the industry could at the maximum extent to ensure the national will; while on the other hand, conciliating varied conflicts caused by heterogeneous departmental interests has sacrificed efficiencies to large extent as well.

For example, as elaborated, the telecommunication industry in China is not only regulated by the MIIT, who performs as the industry regulator, but also supervised by the SASAC, as major players and core assets are all state-owned. This in nature could lead a number of conflicts, and at the meanwhile, constrained choices for policy-makers as they have to balance heterogeneous interests from different authorities. Similarly, in terms of pricing the telecom services, conciliations have to be made between industry regulators (like MIIT) and macro-economic planners (like NDRC, who values stability and growth). In fact, there exist many similar conflicts in the supervisory architecture. Nevertheless, regardless how conflicts are generated, all of them should be ultimately conciliated by subjecting to the CPC's discretion.

6.3.4 Market competitions in China's telecommunication industry

There always exist various interest groups in worldwide telecommunication markets, who are witnessed, in quite a long-term, to keep on competing with each other with aim to set up new equilibriums. The frequency and degree of reconsolidations vary across countries relates with factors such as institutions, legal systems, property rights and cultural norms (Mu and Lee, 2005, Tilson and Lyytinen, 2006b, Kwak et al., 2012). Meanwhile, featured by several China specific characteristics, the telecommunication market in China also maintains significant distinct with other nations.

One of the most obvious differences is: the mobile operators, who perform as the hub in the market, are exclusively GSEs, and the market behaviors are mostly institutions-driven, but not market-driven (Xia, 2012b). Under market driven situations, firms performs like market rivals and commonly pursue the maximization in terms of profits or shares; while in China's institutions-driven market, GSEs are primarily controlled by administrative and regulatory forces, and their relationships are quite complicated: sometimes are rivals, while sometimes are partners (Chen and Zhang, 2011).

Government authorities in the regulatory regime could impact almost every participator group in the marketplace. They can play multiple roles and impact the marketplace both directly and indirectly. For example, jointly administrated, supervised and regulated by SASAC, NDRC and MIIT, GSEs in the market are not just constraint in mobile operators, many leading enterprises in different participator groups are also state-owned, such as Datang and ZTE who are representatives for chipmakers, network equipment and handset producers (Yan, 2007). In addition, despite of controlling GSEs, many participant groups, such as content and service providers, are also strictly taken charge and regulated by government authorities, such as SASAC, MIIT, NDRC, SAIC, SARFT and MOF (Xia, 2012b). Based on documentary research, at the 3G and 4G eras, the market participators and their relationships in China's telecommunication field are identified, and a strategic network of the contemporary telecommunication market are briefly delineated in the Figure 6.6 as followed.

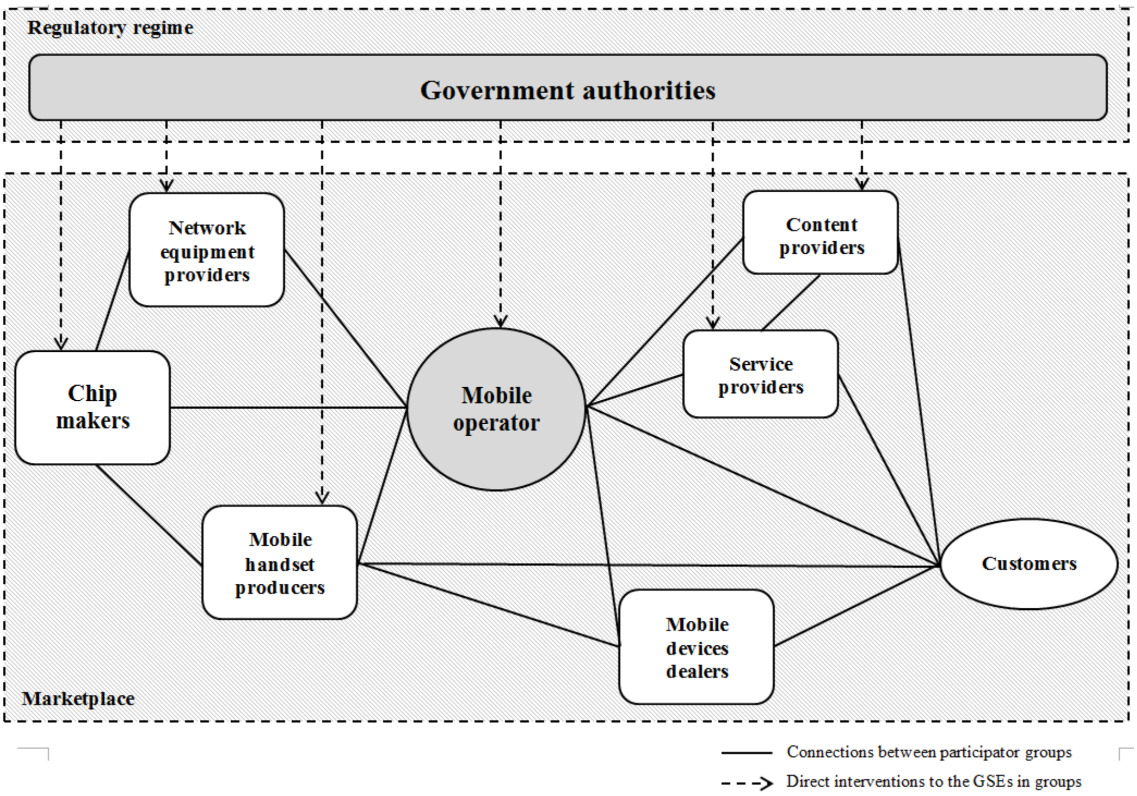

Figure 6.6 Structure of China's telecommunication market during the TD-SCDMA and TD-LTE innovation *(source: author delineated from Hu et al., 2012)*

The hub: three mobile operators

As shown in the Figure 6.6, mobile operators group are the only node that connect with all other participator groups. Both quantity and quality of linkages between three mobile operators with other players confirm the hub position of mobile operators in China's telecommunication market. Mergers and acquisitions, constructing alliance, and retaining long-term contracts are recognized as three primary approaches for them to reinforce their hub positions in the market (Hu et al., 2012).

As GSEs, despite of the institutional arrangement, adopting the platform strategy is believed as the other catalyst for their hub positions. Benefiting with huge installed bases as well as government support in both resources and policies, mobile operators hold considerable leverages to establish such a platform by negotiating with other participants, like customers, manufacturers, services and contents providers. For example, by running the platform, mobile operators have achieved several targets that planned, such as establishing their own App store and embedded them in the customized handsets by cooperating with App providers and handsets producers.

Benefiting with the hub position, each mobile operator has its own alliance network including service and content providers, handsets and network equipment manufacturers, as well as research institutes (Kwak et al., 2012). Within the alliance networks, firms both compete and cooperate with each other (Kwak et al., 2011). Besides, these alliance players could be either domestic or foreign firms: apart from foreign network operators are prohibited to entry China's telecom market to run the network, there is no obvious limitation in other fields. Therefore, as a result, China's telecommunication industry has become global (Stewart et al., 2011, Xia, 2011).

Nevertheless, as former discussed, in terms of the market, the general spirit of telecommunication reform in China is to break monopoly and encourage competitions (Gao et al., 2013). Along with the deepened reform and the adoption of 3G and 4G systems, the hub position of mobile operators in China's telecom market is not as secure as before in the 2G eras. For example, powerful handset producers such as Apple and Samsung, as well as content providers like Tencent and Sina, all hold considerable bargaining powers by leveraging with huge number of customers. In addition, in 2014, virtual network operators were licensed, and the China Communications Services Corporation (CCSC) responding for constructing and managing telecommunication infrastructures was established (CCS, 2014, CCS, 2015).

Network equipment producer

The development of domestic network equipment producers and implementation of China's domestic 3G and 4G have mutually promoted each other (Hu et al., 2012). Before China's domestic standard was launched, domestic network equipment producers, including Datang, Huawei and ZTE, are hardly capable to participant into global telecommunication vendors' competition. By operating GSM and CDMA One in the 2G era, both domestic mobile operators and equipment producers are highly depending on international giants like Ericsson, Siemens and Alcatel. Launching domestic standards has produced a chance for domestic firms to overtake with their international competitors (Bruche, 2009, Xia, 2012b).

As former introduced, there is no obvious barriers for foreign equipment producers to access China's telecom market, thus both domestic and foreign firms have to compete on the same stage (Gao, 2015). As some major domestic network equipment producers like Datang and ZTE are GSEs, and competitions in market are supervised by authorities like the NDRC and SAIC, thus actors in this group connect not only with mobile operators and chipmakers, but also with government authorities.

Chipmakers

In terms of chip-making, chipmakers are significant players in telecommunication industry as the chip-making encloses most patents and the chip is normally the most expensive and profitable module of a mobile terminal (Qualcomm, 2014). The chip making industry is supervised by government authorities like NDRC and SAIC, and some chip-making specialized subsidiaries in Datang, ZTE and Spreadtrum are GSEs.

The chip making industry in China were quite undeveloped, in fact, quite limited domestic firms in the 2G era were capable to produce chips for neither GSM nor CDMA devices, not mention to participate global competitions. Qualcomm had almost monopolized the overall global CDMA chip market in the 2G era and beyond (TDIA, 2013). Nevertheless, along with the adoption of 3G systems, both China's domestic and global telecommunication chip market has been largely reshaped. For example, former leading enterprises such as Qualcomm and Intel are facing fierce challenges from emerging competitors, which not only including newly specialized chipmakers like Spreadtrum and VIT, but also including handsets manufacturers, like Samsung, Huawei and ZTE (TDIA, 2014).

Furthermore, despite of handsets manufacturers who aims to reduce dependency with chip suppliers, China's mobile operators also maintain largely interests in supporting domestic chipmakers to catch up with traditional foreign leading firms especially in technology (Hu et al., 2012). As mobile operators in China are desperate to launch 3G and 4G services, which would be largely facilitated if the devices can be cheap enough for ordinary customers. Thus it has been witnessed that, strategic partnerships between mobile operators and domestic terminal producers as well as chip makers are widely established. For example, started from May 2009, China Telecom has cooperated with a Taiwan-based chipmaker – VIA Telecom in designing, producing and retailing of CDMA2000 devices (EnfoDesk, 2013). Besides, as the world's only operator of providing TD-SCDMA services, China Mobile even allocated 600 million RMB fund to terminal producers and chipmakers to encourage them to develop TD-SCDMA-based chips and devices (ChinaMobile, 2014).

Handset manufacturers and dealers

Similar as network equipment producers, domestic handset manufacturers also started to expand and capable to compete with foreign firms in the market after domestic mobile standard was launched. Unlike in the 2G era, there is no interaction between mobile operators and handset manufacturers, all three mobile operators in the 3G era started to establish collaborations with handset manufacturers. They were witnessed to adopt the strategy of collective procuring handsets from manufacturers, then customizing handsets with their own 3G services, and at last reselling customized handsets to mobile handsets dealers, or just directly to their customers (Chen and Zhang, 2011). A new customer normally can get a 3G handset for free if signed the fixed contract with an operator, or can enjoy a price reduction when using 3G services if he buys the designated handset from the operator (EnfoDesk, 2013).

Mobile operators' handsets procuring, customizing, and retailing have fundamentally reshaped the relationships between operators, handsets manufacturers and handsets dealers. In the 3G era, they both compete and collaborate with each other. For each of mobile operators, three types of sales channels are identified: sale by themselves in their own business halls, or via physical stores, or online stores. In their own business halls, customers could both buy handsets and deal with mobile services; physical stores sale both handsets and mobile services packages authorized by operators, and the handsets as well as service packages, could be any operator's or even unlocked; online stores only sell handsets, could be both operator customized or not, but buyers must subscribe 3G services at the carriers' business halls (Hu et al., 2012, EnfoDesk, 2013).

Therefore, after 3G launched, mobile handsets producing and retailing are no longer purely related with the products, but the quality of mobile services and the influence of mobile operators also matters. Holding partially business in producing mobile handsets, ZTE is the only GSE in handsets manufacturer group, but not the only domestic one. China's huge telecommunication market is not only valued by domestic manufacturers such as Lenovo, Huawei and ZTE, but also attracts great interests from international giants such as Apple, Nokia and Samsung. Many large forces in the market have already established strategic partnerships with China's mobile operators and domestic dealers.

In terms of dealers, no physical or online store is state owned. They are increasingly emphasized by the three mobile operators, as China Mobile, China Unicom and China Telecom are all witnessed to build strategic partnerships with Gome and Suning, who are the two mostly influential dealers in China. Therefore, similar as relationships between government authorities and chipmakers, despite of general market supervision by authorities like the NDRC, MOF and SAIC, few direct interactions exists between government authorities with handsets manufacturers and dealers.

Service providers and content providers

Due to broader bandwidth and faster speed of data transmission, more diversified mobile services and multi-media contents as well as dazzling applications, such as mobile payments, instant messaging and microblogging, are all enabled by the 3G and later mobile wireless systems. So far, in China, the 3G and 4G services are mostly adopted in individual level communication and entertainment, while the business level adoption and commercialization are quite fall behind. Insufficient speed, less diversified services and devices, and expensive costs have been recognized as reasons for the lag (CNNIC, 2013). Nevertheless, the emergence of 3G services have still reshaped and intensified the linkages among participated firms. For example, being aware of the core position of smart phones and pads, many content providers start to produce handsets that bundled with their own services, such as HTC, Baidu and LeTV. Besides, some content providers also cooperated with manufacturers to preinstall their services or applications in customized handsets, such as Sina Weibo, QQ IM, Wechat, Taobao, etc.

Cross-disciplines cooperation between different participants and their integrations in the mobile wireless systems have enabled the 3G and 4G customers to enjoy more and more diversified contents, as well as convenient services such as mobile banking and shopping, which to large extent have promoted the adoption of 3G and 4G standards in China (Fan, 2006, Stewart et al., 2011, Chen and Zhang, 2011). Therefore, as the figure demonstrated, services and contents providers, as well as application providers connect closely with mobile operators and customers; for those contents and services providers who want to preinstall or run their applications in customized handsets, they also cooperate with handsets manufactures and dealers through application providers as well.

At last, both content providers and application providers are under the supervision of SARFT, who regulates contents as prior introduced. Apart from some state-owned media playing as the content providers, most of content and application providers are not GSEs, which means they just comply with general market supervisions in their own fields. Thus in the figure, no direct linkage is delineated between government and them. In terms of service providers, a number of them are the authorities that provide public services, like online banking. Therefore, despite of identities for some of GSEs in this group, most of services that they provide are normally administrated and supervised by government authorities like the NDRC, MIIT, MOF, SAIC and CSRC, etc. which means interactions between services providers and the government authorities are more direct.

Customers

Customers always play as the core driving force for the development of telecom market, and the penetration of network and the loyalty of customers are the key indicators for analyzing every telecom market in the world (Zhang and Liang, 2011, Tilson, 2008, Jarvenpaa and Loebbecke, 2009, Henten et al., 2004). Due to late adoption of 3G services, the absolute level of network penetration rate in China is lower than other 3G adopted nations, but the rate of growth is remarkably high (CNNIC, 2013).

There are several characteristics of Chinese 3G and 4G customers that distinguish the China's 3G and 4G markets with others. Firstly, the huge base of mobile subscribers is the foundation that no other market can be compared with. Secondly, Chinese customers have different consumption habits, and to some extent these differences have been magnified by 3G and 4G adoption. For example, the most obvious different is Chinese customers are less willing to pay for contents and applications (Siu et al., 2006). As indicated by CNNIC (2013), more than 80% of 3G subscribers in China did not purchase any applications or contents in the second half of 2011. Third, as Kshetri et al. (2011) indicated, China's telecom market generally lacks of focus on subscribers, and they have little influential powers on the telecom related policy-makings.

So far, associating with the relationship figure that we delineated at the beginning of this section, different groups of key participators, including their roles and interactions with each others are all briefly elaborated. As a summary, we generate the major roles and activities of key actors in China's telecommunication market in the Table 6.7, which not only aimed to provide an overall picture about how the market is structured, but also to facilitate further discussions especially when any specific group or firm is mentioned. The review of market structure about telecommunication industry after the 3G launched in China, has substantially confirmed the industry is keep on transforming towards full competition. The market has gradually entered the rapid growth track, as participants are increasingly diversified and competent, and more and more new 3G/4G services are becoming available and abundant, which have jointly led to a high growth rate of 3G and 4G subscribers and terminal penetrations (Hu et al., 2012).

Table 6.7 Key actors in China's telecommunication industry

Key actors	**Roles and Activities**	**Representatives**
Mobile operators	Operate mobile networks (2G, 3G and 4G), provide telecom services (basic and add-ons), and perform as a platform linking all groups of actors in the industry.	China Mobile, China Unicom, China Telecom
Government authorities	General regulation and industrial development Price regulation Content supervision GSEs administration and state-assets supervision Unfair Competition and monopoly regulation Nominate and evaluate GSEs executives Market concentration regulation	MIIT NDRC SARFT SASAC SAIC Dept. of Organization MOC
Network equipment producers	Provide network equipment for TD-SCDMA Provide network equipment for WCDMA Provide network equipment for CDMA2000 Provide network equipment for TD-LTE Provide network equipment for FDD-LTE	Datang, ZTE, Huawei Huawei, Ericsson, ZTE Huawei, Alcatel, ZTE Huawei, ZTE, Ericsson Huawei, ZTE, Alcatel, Ericsson
Chipmakers	Provide chips for TD-SCDMA Provide chips for WCDMA Provide chips for CDMA2000 Provide chips for TD-LTE Provide chips for FDD-LTE	Datang, MTK Qualcomm, Ericsson, Infineon Qualcomm and VIT MTK, Datang, Spreadtrum, VIT Qualcomm, MTK, Marvell, HiSilicon
Handsets manufacturers	Produce mobile handsets for different networks, and some of them establish and install application stores in their own brand devices	Huawei, ZTE, Lenovo, Apple, Rim, Nokia, Samsung, Coolpad, Xiaomi, Lephone, Chuizi, Meizu
Handsets dealers	Retailing. Sell mobile handsets to customers, including both unlocked devices and mobile operators' customized handsets and other devices.	Gome, Suning, Jingdong, Dixintong, 360buy, P2P online stores in Taobao, Tianmao, etc.
Services providers, content/application providers	Mobile Instant Messaging Mobile Social Networks (including Microblogging) Mobile Payment and Digital Wallet Mobile Shopping Mobile Television and online video	Tencent, China Mobile Tencent, RenRen, Kaixin, Sina Unionpay, Commercial Banks Alibaba, Amazon, Jingdong Yuntu TV, LeTV, Aiqiyi, Sohu
Customers	Buy mobile devices and subscribe to 3G and 4G networks	N/A

Source: summarized by the author

6.4 SUMMARY

Through understanding the backgrounds of the TD-SCDMA and TD-LTE innovation, some characteristics of the technologies and China's telecommunication industry were revealed. Firstly, through reviewing the historical evolution of mobile technology, we found TD-SCDMA is a path-breaking technology, and TD-LTE could be viewed as a path-dependent one.

Secondly, evolving with the national S&T policy, China's NIS and its determined national innovation policy also evolved, and demonstrated different features in different phase of S&T policy evolution. The two innovation cases took places at the most recent phase, in which indigenous technology innovation is emphasized. Accordingly, the NIS was featured as strongly centralized under the government control, and policies, strategies and reforms in terms of designing and implementing are still mainly led by the central government authorities (Liu and White, 2001, Motohashi and Yun, 2007, Liu et al., 2011). Along with addressing the deficiencies what in NIS, the national innovation policy in this phase was mainly to satisfy the target of promoting indigenous innovation, and is featured for example: policies are not just designed and implemented throughout by a top-bottom approach, more influences are made by private sector stakeholders (Liu and Cheng, 2014); the evaluation and award mechanisms in terms of fostering innovations have been systematically reestablished (Liu and Cheng, 2014, Zhu, 2014, OECD, 2015a); soft environment for innovation are gradually considered as significant as building the physical R&D infrastructures, as more efforts in establishing the innovation friendly environment and cultivating the social capabilities for innovation are taken (Kwak et al., 2012, Vialle et al., 2012, OECD, 2015b).

Thirdly, as to China's telecommunication in specific, It is found that the government is interested in advancing the industry through promoting indigenous technology innovation, as it could also facilitate the economy development and enhance the competitiveness. Nevertheless, the intense confliction of bureaucratic interests among various government authorities and interests groups also resulting in an asymmetric and complex environment for China's telecommunication industry. In the history of industry development, five times major structural reforms were observed. Both supervisory architecture and marketplace competitions were affected. As Gao et al. (2013) summarized, the regulatory regime of China's telecommunication has shifted from *fragmented* and *centralized* towards *coherent* and *decentralized*; meanwhile, the marketplace have shifted from *monopoly* to *competition*.

In this chapter, through reviewing the history of mobile technology evolution and illustrating the telecommunication backgrounds in China, both technological and social backgrounds of TD-SCDMA and TD-LTE mobile system innovations are elaborated. Associating with the backgrounds, in the next chapter, we particularly focus on understanding how TD-SCDMA and TD-LTE innovation in China were achieved.

CHAPTER 7: CASE STUDY OF 3G TD-SCDMA MOBILE SYSTEM INNOVATION IN CHINA

7.1 INTRODUCTION

Drawing upon the developed theoretical framework, this chapter presents the case study of China's 3G TD-SCDMA development and diffusion to understand how the government intervened in TD-SCDMA innovation system to promote the innovation. Specifically, section 7.2 summarizes the development and diffusion process of TD-SCDMA; section 7.3 delineates structure of TD-SCDMA innovation system, including the institutional environment and key system actors; section 7.4 elaborates how system functioned to produce the innovation along with the process of innovation, the challenges that hindered the system functions are identified and how the government intervened to address the identified challenges are illustrated; section 7.5 assesses the performance of TD-SCDMA innovation system in both technology development and diffusion stage; section 7.6 concludes this chapter at the end.

7.2 TD-SCDMA INNOVATION PROCESS

China has adopted a national policy of promoting indigenous technology innovation after completing the reform of its S&T system. Apart from security considerations, to foster indigenous innovation capabilities was also a significant concern, as paying high rate of IPR payment with highly technology dependence on foreign firms had largely constrain the development of domestic high-tech industries. Therefore, when the global telecommunication market was quickly expanding in the mid-1990s, China decided to develop its home-grown mobile technology with strong national support.

The Chinese 3G TD-SCDMA, as one of three international third generation mobile wireless system, was authorized by ITU in May 2000 and accepted by the 3GPP in March 2001. Before TD-SCDMA, TDD based technology was never applied in the wide area, and FDD was recognized as the only suitable solution. In fact, in the 2G era, FDD based mobile systems were extremely success, like GSM and CDMA (IS-95). Nevertheless, in the 3G era, data services became more and more significant, which to some extent has revealed some deficiencies of FDD systems due to the efficiency of spectrum utilization and the convenience of signal transmitting. TDD technology is capable to deal with the deficiencies in FDD system, however its key fatal challenge has always been deploying in wide areas. This fatal challenge for TDD system was solved by introducing the novel technology of smart antenna and uplink synchronization.

The first time large commercial scale deployment of TD-SCDMA in China also confirmed the feasibility of TDD system. Before understanding the TIS of TD-SCDMA and government intervention during its process of innovation, we first delineate the process of TD-SCDMA innovation by following the sequential stages of technology development and diffusion. The key events that composed the chronology of TD-SCDMA innovation are summarized in Table 7.1.

Table 7.1 Innovation process of TD-SCDMA in China

Stages	Time	Key Innovation Events
TD-SCDMA Development *(Mid-1990s to May 2000)*	Mid-1990s	CATT was ordered to explore 3G technologies.
	March 1995	Xinwei was formed as a joint venture of CATT and Cwill owning the SCDMA scheme of smart antenna technology. MPT allocated 20 million RMB as support.
	April 1997	ITU started to call for candidate proposals for 3G mobile standards
	July 1997	The 3G Transmission Technology Assessment and Coordination Group (TTACG) was formed by MPT responsible for selecting signal transmission solutions.
	Nov. 1997	Siemens jointed in with its TD duplex signal transmission method.
	Jan. 1998	Xiangshan Mountain Meeting was held to discuss how to respond for ITU's call. The proposal submitted by Datang was approved.
	April 1998	3G R&D Team for drafting China's proposal of 3G standard was set up.
	June 1998	CATT submitted TD-SCDMA as the Chinese 3G standard proposal to ITU.
	July 1999	CATT was constructed to Datang Telecom. CCSA joint 3GPP.
	Nov. 1999	TD-SCDMA was adopted by ITU from 16 proposals for further evaluation.
	May 2000	TD-SCDMA was formally accepted by ITU as an international 3G standard.
TD-SCDMA Diffusion *(Late 2000 to January 2009)*	Dec. 2000	Datang, Potevio and ZTE started small scale system test on TD-SCDMA.
	March 2001	TD-SCDMA was formally accepted by the 3GPP.
	Nov. 2001	Datang and Siemens signed agreement to collaborate on TD-SCDMA
	Feb. 2002	Datang formed Datang Mobile to speed up TD-SCDMA commercialization
	June 2002	The first version of TD-SCDMA system – Release 4 was finally completed.
	Oct. 2002	TD-SCDMA Industry Alliance (TDIA) was formed.
	Oct. 2002	MII allocated 3G operation spectrums giving privilege to TD-SCDMA (155 MHz).
	Nov. 2003	Datang transferred IPRs to other TDIA members with government compensation.
	Dec. 2003	The TD-SCDMA Promotion Group was formed by CATR
	Feb. 2004	MII launched TD-SCDMA R&D and Industrialization Program (TRIP) to subsidize domestic firms in their R&D with a budget of 708 million RMB.
	March 2005	China's government organized TD-SCDMA Industrialization Special Test (TIST) to verify commercial readiness of TD-SCDMA infrastructure and equipment
	Jan. 2006	MII published TD-SCDMA as a national standard.
	March 2007	Government requested China Mobile to operate TD-SCDMA commercial services during 2008 Beijing Olympic Games
	April 2007	China Mobile delivered TD-SCDMA based on pre-commercialized network.
	July 2008	China Mobile joined in TDIA.
	Aug. 2008	China Mobile provided TD-SCDMA services in 8 Olympic Games cities.
	Jan. 2009	3G operation licenses were issued to China Mobile

7.2.1 TD-SCDMA development process

The research and development of TD-SCDMA mobile system's key technologies was officially started in 1995. A former part of current MIIT – *The Ministry of Posts and Telecommunications (MPT)* ordered its affiliate *China Academy of Telecommunications Technology (CATT)* to lead the innovation of the third generation mobile wireless system. In 1995, as the first step towards developing China's home-grown 3G mobile system, Xinwei Telecom Technology Co., Ltd. was founded as a joint venture of CATT and Cwill under the arrangement of Zhou Huan – then the director of science and technology department of MPT.

Standing for "China wireless access", Cwill as a technology start-up company was initially formed by two Chinese engineers – Chen Wei (a project manager at Motorola Semiconductor Department) and Xu Guanghan (a lecturer in the University of Texas). The core technology that held by Cwill was named as *uplink synchronous technology* – an intelligent antenna technology, which could constitute a new technology – SCDMA (synchronous CDMA), when combined with the contemporary CDMA technology. The mission of Xinwei was to explore the possibility of incorporating SCDMA technology into a new 3G mobile system.

In April 1997, ITU officially started to call for proposals of the third generation mobile wireless standards. The Post & Telecom Research Institute viewed this as the opportunity to promote SCDMA technology into an international level. Several months later, in July, MPT formed the *3G Transmission Technology Assessment and Coordination Group (TTACG)* to response for selecting the best solution for signal transmission, which is another basic but significant module of a mobile wireless system. A breakthrough in selecting signal transmission was achieved due to the participation of Siemens, who brought the Time Division (TD) duplexing technology.

Initially, when EU enterprises started to invest into the R&D of 3G technology, Siemens had devoted its resources to develop TD duplexing technology for signal transmission. In the contemporary, most of EU technology vendors believed the 3G mobile system in EU would be a technology evolution derived from the current deployed 2G system – GSM, a frequency division based CDMA system (TV_S2)[14]. Therefore, unfortunately but also no surprisingly, Siemens' TD-CDMA was not accepted as the EU proposal in the voting by 41.5% against WCDMA's 58.5%. However, later this turned out to be a great opportunity for the development of Chinese 3G mobile system, as TD duplexing as signal transmission solution could perfectly match the SCDMA. In November 1997, Siemens was enrolled. So far, by combining TD duplexing and SCDMA multiplexing, Cwill and Siemens then had set up the basic blueprint for Chinese home-grown 3G standard.

In January 1998, the Xiangshan Meeting was held for discussing how to response to ITU's call for 3G proposals. Datang raised a TD Duplexing and SCDMA multiplexing based technical proposal for ITU submission. In the meeting, Datang demonstrated three convincing reasons: firstly, some data services would be supported better by TDD than FDD, especially in 3G era; secondly, by adopting TDD technologies like smart antenna, SCDMA could be more efficient in address issues especially when operating in unpaired spectrum; thirdly, as the largest developing and catching-up country, China should participate in international standardizations, and promoting indigenous standards in telecommunication would be a great opportunity due to its incomparable market (TV_D1). Supported by MII, the decision was made that China would submit a TDD and SCDMA based technical proposal to ITU based on the proposal raised by Datang.

Then in the subsequent months, Datang was busy on adjusting TD-SCDMA to meet the requirements issued by IMT-2000, including enhance the bandwidth from initial 0.5MHz to 1.25MHz (TV_D1). In April 1998, for better drafting Chinese 3G proposal, the R&D Team was formed by the CATT with composing of engineers and experts from several related research institutes, agencies and technology enterprises. The final draft of TD-SCDMA was finished and submitted to ITU by the CATT on behalf of the Chinese government at the end of June 1998, right before the deadline.

[14] TV_S2 is the code of interview. More details could be found in Appendix 9. Hereinafter is same.

Along with activities in ITU, close international cooperation related to submitted 3G proposals were also intensively taking places, one of the most significant events happened in this period was the founding of 3GPP in December 1998. 3GPP was founded by main international standards development organizations (SDOs), including ETSI from the EU, ATIS from the US, TTA from Korea, TTC and ARIB from Japan, and CCSA from China. According to the agreements when founding the organization, members in 3GPP would develop the related specifications if their proposals were adopted by the ITU. No matter the proposal would be approved or not at last, the consensus building for the adopted proposals would still keep on going during the evaluation process taken in the ITU (TV_HB).

When TD-SCDMA was first introduced in 3GPP, several workshops were conducted for evaluating this new comer. Based on the agreement, representatives from many MNEs and research institutes including Siemens, Ericsson, Nokia, Datang and CATR had taken part in the TD-SCDMA evaluation, and emphases were mostly put on the new technology – smart antenna and asymmetric spectrum utilization (RD_TR2). When TD-SCDMA started showing the possibility of accepting by the ITU as one of international 3G standards, a bifurcation happened between Datang and Xinwei at the end of 1999, the Datang decided to transfer the development of TD-SCDMA to the development group to Datang and switched most of the personnel from Post & Telecom Research institute to Datang Research Centre.

In 5th November 1999, TD-SCDMA was adopted by the ITU from 16 submitted 3G proposals. In May 2000, the ITU officially granted TD-SCDMA as one of the three international 3G standards, together with CDMA2000 backed by the US and WCDMA from the EU. After several rounds of testing and evaluation, TD-SCDMA was approved formally by 3GPP in March 2001. After intensive R&D, the first version of TD-SCDMA was finally achieved in June 2002, named as Release 4. In later versions from Release 5 to 11, several significant features of HSPA, HSPA+ and MU MIMO were introduced to enhance the performance of TD-SCDMA, and the Release 11 was the final version for later commercialization (RD_TR2). To illustrate the evolution process more intuitive, Figure 7.1 illustrates the milestones of TD-SCDMA standard evolution based on a year divided time line.

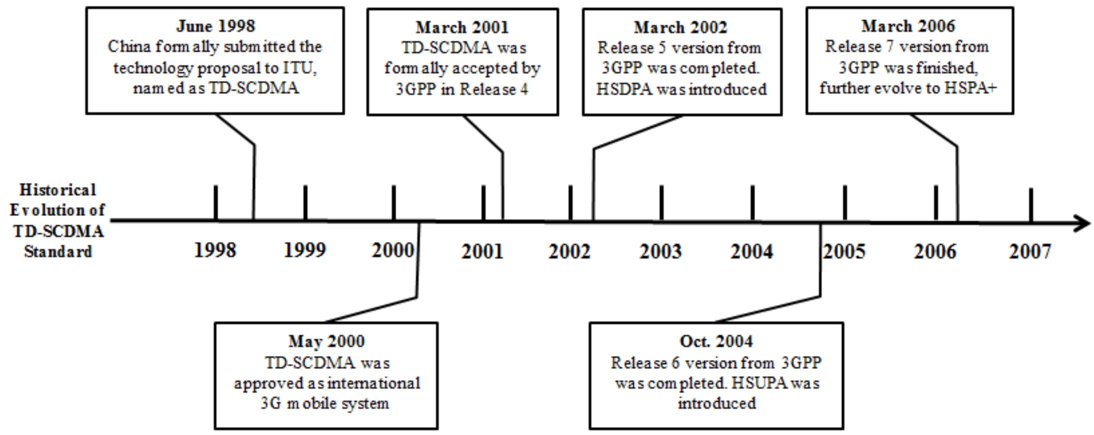

Figure 7.1 The evolution path for TD-SCDMA standard (Source: author illustrated based on *TDIA, 2013*)

7.2.2 TD-SCDMA diffusion process

The diffusion of a mobile wireless system standard normally enclose four sequential phases: phase 1 includes R&D on system equipment and mobile terminals; phase 2 includes field trials in limited scale; phase 3 includes large-scale network trials; and the last phase includes the deployment of commercial networks. From this perspective, the diffusion of TD-SCDMA system started from late 2000, when Datang, Potevio and ZTE carried out first round of system test on TD-SCDMA in December. Coincidently, as former elaborated, the MPT was reconstructed into the *Ministry of Information Industry (MII)* as one of the results of the fifth national governance system reform (Chen and Zhang, 2011). Then the MII restructured CATT to Datang Telecom, as MII believed that a state-control-enterprise would be more suitable and flexible in leading the TD-SCDMA diffusion if compared with CATT. Later in 2001, after TD-SCDMA was accepted by 3GPP, Datang and Siemens then established a cooperation partnership on commercializing TD-SCDMA.

Initially, although TD-SCDMA was authorized by the ITU as global standard, neither domestic nor foreign mobile operators, as well as technology vendors showed interests in investing into this Chinese home-grown technology. Facing a great uncertainty, most enterprises had put their emphases on WCDMA and CDMA2000, and took the strategy of “wait and see” in terms of TD-SCDMA (MO_CMB4; MO_CUB1; MO_CTB3). Therefore, facing such challenge situation, the government in China had decided to take every effort to promote this indigenous innovated mobile system. Datang as the owner and the pioneer of core TD-SCDMA technologies was assigned to take the leading role in promoting the diffusion of TD-SCDMA with government support (TV_D1).

In October 2002, with the leading of Datang, a significant industrial alliance – *TD-SCDMA Industry Alliance (TDIA)* was established by the MII. The main target of it was to promote the diffusion of TD-SCDMA (IA_TD2). TDIA gradually enrolled key actors not only from every single segment of the industrial value chain, including system equipment, testing instruments, terminals as well as chipsets, but also attracted more than 200 local technology vendors in supply chain. Its size has expanded tremendously, from the initial few leading companies like Datang, Huawei, Lenovo and ZTE to 90 members by the end of 2014, including both domestic firms and MNEs.

Also in October 2002, the MII issued Decree No.479, which allocated 155MHz asymmetrical frequencies in spectrum to TD-SCDMA. WCDMA and CDMA2000 each were allocated with 60MHz. This move had sent out a strong signal that Chinese government would have no hesitate in supporting indigenous innovated TD-SCDMA. Later on, in November 2003, the MII incited Datang Telecom to transfer its key TD-SCDMA IPRs to another two GSEs – Potevio and ZTE, which was aiming to accelerate the commercialization by transferring their R&D attentions from WCDMA and CDMA2000 to China's home-grown TD-SCDMA. To ensure the transfer could be finished quickly and smoothly, the government also assigned substantial financial compensation to Datang.

In December 2003, leaded by CATR, the TD-SCDMA Promotion Group was formed to create the roadmap for product development in almost every segment in value chain. The aim of doing this was to ensure the smooth coordination among participated firms towards TD-SCDMA diffusion. Similarly, in February 2004, MII also launched *TD-SCDMA R&D and Industrialization Program (TRIP)* to subsidize domestic enterprises to invest in TD-SCDMA R&D with a budget of 708 million RMB.

Later on, in March 2005, MIIT organized *TD-SCDMA Industrialization Special Test (TIST)* to verify commercial readiness of TD-SCDMA infrastructure and network. TDIA members leading by Datang Telecom, Potevio and ZTE then carried out several rounds of system test on TD-SCDMA. In January 2006, with the aim to persuade domestic firms to invest resources into TD-SCDMA rather than the other two systems, MII then issued the No.91 Decree to legitimize TD-SCDMA as a national 3G mobile system standard. Along with launching the No.91 Decree, in total 23 significant technology specifications were also published. In contrast, WCDMA and CDMA2000 were announced to be also adopted as the other two 3G systems in China nearly a year later.

However, even so, China Mobile and other operators, as well as technology vendors still reluctant to invest in TD-SCDMA. In the contrary, China Mobile started to deploy WCDMA networks in some big cities (MO_CMB4). In March 2007, the government requested China Mobile to operate TD-SCDMA commercial services during 2008 Beijing Olympic Games, in support of the national initiative of showing the newest technology achievements to the world. In April 2008, China Mobile delivered TD-SCDMA services based on the contemporary pre-commercialization networks in Beijing and other cities hosting the Beijing Olympic Games.

In January 2009, when the test results from pre-commercialization trials showed that the contemporary TD-SCDMA system based on available products could offer stable and high quality 3G services, China government then issued 3G licenses and officially kicked-off the Chinese 3G market. China Mobile as the contemporary largest mobile operator was granted a TD-SCDMA license, while its rivals China Unicom and China Telecom received licenses for WCDMA and CDMA2000, respectively (Stewart et al., 2011). After getting the license for TD-SCDMA, China Mobile then issued a R&D fund to subsidize the development the handsets, terminals, and network equipment to support TD-SCDMA, approximately about 20 million RMB per bid (MO_CMB2). By the end of 2014, the statistic record indicated that the subscriber number of TD-SCDMA has reached 230 million, taking nearly half of the mobile market in China at the contemporary.

7.3 STRUCTURE OF TD-SCDMA INNOVATION SYSTEM

7.3.1 TIS institutions: highly government controlled institutional environment

As Teece (1986) suggested, the success chance of a new technology increases if it is supported by the government. Chinese government has taken great efforts to support TD-SCDMA innovation through controlling the TIS institutional environment in a high degree and manipulating it into highly indigenous innovation favored. This was feasible and operable because in China, *"the law is marginalized and the legal system relegated to a lowly position in a spectrum of meditative mechanisms, while at the same time available for manipulation by powerful sectors within the state and the society at large"* (Myers, 1997, p.188). Affected in development and diffusion stage of TD-SCDMA, the TIS institutions were particularly emphasized from three dimensions, namely as regulative, normative and cognitive institutions, respectively.

Regulative institutions

As former introduced, regulative institutions normally composed by a serious of "explicit regulative processes", like rule setting, sanctioning and monitoring activities (Scott, 2001). Regulative institutions are capable to contribute to TD-SCDMA innovation as they could impact the future behaviors through building the rules, manipulating sanctions, and inspecting participators' conformity. In the TIS of TD-SCDMA, regulative institutions played a significant role to promote the technology in both development and diffusion stage, as they were highly controlled by the government and had been particularly manipulated into TD-SCDMA favored.

For example, at the early stage of TD-SCDMA development, the proposal raised from Datang was authorized as the only 3G mobile system standard that China was about to develop. In the diffusion stage, before TD-SCDMA commercialization, MII announced TD-SCDMA as the only national 3G standard in 2006, and issued the Decree No.479 to allocate bias spectrum to this domestic 3G standard. Comparatively, the other two

WCDMA and CDMA2000 each just got 60MHz. Moreover, also during the diffusion of TD-SCDMA, MII launched TRIP in 2004 to subsidize domestic enterprises to invest in TD-SCDMA with a huge budget, which had sent out a strong and clear signal to participators to demonstrate which standard is favored by the government.

Such kind of preferential regulative policies had no wonder well demonstrated the preference towards indigenous innovated TD-SCDMA, which to large extent, had created a well regulatory institutional environment for the technology to develop and diffuse. As Xu Guanhua, then the Minister of Science and Technology Ministry spoke during the commercial readiness test of TD-SCDMA in 2005:

> *"We will continue to support TD-SCDMA and encourage more and more firms both from home and abroad to join the development of the technology. Besides, we have full confidence in the business prospects of TD-SCDMA and will take every effort to support the commercialization of TD-SCDMA" (MOC, 2005).*

When being asked about why Chinese government was so intentionally to establish regulative institutions for promoting TD-SCDMA, an interviewee provided own insight through comparing the case of telecommunication catching-up in Korea (GA_NB1). Korean government adopted CDMA as its national standard for 2G mobile system and publically cooperated with leading MNEs such as Qualcomm and Nokia. It turned out that such industrial policy was successful, as it helped to establish linkages between Korean domestic operators, R&D institutes and technology vendors with international technology giants, and further to establish them in mobile technology. Previously, there was no Korean operator or manufacture had participated in 1G standardization and the contemporary existing 2G standards' development. However, through collaborating with Qualcomm and other MNEs, Korean operators and several domestic manufactures have been well developed and even participated in founding the *CDMA Development Group (CDG)*, which played leading roles later in promoting CDMA around the world.

The policy makers believed that the mode of China's technology innovation catching-up in telecommunication field could not only learn from the Korean' experience in 2G era, but also facing a chance to pursue a further achievement, which was to create a

Chinese indigenous innovated and high IPRs controlled international 3G mobile standard (GA_NB1). As the interviewee explained, the time itself was indeed a great opportunity for government to make decision, as when government decided to invest, it coincided with the change of mobile technology generation from 2G to 3G. It seemed easier to participate in establishing a new technology on the occasion when generation changing, rather than competing with established and matured technologies.

Besides, as another respondent complemented, within the telecommunication field, main industry participators such as mobile operators and equipment manufactures were mostly GSEs, which means the government could have a determining impact on the innovation. This could also significantly enhance the chance for TD-SCDMA to success as well (GA_NB3). Moreover, in terms of rationales for the government to support, the consideration of national security, national economic transition and technology dependencies were also mentioned as well (e.g. GA_M3; GA_NF; UN_BU1; RD_S1).

Normative institutions

Apart from promoted by regulative institutions, TD-SCDMA as the first China indigenous innovated also favored by high degree of normative institutions as well. As former elaborated, normative institutions, including both values and norms generally introduce a prescriptive, evaluative and obligatory dimension into social life (Scott, 2001). In short, normative institutions help to both define objectives and designate ways to achieve such objectives. In TD-SCDMA innovation, such normative institutions originated mostly from the sense of *"national pride"*, which was believed can be significantly enhanced if China could be a leader or a representative in such a high tech area, and get rid of technology dependency with foreign enterprises (GA_M2; RD_S1).

> *"…we cannot always relay on others' R&D results to enhance our own capabilities in science and technology, let alone always follow the technology frontiers. We have no other choices but to strongly support our own indigenous technology innovation…" (GA_M2)*

Nevertheless, such kind of normative institutions to some extent could be owed to the intentionally publicity and establishment by the government in China. For example, selecting Beijing Olympic Games as the time to launch the 3G TD-SCDMA services is a typical case that well worth to ponder. As a MIIT interviewee suggested, the government, especially the leaders are always expecting to achieve a more technology-orientated national economy, which might also increase its respect at the same time. Therefore, when holding the Beijing Olympic Games in 2008, even the TD-SCDMA mobile system had not been commercially operated in large scale, the government still pushed China Mobile to launch TD-SCDMA services during such an international mega-events, as the government had recognized this mega-events as a great opportunity to brand, or to demonstrate the newest national achievement in technology (GA_M3).

Despite of intentionally showing the national technology achievement, there was also an interviewee indicated that launching immature TD-SCDMA system in Beijing Olympic Games was also a kind of compelling decision. This is because Olympic would attract many foreigners to Beijing and 3G services in contemporary was already available in most foreign countries, even if launching TD-SCDMA might not really increase the international image as the government "valued", but it was no doubt the image would be "harmed" if China could not provide 3G services during such mega-events as the Chinese Olympic committee previously promised (UN_BU1).

Cognitive institutions

Cognitive institutions are understood as the "shared conceptions that constitute the nature of social reality and the frames through which meaning is made" (Scott, 2001, p.57). Although cognitive perceptions are carried by individuals, they still maintain a social nature, which means cognitive institutions could be shaped and cultivated if the common shared social is involved (David and Steinmueller, 1994). Within the TIS of TD-SCDMA, cognitive institutions contributed to the technology mostly because of the so called *"national goals"* in China. TD-SCDMA innovation related national goals could be summarized mainly from two aspects, namely as the consideration of reducing the IPRs payments, and enhancing the national security, respectively.

In terms of IPRs payments, the outflow of royalties has always been a great concern during the high-tech development in China. The Chinese government, as well as the domestic firms no wonder expect to reverses such flow of fees. Meanwhile, they believe that a catching-up country like China, could not always be viewed as “the market” for developed nations. Although in the starting stage the huge market potential could be used as a leverage to import advanced technologies, at end of the day, China should develop its own high-techs and sell them into global markets (RD_S1; RD_TR1). For elaborating the perspective of supporting indigenous standardization in high-tech area, an interviewee also quoted and demonstrated that,

> *“Third-class enterprises sell products, the second-class sells technology, while the first-class sells standards. If in analogy to different classes of nations, the truth is still the same”. (GA_M3)*

The consideration of reducing IPRs payments as a cognitive institution has facilitated the TD-SCDMA innovation significantly, as the participants have all shared common beliefs in terms of the IPRs issues. As interviewees have indicated that,

> *“If we adopt foreign standards in 3G, then the technology no wonder is controlled by foreign firms, manufactures for example. However, if we have and use our own standard, like TD-SCDMA, then our domestic firms could control the technology by themselves, which means as least they are at the same level when competing with oversea manufactures”. (IA_TD1)*

> *“TD-SCDMA will play a significant role in promoting the development of entire Chinese telecommunication industry…Chinese enterprises normally have to pay 20-40% of the price of every phone or other devices to over sea IPRs holder, among which, the patent licensing could take 3% of the prices”.(TV_Z2)*

As a result, Chinese enterprises have controlled most of TD-SCDMA IPRs, and they also supplied most of infrastructures, terminals, and other system components. For example, according to the annual report of China Mobile in 2010, the company had subsidized TD-SCDMA handset orders to 19 technology vendors in total, in which the domestic vendors had taken 85% of the overall amount (ChinaMobile, 2010).

Apart from the IPRs considerations, cognitive institutions within the TIS of TD-SCDMA also motivated the innovation from the perspective of enhancing the national security, which identified by a high-level interviewee including both economic security and military security (GA_NB1). Economic security would be severely threatened if China played as a purely high-tech importer and a simply high-tech consumer. Besides, military security was also a major consideration for Chinese government to promote indigenous innovation in high-tech section. If TD-SCDMA had not been developed, then there was no China controlled 3G mobile system could be relied. Nevertheless, when government agencies want to use certain advanced 3G services, the imported software, hardware as well as operating systems would become significant leaks for the national security then (ibid.). The considerations of military security were also involved in other interviews, for example, interviewees from government agencies indicated:

> *"...high tech has become essential to current national defense, especially preventing the attacks from networks...the western countries now are putting more and more emphasizes on developing high-tech weapons, as you see now they have been widely adopted in actual battles already". (GA_M2)*

> *"...if we cannot control the technology in key areas by our own, we can hardly control the initiative of competition and development, and even cannot ensure the national security in economy." (GA_M1)*

To bridge the potential leaks towards national security, in 2004, Datang installed Linux operating system for the 3G TD-SCDMA devices purchased by the government, as the Linux system could protect entities from attacks by hackers (TV_D1). Thus, as we summarized at the beginning, the institutions within the TIS including regulative, normative and cognitive institutions were highly government controlled and had jointly motivated the development and diffusion of the favored TD-SCDMA mobile system.

7.3.2 TIS actors: heterogeneous actors in highly GSEs centred innovation system

The innovation system of TD-SCDMA was constituted by several groups of actors. They jointly undertook the process of innovation but with heterogeneous interests, resources and capabilities in innovation. They both cooperated and competed with each other during the development and diffusion of TD-SCDMA. Just to be clarified in advance, government authorities such as MIIT, NDRC and SASAC had obviously played significant roles in the TD-SCDMA innovation, but they were not the innovation undertakers and thus were recognized as the components of the regulatory system, but not as the TIS actors (see figure 4.1 and figure 6.4). Similarly, as significant components of the demand side of value chain, the application providers, content/service providers, as well the services users were located mostly in the market place, rather than learning as TIS components (see figure 4.1 and figure 6.5). Categorized with different roles, key TIS actors in different groups and the key activities of each group in TD-SCDMA innovation are summarized in Table 7.2.

Table 7.2 Key actors in TD-SCDMA innovation system

Groups	Key Actors	Roles and Activities
Mobile operators	• GSEs: China Mobile	• Operate mobile networks (GSM & TD-SCDMA) • Provide basic and advanced telecom services • Perform as a platform linking all groups of actors
Technology Vendors	• Chipsets: Datang; Spreadtrum; CYIT; RDA • Networks: Huawei; ZTE; Potevio; Ericsson; Siemens; Nokia; Alcatel; Cwill; Xinwei • Devices: Huawei; ZTE; Lenovo	• Participate in developing TD-SCDMA standard • Conduct R&D on TD-SCDMA system components • Provide network equipment, chipsets, terminals and handsets for TD-SCDMA mobile system
R&D Institutes	• PRIs: CATT; CATR; CAS; CAE • Firm-based: ZTE; Datang; Huawei; Potevio; Xinwei; Siemens	• Conduct R&D to develop TD-SCDMA standard • Conduct R&D on TD-SCDMA system components • Conduct research on TD-SCDMA related policies
Industrial Alliances	• TDIA: Datang, Huawei, ZTE, Lenovo, Potevio, T3G, Samsung, Philips, Motorola • 3GPP: Siemens; Ericsson; Nokia, Datang; CATR	• Conducted R&D and test on TD-SCDMA • Promote R&D on TD-SCDMA system components • Facilitate the diffusion of TD-SCDMA standard • Conduct research on TD-SCDMA related policies

According to different roles that played, actors in the TD-SCDMA innovation system could be categorized as the *R&D institutions, Universities, mobile operators, technology vendors and industrial alliances*. Despite of composing by heterogeneous actors, another feature of TD-SCDMA innovation system was that the leading actors in each group are most likely the GSEs. The high degree of state involvement in domestic economy, to largest extent, had ensured there was at least one GSE locating in the leading position in every single segment along the value chain of telecommunication industry. The government impacted the TIS actors and their behaviors to coordinate and balance varied interests, resources and capabilities to promote TD-SCDMA innovation in both development and diffusion stages.

In terms of TD-SCDMA development, technology vendors and R&D institutes, including both PRIs and firm-based, had jointly played significant roles to response for the R&D and producing system components such as chipsets, handsets, terminals, antennas, basic infrastructures, as well as system testing instruments. These vendors included both domestic telecommunication enterprises and foreign ones (MNEs). Domestic firms included both GSEs and private ones, and the most common form for MNEs to participate in China's indigenous innovation was to establish the joint ventures (JV) with the domestic Chinese enterprises.

Actually, due to the saturated situation of the mobile market in the EU and the US, the telecommunication MNEs were quite active in participating in pushing China's 3G schedule, as China was holding the largest mobile market in the world and even if a slight slice of the cake (market share) was still attractive enough for them. For example, Huawei established a JV with Siemens in 2004 to focus on the R&D, producing and marketing of TD-SCDMA technology, Siemens held 51% and Huawei held 49% of share, with the total investment of 1 million USD (Sina, 2004). Potevio also established a JV with Nokia in 2006 to response for the construction of TD-SCDMA base stations, 150 billion USD was invested with Potevio and Nokia held 51% and 49% of share, respectively (Xinhua, 2006). Many similar joint ventures for investing in TD-SCDMA could be observed, such as Ericsson and ZTE, Alcatel and Datang, NEC and Torch, etc.

No wonder, not all domestic vendors and MNEs were looking to further increase of TD-SCDMA; in contrast, most of them were interested in investing to the other two standards – WCDMA and CDMA2000 in contemporary.

Despite of participating in developing the TD-SCDMA, many R&D institutes and technology vendors were active in promoting the diffusion of the technology as well. In terms of TD-SCDMA diffusion, the other two groups of TIS actors were also significant in pushing the domestic 3G standard – the mobile operators and the industrial alliances. Unlike technology vendors, only three Chinese mobile operators in the 3G era were allowed to run mobile services, known as China Mobile, China Unicom and China Telecom. No foreign mobile operator was allowed to operating mobile system in Mainland China. As former introduced, China Mobile was assigned to operate TD-SCDMA system, while the Unicom and the Telecom was issued with WCDMA and CDMA2000 licenses, respectively. TD-SCDMA Industrial Alliances (TDIA) leaded by Datang was established by then the MII, which was the most significant industrial alliance responsible for promoting the diffusion of TD-SCDMA.

Neither mobile operators nor industrial alliances had participated in the development of TD-SCDMA, as they both started to function in the diffusion stage. In addition, China Mobile, China Unicom and China Telecom are all GSEs, and the Chinese government plays as a full controlling shareholder of these “big three”, gave them licenses, located spectrums, and offered support both directly and indirectly. In market, each of them has its own alliance network with R&D institutes, service sub-providers, technology vendors as well as handsets dealers. As introduced, these technology vendors could be either domestic firms or MNEs, apart from foreign mobile operators are prohibited to entry Chinese telecommunication market to run the network, there is no obvious limitation in the sub-service and equipment field. Therefore, to some extent, such kind of GSEs mobile operator centred structure not only ensured the absolutely government control in the domestic telecommunication industry, but also promoted the globalization of TD-SCDMA due to the international cooperation in terms of technology R&D and manufacturing.

7.4 TD-SCDMA INNOVATION SYSTEM FUNCTIONS, CHALLENGES AND GOVERNMENT INTERVENTIONS

Seeking legitimacies for ensuring long-term survives, innovation system actors play different roles and thus a serious of innovation activities is achieved. As introduced, the system actors' activities that capable to impact the innovation goals, no matter positive or negative, are recognized as the system functions (Johnson, 1999). Therefore, based on the captured TIS institutional environment and actors, in this section we interpret how TIS contributed to TD-SCDMA development and diffusion through undertaking seven system functions, namely *knowledge development, knowledge diffusion, entrepreneurial experimentation, research guidance, resource mobilization, market formation* and *legitimation*, respectively (Hekkert et al., 2007).

Achieving the TIS functions need to use and coordinate a variety of resources and capabilities (Chaminade et al., 2009). Nevertheless, as introduced, of different system actors, they normally hold different interests towards innovation, and control different resources and capabilities (Chaminade and Edquist, 2010, Samara et al., 2012). This could become challenges to the achievement of TIS functions, thereby hinders the success of innovation (Bergek et al., 2008). Furthermore, challenges could also arise due to deficiencies in resources or capabilities that required (Gao, 2015). Therefore, when understanding how each TIS function is achieved, in this section we also pay attention on identifying the challenges that faced in TD-SCDMA innovation.

To ensure the success of TD-SCDMA innovation, several government interventions were taken to address the challenges that identified. It was observed that, most of the TIS functions were impacted by the strong government interventions through influencing, or even manipulating, the TIS components in different innovation stages. Drawing upon the developed framework, the TIS functions along with TD-SCDMA development and diffusion, challenges faced in TIS functions in each stage, and the relevant government interventions are summarized in the Table 7.3 as followed.

Table 7.3 TIS challenges and government interventions in TD-SCDMA innovation

<table>
<tr><th>Innovation Stages</th><th>TD-SCDMA Development</th><th>TD-SCDMA Diffusion</th></tr>
<tr><td>Challenges in TIS functions</td><td><u>Knowledge development</u>
• Develop a 3G standard within the time schedule requested by ITU
<u>Knowledge diffusion</u>
• Lacking of matured R&D networks
<u>Research guidance</u>
• Chose innovation path for Chinese 3G
• Reverse negative expectations on indigenous introduced 3G TD-SCDMA
<u>Entrepreneurial experiments</u>
• Reduce high uncertainty in perceptions
• Select surrogates to lead R&D activities
<u>Resource mobilization</u>
• Weak R&D capability in contemporary
• Lacking of experts in R&D</td><td><u>Entrepreneurial experiments</u>
• Reduce high uncertainty in perceptions for TD-SCDMA to succeed in market
• Select a surrogate to lead test and diffusion
<u>Resource mobilization</u>
• Few domestic and foreign firms are interested to invest in TD-SCDMA
<u>Market formation</u>
• Persuade 2G users to upgrade to 3G
• Select a surrogate to operate TD-SCDMA
• Persuade vendors to invest in TD-SCDMA
<u>Creating legitimacy</u>
• Establish comparative advantages for TD-SCDMA against the other two alternatives</td></tr>
<tr><td>Government interventions</td><td>Interventions on TIS Institutions
<u>Regulative</u>
• Path-breaking innovation was decided, as MPT ordered CATT to explore Chinese own 3G technology;
• Datang's TD-SCDMA proposal was recognized as national 3G innovation path
• Low rate primary loan and high rate VAT refund were granted to support the R&D of TD-SCDMA
• Publish technology specifications on R&D

Interventions on TIS Actors
<u>Regulative</u>
• MII-affiliate CATT was designated to lead standard development
• Cwill with SCDMA technology of intelligent antenna solution was selected
• Xinwei as a joint venture of CATT and Cwill focused on SCDMA development
• Siemens with TD technology in signal transmission method was selected
• Datang Telecom led TD-SCDMA R&D
• 3G R&D Team as a consortium drafting China's proposal of 3G standard
• CATT held dominant share in Xinwei and chaired 3G R&D Team being key actors in TD-SCDMA development
• Moved TD-SCDMA R&D group to Datang
• MPT spent 20 million RMB to support the formation of Xinwei, 1.3 billion RMB to Datang for TD-SCDMA development
• MII offered over 1 billion RMB fund and 2/3 normal commercial loan rate to support R&D on TD-SCDMA</td><td>Interventions on TIS Institutions
<u>Regulative</u>
• Preferential policies were granted to TD-SCDMA in allocating radio frequency, timing of granting national standard status and issuing 3G licenses
• Low rate primary loan and high rate VAT refund were granted to support TD-SCDMA
• Publish technology specifications
<u>Normative</u>
• Provide TD-SCDMA services during Beijing Olympic Games for national pride
<u>Cognitive</u>
• High level officials including Premier Minister voiced support to TD-SCDMA
• Publish technology specifications on R&D
• MII launched TRIP with 708 million RMB as the budget to subsidize domestic vendors
• Advocated reducing IPRs payments and enhancing national security as national goals

Interventions on TIS Actors
<u>Regulative</u>
• TDIA was formed with 25 members. It was an arena for firms to exchange concerns on 3G technology and market
• Foreign firms jointed in TD-SCDMA diffusion process independently and through forming joint ventures with GSEs
• Datang Telecom, Potevio and ZTE jointly were in charge of TD-SCDMA test and led TD-SCDMA industrialization
• China Mobile was assigned to operate TD-SCDMA in China
• IPRs were transferred from Datang Telecom to other TDIA members
• 38 billion RMB loan were offered to TD-SCDMA vendors with 2/3 normal loan rate</td></tr>
</table>

7.4.1 Knowledge development

Knowledge development is the fundamental function of the TIS and contributed to the TD-SCDMA innovation basically in the development stage. The function was undertaken mainly by the public R&D institutes and several technology firms. The research and development of key technologies for TD-SCDMA was officially started in 1995. In contemporary, mainly two severe challenges were faced: one is lacking of sufficient capable R&D actors; the other is the deficiency in time to develop a new 3G standard before the deadline that was set by the ITU. As recalled by an interviewee:

> *"Initially, relatively small scale R&D networks were established, and few boundary-cross interactions between actors in the R&D group and the others were observed. In the contemporary, honestly, we did not have the foundation of developing such a complex technology system, as we neither had enough experiences nor capable R&D institutes. Needless to say we only had three years to finish it." (TV_D1)*

To address such severe challenges that faced, China's government had taken strong regulative interventions like directives to TIS actors, especially to the public R&D institutes and the relevant GSEs. Besides, when specific deficiencies were faced, such as lacking of capable actors to undertake the innovation, the government also took regulative instruments like tax relief and subsidy to change TIS institutions to "invite" the useful actors; or issued directives and funding to "establish" the needed actors.

For example, at the very beginning, MPT ordered its affiliate CATT to lead the standardization of the third generation mobile system. Xinwei was founded in 1995 as a joint venture of CATT and Cwill with aim to integrate the uplink synchronous technology to constitute the SCDMA. Similarly, in July 1997, MPT formed the TTACG to response for selecting the best solution for signal transmission. Besides, the enrollment of Siemens in 1997 by CATT brought the Time Division (TD) duplexing technology. Datang, founded by CATT, were taking the lead in this R&D project and raised a TD Duplexing and SCDMA multiplexing based technical proposal for ITU submission. Furthermore, for better drafting Chinese 3G proposal, the R&D Team was formed by the CATT (TV_D1).

7.4.2 Knowledge diffusion

Knowledge diffusion is another fundamental function of the TIS and contributed to the TD-SCDMA innovation in both development and diffusion stage. The function contributed in TD-SCDMA development stage because the TIS helped spread the new technological concept to potential adopters and they might keep on working to perfect the initial versions of TD-SCDMA standard. In addition, the function also contributed in TD-SCDMA diffusion because these participators in revision and perfecting the initial versions may include the potential technology vendors who might produce TD-SCDMA based products like chipsets and handsets.

The function of knowledge diffusion was collectively undertaken by R&D institutes and influential industrial associations in the TD-SCDMA innovation, and was achieved, or facilitated by the interactions between enrolled actors and the established both formal and informal networks. The primary challenge was few R&D networks existed to perfect and to diffuse TD-SCDMA. To address this challenge, China's government took regulative interventions including directives and subsidies directly to support TIS actors to diffuse TD-SCDMA knowledge into established and influential R&D networks in global, and at the same time inviting more actors and establishing own R&D networks.

For example, several workshops were conducted when TD-SCDMA was first introduced in 3GPP by CATR and Datang with the support of the government. Based on the agreement in 3GPP, representatives from many MNEs and research institutes including Siemens, Ericsson, Nokia, Datang and CATR had taken part in the TD-SCDMA evaluation (RD_TR2). Being recognized and accepted by these international influential organizations had significantly increased the chance that TD-SCDMA to be authorized by ITU as international 3G mobile standard (UN_BE). Besides, at the end of 1999, Datang transferred the development of TD-SCDMA to the development group to Datang and switched most of the personnel from Post & Telecom Research institute to Datang Research Centre. Thus as observed, with the support from government, R&D networks were gradually established to facilitate the knowledge diffusion for TD-SCDMA.

7.4.3 Research guidance

Research guidance is another fundamental function of the TIS and contributed to the TD-SCDMA innovation in both development and diffusion stage. The function contributed to TD-SCDMA development because the TIS helped scoping the decisions on what is to be developed and how to develop; the function contributed to TD-SCDMA diffusion because the TIS helped establish positive expectations to affect the vendors and operators to invest in TD-SCDMA and produce TD-SCDMA based products or to offer TD-SCDMA based mobile services. The function was collectively undertaken by R&D institutes, influential industrial associations and powerful GSEs in China in terms of TD-SCDMA innovation.

Nevertheless, several severe challenges were faced to achieve this TIS function in both stages. For example, in the development stage, no China's domestic R&D institutes and firms had ever participated in developing 1G and 2G mobile systems, which means how to select innovation path for Chinese 3G. As recalled by the interviewees:

> *"…GSM and CdmaOne were two dominating 2G standards we used, so we really had a hard thought that if we do not take the derived 3G standards (WCDMA and CDMA2000), what would be the best choice to make a path-breaking, or a breakthrough, 3G technology by our own…" (GA_M3)*

In the diffusion stage, the expectations towards TD-SCDMA were mostly negative with few participators would like to invest in producing TD-SCDMA based products or providing TD-SCDMA based services at the beginning. As recalled by the interviewees:

> *…we neither held experience in developing international telecommunication standards, nor in deploying and commercializing such a complex system. Thus initially we indeed felt negative on its (TD-SCDMA) future…" (MO_CMB1)*

To address such severe challenges, it is observed that the government took strong regulative interventions to manipulate both TIS institutions and TIS actors. For example, aimed to address challenges in development stage, the government personally created the R&D networks by assigning CATT as the cornerstone actor to response for TD-SCDMA innovation. With full government authorities, CATT enrolled or created other key TIS actors and established the R&D network as former introduced. A typical event was that Xinwei received 20 million RMB ($2.5 million) from MPT when formed by CATT and Cwill, which to large extent had well stated the government support toward this domestic standard. Moreover, high level government officials also kept on voicing their supports to TD-SCDMA. As early as in January 1998, the Chief Scientist of MPT set the tune that China would develop and use its own 3G, as China couldn't rely on foreign technologies forever in constructing its infrastructure.

Furthermore, in terms of addressing challenges that faced in the diffusion stage, the government also took strong regulative interventions, such as directives, subsidies and bias industrial policy, to guide the research. For example, a special fund, as a part of national mobile projects and electronic development funds, was arranged by MII to support the R&D of TD-SCDMA. In total, over 1 billion RMB, and around 10 thousand technicians and researchers were invested. Besides, in December 2003, leaded by CATR, the TD-SCDMA Promotion Group was formed to create the roadmap for product development in almost every segment in value chain. The aim of doing this was to ensure the smooth coordination among participated firms towards TD-SCDMA diffusion. Similarly, in February 2004, MII also launched TD-SCDMA R&D and Industrialization Program (TRIP) to subsidize domestic enterprises to invest in TD-SCDMA R&D with a budget of 708 million RMB. In January 2006, with the aim to persuade domestic firms to invest resources into TD-SCDMA rather than the other two systems, MII then issued the No.91 Decree to legitimize TD-SCDMA as a national 3G mobile system standard (MIIT, 2006). Along with launching the No.91 Decree, in total 23 significant technology specifications were also published to guide the research on TD-SCDMA system.

7.4.4 Entrepreneurial experimentation

Entrepreneurial experimentation is a fundamental TIS function that contributed to the TD-SCDMA innovation mostly in the diffusion stage. TD-SCDMA as a completely new technology in nature involved a considerable degree of uncertainty both in technology and commercialization, the function of entrepreneurial experimentation contributed to TD-SCDMA diffusion with help to reduce these uncertainties. In the TD-SCDMA innovation, the entrepreneurial experimentations were mainly undertaken by GSEs in different industrial sector with strong government support.

The challenges that faced in achieving this function was also severe, as in terms of conducting entrepreneurial experiments, in the contemporary, high uncertainties for developing a Chinese indigenous 3G technology were perceived, and neither domestic firms nor MNEs were interested in being the pioneer to invest in TD-SCDMA. Facing a great uncertainty, most enterprises had put their emphases on WCDMA and CDMA2000, and took the strategy of "wait and see" in terms of TD-SCDMA (MO_CMB4; MO_CUB1; MO_CTB3). For example, interviewees explained why they were not active in investing in TD-SCDMA at the initial stage as:

> *"...government policy was not clear enough, and we certainly not confident about the future of TD-SCDMA, not just about the market, even about the technology itself...Huawei is a company, which means profits and surviving are most important, we have to listen to the market..." (TV_HB)*

> *"In fact, we all believed that WCDMA was the best solution for China Mobile to update into 3G system, as we already took incomparable market share in terms of mobile subscribers and GSM was adopted at that time. We did not want to face uncertainties, and we supposed that the TD-SCDMA system could be a complement if necessary..." (MO_CMB3)*

To address such severe challenges, China's government took strong regulative interventions like directives and subsidies to manipulate the TIS actors. For example, the government mandated its full controlled R&D institutes and GSEs to take the lead in conducting the entrepreneurial experimentations for TD-SCDMA. In late 2000, Datang, Potevio and ZTE carried out first round of system test on TD-SCDMA in December. Later, MPT was reorganized as MII and the MII restructured CATT to Datang Telecom, since MII believed that a SOE or a GSE would be more suitable and flexible in leading the TD-SCDMA diffusion if compared with CATT. Therefore, Datang as the owner and the pioneer of core TD-SCDMA technologies was assigned to take the leading role in promoting the diffusion of TD-SCDMA. Later in 2001, after TD-SCDMA was accepted by 3GPP, Datang and Siemens then established a cooperation partnership on commercializing TD-SCDMA. Furthermore, the products of ZTE and Potevio formed the core part of the pilot test network. The leading role of these GSEs created the so-called "penguin phenomena". Strong government supports, to large extent, had relieved the high uncertainty they were facing (TV_D1). Other firms then followed and started to invest in TD-SCDMA products.

7.4.5 Resource Mobilization

Resource mobilization is a fundamental TIS function that contributed to the TD-SCDMA innovation in both development and diffusion stage. The function was crucial as the success of innovation is heavily depending on whether the resources are available, or efficiently applied to core actors. In this case, the TIS played significant roles in mobilizing requested resources, such as financial capital, human capital and complementary assets to support the TIS actors to develop and to diffuse the TD-SCDMA. Function of mobilizing resources was mainly undertaken by the government authorities who had control or impact on resources allocations.

In the development stage, TD-SCDMA innovation normally faced the deficiencies in lacking of sufficient complementary assets and capable innovation undertakers such R&D capabilities and technology firms. Comparatively, in the diffusion stage, although the government in China held enough financial resources to support TD-SCDMA diffusion, most of them were state assets with very limited number of private capitals were interested to invest. To address these identified challenges in each stage, the government took strong regulative interventions, such as directives, subsidies and funds, not only to manipulate TIS actors, but also to affect the institutional environment in TIS.

For example, in the development stage, financially, Xinwei received 20 million RMB from MPT when established in 1995 (Marukawa, 2010); Datang was subsidized with at least 1.3 billion RMB for supporting TD-SCDMA development (Sina, 2006). Besides, to mobilize human capitals, CATT had transferred the development group of TD-SCDMA from Xinwei to Datang and switched most of the personnel from Post & Telecom Research institute to Datang Research Centre.

Similarly, in the diffusion stage, financially, the TRIP launched by MII was assigned with a budget of 708 million RMB to subsidize participating domestic firms for industrialization; national banks were asked to offer loans with privileged interest rates for TD-SCDMA related projects as well, like establishing pilot networks and conducting system tests. Taking Datang as example, the company alone received over 1.5 billion

RMB during 2005-2007; besides, direct financial subsidies on revenue had increased at an annual rate of around 40 million, which already excluded a high rated VAT refunds (TV_HS2). Similarly, other leading companies like China Mobile and ZTE, also received considerable amount of financial supports.

Moreover, aimed to motivate the key participators to invest in TD-SCDMA, MII arranged Datang Telecom to transfer core IPRs of TD-SCDMA to other key members in TDIA, especially to Potevio and ZTE. To ensure the transfer could be finished quickly and smoothly, the government also assigned substantial financial compensation to Datang. This move let broad ranges of TD-SCDMA stakeholders receive standard fundamentals so that they could invest in this technology. It helped forge trust among different technology players, motivating them to devote their resources to TD-SCDMA diffusion (Blind, 2004). As a senior manager in ZTE commented, this transfer enabled them to quickly approach the frontier of TD-SCDMA diffusion; ZTE started to treat TD-SCDMA as its own standard, and engaged 3,000 R&D staffs and other resources in its commercialization (TV_Z1).

Furthermore, as the most vital assets for telecommunication, the spectrum as a nonrenewable resource was also mobilized by the government to support TD-SCDMA with obvious preferential policies. For example, in October 2002, the MII issued Decree No.479, which allocated 155MHz asymmetrical frequencies in spectrum to TD-SCDMA. WCDMA and CDMA2000 each were allocated with 60MHz (MII, 2002). This move had sent out a strong signal that Chinese government would have no hesitate in supporting indigenous innovated TD-SCDMA.

7.4.6 Market formation

Market formation is a fundamental TIS function that contributed to the TD-SCDMA innovation in the diffusion stage. The function helped articulate the demands for potential customers and create competitive advantages. In the TD-SCDMA innovation, the activities of market formation were mainly undertaken by the GSEs in different industrial sector with strong government support.

In fact, several severe challenges were faced to form the TD-SCDMA market. For example, contemporary 2G subscribers did not facing the urgent need of using 3G services, since no 3G contents, services and even handsets were available in the contemporary market in China. Besides, even if 3G was needed, then convincing customers and industrial participators to select TD-SCDMA but not the other two matured alternatives was unlikely possible. Facing such a not optimistic circumstance, counting on the TIS itself to turn this situation around was also unlikely possible, thus it was observed that the government not only took strong regulative interventions on TIS actors, but also used regulative, normative and cognitive instruments to create and shape the institutional environments for TD-SCDMA market formation.

For example, then the most powerful operator – China Mobile was selected to operate TD-SCDMA and to take the lead in forming the market. Nevertheless, at the beginning, all the mobile operators and technology vendors were reluctant to invest in TD-SCDMA, including China Mobile. In the contrary, China Mobile had started to deploy WCDMA networks in some big cities (MO_CMB4). In March 2007, the government asked China Mobile to operate TD-SCDMA commercial services during 2008 Beijing Olympic Games, in support of the national initiative of showing the newest technology achievements to the world. As a typical GSE, China Mobile had no choices but to take the government order. Thus in April 2008, China Mobile delivered TD-SCDMA services based on the contemporary pre-commercialization networks in Beijing and other cities hosting the Beijing Olympic Games (Sina, 2008). To deploy the services during Olympic had largely facilitated the market formation of TD-SCDMA.

In fact, the operator for TD-SCDMA itself had already added decisive comparative advantages to the technology, and has been recognized as a very smart government intervention. Because in the contemporary, China Mobile had largest installed base of 2G subscribers, good reputation in service, convincible and leveraging power to stimulate the vendors, and considerable profits available for further investment. Besides, China Mobile had extensive experiences in performing as the platform for integrating the industrial participants, products and services. The government took direct regulative orders to request China Mobile to take the lead had largely facilitated market formation.

Similarly, TDIA was established by the MII to promote the diffusion of TD-SCDMA (IA_TD2). TDIA gradually enrolled key actors not only from every single segment of the industrial value chain, including system equipment, testing instruments, terminals as well as chipsets, but also attracted more than 200 local technology vendors in supply chain. Its size has expanded tremendously, from the initial few leading companies like Datang, Huawei, Lenovo and ZTE to 90 members by the end of 2014, including both domestic firms and MNEs (TDIA, 2014).

Furthermore, TD-SCDMA favored institutional environment was also established based on government interventions. For example, in January 2009, when the test results from pre-commercialization trials showed that the contemporary TD-SCDMA system based on available products could offer stable and high quality 3G services, China government then issued 3G licenses and officially kicked-off the Chinese 3G market. China Mobile was granted a TD-SCDMA license, China Unicom and China Telecom received licenses for WCDMA and CDMA2000, respectively. After getting the license for TD-SCDMA, China Mobile then issued a R&D fund to subsidize the development the handsets, terminals, and network equipment to support TD-SCDMA, approximately about 20 million RMB per bid (MO_CMB2). By the end of 2014, TD-SCDMA subscribers has reached 230 million, taking nearly half of the mobile market in China at the contemporary (TDIA, 2014).

7.4.7 Creating legitimacy

Creating legitimacy as a fundamental TIS function contributed to TD-SCDMA innovation mainly in the diffusion stage. The related activities were jointly undertaken by mobile operator, technology vendors and R&D institutes who had invested in the TD-SCDMA with strong government support. By creating legitimacy, the function undertakers helped counteract the resistance to change and facilitate TD-SCDMA to merge into the incumbent regime.

In earlier stage for TD-SCDMA to commercialize, the most severe challenge was that TD-SCDMA as the new comer could hardly compete with the incumbent matured WCDMA and CDMA2000. To address the challenge, the government not only used strong regulative interventions on institutional environment to create enough protected spaces for TD-SCDMA, but also took normative and cognitive interventions like advocating enhancement of national pride and the national security to lobby the market to create legitimacy for TD-SCDMA to better diffuse.

For example, TD-SCDMA was granted as a national standard as early as in January 2006, comparatively, WCDMA and CDMA2000 did not get such recognition until May 2007. In fact, although WCDMA and CDMA2000 had already matured and ready to launch, China's government did not launch 3G services until TD-SCDMA became ready for commercialization in 2009. Such strategy to some extent had created enough protect spaces for TD-SCDMA. As an interviewee in China Unicom said:

> *"…we had made a long time preparation to launch 3G WCDMA, the technology was mature and our market investigation showed a very positive result, we just wait the point to launch the service when MII give us license…"(MO_CUB2)*

Besides, the dominant incumbent players especially foreign technology giants did not like to see Chinese standards emerging to challenge their dominant position. But these firms could not afford to lose the huge interests of Chinese market. They were convinced to support TD-SCDMA as the government kept voicing their firmly support to TD-SCDMA. For example, a relatively balanced approach was adopted in the hope of creating a level-playing-field for all stakeholders in adopting the China-born 3G standard. TDIA as an arena for firms to discuss key issues about TD-SCDMA diffusion was open to domestic and foreign vendors as well as their joint ventures. These firms focused on different aspect of TD-SCDMA system. For example, LG succeeded in producing mobile handsets; T3G, a joint venture of Datang, Samsung and Texas Instruments, specialized in chip design; Datang, Potevio and ZTE formed joint ventures with Alcatel, Nokia and Ericsson, respectively, to invest in TD-SCDMA network.

To sum up, the case of TD-SCDMA innovation in this section has demonstrated that how the TD-SCDMA TIS structural components could decide the system functions with government intervention. Whether the system could be well functioned or not then could decide whether the system targets could be achieved or not. In the following section, we summarized the performance of TD-SCDMA innovation system in both development and diffusion stage.

7.5 PERFORMANCE OF TD-SCDMA INNOVATION SYSTEM

7.5.1 Technology development: creating competitive Chinese 3G technology

In technology development stage, expectations of TD-SCDMA innovation could be recognized as developing a competitive Chinese 3G technology and at the same time promoting indigenous innovation capabilities. From this perspective, China's initiative of developing domestic 3G technology could be viewed as a success. For example, through unremitting efforts that elaborated, TD-SCDMA as a technology was successfully developed and officially authorized by ITU as one of three international 3G standards. It is an advanced technology as several new features and techniques are first time introduced, such as adding smart antenna and time division duplexing technology, which made TD-SCDMA became the first TD based mobile system.

Besides, although this was the first time that Chinese domestic firms took the lead in developing an international level mobile technology, the key actors in each segments had well achieved their tasks, and at the meanwhile, largely enhanced their R&D capabilities. For example, according to SIPO report, there were 214 core patents for TD-SCDMA technology (148 for TD and 66 for SCDMA), in which the Chinese domestic enterprises held 43 core patents for TD and 35 for SCDMA (SIPO, 2011). Benefiting from participating in the TD-SCDMA development, domestic firms such as Datang, Huawei, Potevio and ZTE had not only started to break the dependency with foreign technologies, but also gradually grown into powerful vendors in global telecommunication field (RD_S2; UN_BU1).

7.5.2 Technology diffusion: promoting industrialization, commercialization and national economic growth

In the stage of technology diffusion, expectations towards TD-SCDMA diffusion could be learnt as to form and cultivate a sturdy industrial value chain, to achieve a high degree of commercialization, and further to drive the overall economic growth (Stewart et al., 2011, Xia, 2012a, Gao et al., 2014). From this point of view, China's initiative of diffusing TD-SCDMA could be viewed as a success, but not that success as expected.

In terms of industrialization, TDIA was established and extended from 8 members in initial to 25 members during TD-SCDMA diffusion, which included 17 domestic firms and 8 joint ventures. For commercialization, in 2009, TD-SCDMA attracted 10.5 million subscribers for China Mobile; by the end of 2012, the number spurred to 87.9 million. If considered the WCDMA and CDMA2000, the total number of 3G subscribers that emerged in the Chinese market was about 234 million (CCID, 2013). Furthermore, in terms of economic growth, according to incomplete statistics, the direct increased employment number was over 1.2 million, and the indirect number was about 2.7 million; the increased investment was about 270 billion, and increased consumption over 605 billion; the contribution of TD-SCDMA to the GDP was about 0.5% in total (Sina, 2008, CNNIC, 2013).

Nevertheless, also assessed system performance in TD-SCDMA diffusion from these three aspects, there still exist several unsatisfactory points. For example, in terms of industrialization, the chipset manufacturing, the very crucial and the most profitable part in the value chain, was still a weakness for TD-SCDMA during its diffusion (RD_S1; UN_BE). In the contemporary, only five enterprises could produce TD-SCDMA chipsets, including ADI/Datang, Spreadtrum, T3G, CYIT and Commit, which were all SMEs if compared with powerful MNEs such as Qualcomm and Intel (ESM, 2007). Furthermore, despite of international giants' inactive in investing in the TD-SCDMA, the technology itself was only implemented in China's mainland with only 1 license was issued to the mobile operators.

In terms of commercialization, although the number of TD-SCDMA subscribers had spurred from 10.5 to 87.9 million in three years (2009-2012), the diffusion situation for TD-SCDMA was still not optimistic if compared with the other two alternatives. For example, by the end of 2012, there were 162 WCDMA networks adopted in 72 countries, which took nearly 70% shares of overall global market; similarly, CDMA2000 licenses were carried by 166 operators in 73 countries, with more than 275 million subscribers all over the world; but TD-SCDMA only operated by China Mobile in the mainland China (ITU 2013). Furthermore, if make an individually review on Chinese market, in 2009, TD-SCDMA's market share is about 42% at initial, while three years later, the figure had decreased to nearly 35%. In December 2009, in terms of market share, China Mobile (operating TD-SCDMA) held 72%, China Unicom (operating WCDMA) held 20%, and China Telecom (operating CDMA2000) had 8%. However, also three years later, by the end of 2012, the figure had significantly changed as China Mobile decreased to 51%, China Unicom tiny increased to 22%, and China Telecom quickly expended to 27% (CNNIC, 2013, EnfoDesk, 2013). It is noteworthy that, 2009 to 2012 were the mainly period for TD-SCDMA commercialization, which to large extent, could reflect the actual diffusion situation of three 3G standards in market.

In terms of economic growth, there also existed some critical perspectives, which indicated that the growth that bought by TD-SCDMA was not convincible enough if compared with the huge amount of investment that had been spent (e.g. Liu and Buck, 2007, Gao and Liu, 2012, RD_S1, UN_SB2). Nevertheless, although both compliment and criticism existed, it is undeniable that TD-SCDMA as a path-breaking technology had established a solid foundation for further catching-up in mobile wireless technology, and this would be reflected at the 4G TD-LTE innovation that later elaborated.

So far, according to the data that been collected, the case of TD-SCDMA innovation in China has been illustrated through understanding the structure of its innovation system, the system functions, challenges and government interventions, as well as the system performance in technology development and diffusion. To conclude the elaboration, we summarized the key system features in the Table 7.4 as followed.

Table 7.4 Features of TD-SCDMA innovation system

Innovation Stages	TD-SCDMA Development	TD-SCDMA Diffusion
Milestones	*Mid-1990s to May 2000* • System development was mostly finished • TD-SCDMA was authorized by ITU	*December 2000 to January 2009* • TD-SCDMA equipment was available • Network and system tests were finished • Spectrum with 155 MHz was allocated • Commercial trial and license were launched
System components	*Key actors* • R&D institutes: CATT/Datang • Vendors: Datang; Xinwei; Siemens *Key networks* • Government – R&D institutes • R&D institutes – Vendors *Key institutions* • Regulative: MPT ordered CATT to explore Chinese own 3G technology; Datang's proposal was recognized as national one; Subsidized to TD-SCDMA development project with funds and low rate loans;	*Key actors* • R&D institutes: CATR; CAS; R&D in firms • Vendors: Datang; ZTE; Huawei; Potevio • Operators: China Mobile • Industrial Alliances: TDIA *Key networks* • Government–Vendors; Government–Operator • Operators – Vendors *Key institutions* • Regulative: MII announced TD-SCDMA as the national 3G standard; Spectrum was allocated with a bias strategy; subsidies; • Normative: National pride in High-tech area • Cognitive: reducing IPRs payments and enhancing national security; high officials voiced support; TRIP subsidizing
System functions	*Knowledge development & diffusion* • Xinwei was formed to focus on SCDMA • Siemens was invited to focus on TD • TTACG was formed to select signal transmission solutions *Research guidance* • CATT was designated to lead TD-SCDMA R&D with full government authorization • MII offered over 1 billion RMB fund to support R&D on TD-SCDMA *Entrepreneurial experiments* • Datang was formed to take lead in developing and testing TD-SCDMA *Resource mobilization* • MPT spent 20 million RMB to support the formation of Xinwei, 1.3 billion RMB to Datang for TD-SCDMA development • Moved TD-SCDMA R&D group to Datang	*Entrepreneurial experiments* • China Mobile was ordered to take lead in the diffusion of TD-SCDMA since the stage of commercial trial *Resource mobilization* • MII launched TRIP with 708 million RMB as the budget to subsidize domestic vendors • National banks were asked to offer loans with privileged interests rates for TD-SCDMA • Offered high rate of VAT refunds for vendors • Transferred IPRs from Datang to key vendors • Allocated 155 MHz spectrum to TD-SCDMA *Market formation & Legitimation* • Advocating national pride and national goals to cultivate and establish normative and cognitive institutional environment • Assigned China Mobile, then the most powerful operator to provide TD-SCDMA
System performance	*Created comparative 3G technology* • TD-SCDMA with new added technological features was created • successfully authorized by ITU as one of the three international 3G standards *Promoted indigenous innovation capability* • Held 43 core patents for TD and 35 for SCDMA • Domestic R&D institutes and vendors grew, and started to reduce dependencies on foreign technologies.	*Promoted TD-SCDMA industrialization* • TD-SCDMA industrial value chain was formed by domestic firms and a few MNEs • Few MNEs interested in participant • Key components like chipsets are still produced by MNEs like Qualcomm *Promoted TD-SCDMA commercialization* • 87.9 million users was attracted in 3 years • Only 1 TD-SCDMA license issued • Only implemented in mainland China *Promoted national economic growth* • 3.9 million employment increased • Generated about 875 billion revenue • Over 0.5% GDP contribution

7.6 SUMMARY

In this section, we elaborated the cases of 3G TD-SCDMA innovation in China. Through summarizing the key events in both technology development and diffusion stages, we first generated a chronology and illustrated the process of China's TD-SCDMA innovation. Then followed the theoretical framework, we elaborated how the government in China promoted this indigenous technology innovation by intervening on the institutional environment and the activities undertakers in the innovation system.

Specifically, associating with the data collected from documentary research and semi-structured interviews, we first delineated the structure of TD-SCDMA innovation system, as a conclusion, we summarized the feature of institutional environment of the system as "highly government controlled and indigenous innovation favored", and identified that the system actors are highly heterogeneous in interests, resources and capabilities, and the GSEs were taking the lead almost in every single fragmentation. Besides, we also found that system actors in different groups undertook innovation activities in different stages, as TD-SCDMA was basically developed by R&D institutes and technology firms, like CATT, Xinwei and Datang; in terms of diffusion, the activities were mostly undertaken by GSEs in operator and vendor group and related industrial associations they chaired or established. Most of the efforts taken in TD-SCDMA development and diffusion were strongly supported by China's government.

Based on understanding the structure of TD-SCDMA innovation system, we also captured each of the seven TIS functions along with the innovation process. It has been observed that seven functions were not independent from each other but interact and influence each other. Some functions contributed more in the development stage, while some functions were observed more in the diffusion stage. The fulfillment of a certain function could have effects on other, and the function fulfillment could also lead to positive cycles of processes that strength each other. For example, the function of knowledge diffusion was well achieved mostly in the development stage, which enables potential vendors help to further develop the technology, but at the same time, it also facilitated the diffusion of matured technology in the later stage.

Furthermore, in TD-SCDMA innovation, several challenges were faced in fulfilling each system functions. It has been observed that some challenges emerged because of high degree of heterogeneity in terms of system actors' interests, resources and capabilities. However, more severe challenges that faced were normally caused by deficiencies in innovation resources and capabilities. For example, in the early stage, the government asked CATT to lead the 3G mobile system innovation, but few domestic R&D institutes or technology firms had experiences and capabilities in developing such an international level telecommunication standard. Similarly, after established Xinwei and invited Siemens to develop TD-SCDMA, few qualified R&D networks could be relied to diffuse and spread the developed knowledge.

These challenges that identified have indicated that traditional technology late-coming country like China normally weak in innovation experiences, capabilities and infrastructures, and for late-coming countries to catch up in technology innovation, these barriers must be addressed. For TD-SCDMA innovation to success, it has been observed that China's government had taken strong support to address these challenges that faced in technology development and diffusion. On the one hand, the government took regulative, normative and cognitive interventions to create and shape the institutional environment in the innovation system to favor the TD-SCDMA innovation; on the other hand, the government also took strong regulative interventions like directive and administrative orders, to manipulate the actors in the innovation system to promote the system functions they undertook.

Supported by the government, the performance of TD-SCDMA innovation system was assessed by considering the specific initiatives of developing and diffusing TD-SCDMA. For example, in the development stage, expectations of developing a competitive Chinese 3G technology and at the same time to promoting indigenous innovation capabilities were realized; in the diffusion stage, expectations of establishing a sturdy industrial value chain, achieving a high degree of commercialization and at the same time driving the overall economic growth have all been successfully achieved.

CHAPTER 8: CASE STUDY OF 4G TD-LTE MOBILE SYSTEM INNOVATION IN CHINA

8.1 INTRODUCTION

Drawing upon the developed theoretical framework, this chapter presents the case study of China's 4G TD-LTE development and diffusion to understand how the government intervened in TD-LTE innovation system to promote the innovation. Specifically, section 8.2 summarizes the development and diffusion process of TD-LTE; section 8.3 delineates the structure of TD-LTE innovation system, including the institutional environment and key system actors that undertook the innovation activities; section 8.4 elaborates how system functioned to produce the innovation along with the innovation process, at the same time, the challenges that hindered the fulfillment of system functions are identified and how the government interventions helped address the identified challenges are illustrated; section 8.5 assesses the performance of TD-LTE innovation system in both technology development and diffusion stage; then section 8.6 concludes this chapter at the end.

8.2 TD-LTE INNOVATION PROCESS

It is observed that, diffusion of 3G mobile systems had tremendously promoted the global market of mobile data services and mobile internet applications. Expanded global mobile market was requesting a better mobile system with broader bandwidth and higher speed, which had offered a necessity of developing the next generation mobile system. Besides, the available spectrum had become more and scarcer, thus higher efficiency of spectrum utilization was required (ITU, 2013). Moreover, the new radio access technology of OFDM was introduced, which was far better than contemporary non-IP based mobile technologies in system performance and spectrum efficiency (SRRC, 2013). All these reasons composed the trigger for the mobile system evolution to next generation. Learnt from former experiences, Chinese government then decided to take an earlier move in developing and diffusing 4G mobile system (CENA, 2012).

China leaded TD-LTE, as one of two international fourth generation mobile wireless system, was authorized by ITU in October 2010. Benefiting from developing and deploying home-grown TD-SCDMA mobile system, China's innovation capability, as well as the maturity of domestic mobile wireless industry, had all been enhanced significantly. International cooperation in technology innovation was also starting to be valued by both domestic firms and the policy-makers. As along with the continuous catching-up through promoting indigenous technology innovation, China had become more capable and active in participating into the setup of international standards and the collaboration of technology innovations.

The development and diffusion of TD-LTE was a typical case that demonstrated how matured telecommunication industry in China leaded the international cooperation to achieve 4G TD-LTE standardization with firmly support from the government. At the start, the process of TD-LTE innovation was delineated in the Table 8.1 by following the sequential stages of technology development and diffusion.

Table 8.1 Innovation process of TD-LTE in China

Innovation Stages	Time	Key Innovation Events
TD-LTE Development *(March 2005 to October 2010)*	March 2005	The idea of developing 4G TD-LTE was first time raised by Datang in China.
	June 2005	Datang on behalf of Chinese government gave a presentation about the basic structure of TD-LTE in 3GPP LTE Ad Hoc meeting, and submitted the proposal.
	Nov. 2005	Datang's proposal was approved by 3GPP in the Ad Hoc meeting in Seoul Korea.
	Dec. 2005	MII decided to support the proposal, and standardization system for TD-LTE established, including agencies, GSEs and R&D institutes
	Nov. 2006	Datang Telecom on behalf of Chinese government submitted the technical proposal of TD-LTE to ITU for consideration.
	March 2007	MII set up the IMT-Advanced Promotion Group to facilitate ITU's evaluation.
	April 2007	3GPP held a special LTE TDD Ad Hoc meeting in Beijing and accepted smart antenna technology for adopting in the LTE standards.
	Sep. 2007	ITU approved the proposal of developing TD-SCDMA based TD-LTE 4G standard.
	Sep. 2007	China Mobile proposed a simplified TDD frame structure
	Nov. 2007	The simplified TDD frame structure from China Mobile was accepted by 3GPP.
	Dec. 2008	3GPP finished the first version of international 4G standards, included both LTE FDD and TD-LTE standards, named as LTE Release 8.
	Oct. 2010	ITU accepted TD-LTE and FDD-LTE as two official international 4G standards.
TD-LTE Diffusion *(February 2010-)*	Feb. 2008	China Mobile cooperated with UK Vodafone and US Verizon Wireless to conduct TD-LTE system test for operation.
	Dec. 2009	MIIT launched first time technique utilization test of TD-LTE.
	April 2010	Huawei first time supplied a TD-LTE system for the Shanghai Expo, and conducted large-scale TD-LTE system test.
	Nov. 2010	MII approved the plan for TD-LTE commercial trial in large-scale, six cities were selected, including Shanghai, Guangzhou, Xiamen, etc. Qualcomm participated.
	Feb. 2011	China Mobile jointly with other international operators initiated the Global TD-LTE Initiative (GTI), aimed to promote TD-LTE deployment.
	Oct. 2011	TD-LTE was first time deployed in India.
	Sep. 2012	China government granted 190MHz spectrum to TD-LTE for commercial use
	Dec. 2012	China Mobile finished TD-LTE network construction, and launched the commercialization of TD-LTE first at Hong Kong and Shenzhen
	Feb. 2013	China Mobile and domestic vendors jointly published 4 TD-LTE mobile devices
	June 2013	China Mobile invited vendors to bid for TD-LTE infrastructure construction
	Oct. 2013	NDRC, SASAC and MIIT jointly launched TD-LTE Industrialization Special Program (TISP). Allocated a budget of 34 billion RMB, aimed to improve the capability of TD development and industrialization.
	Dec. 2013	MIIT issued TD-LTE licenses to three operators, but with bias spectrum allocations
	Jan. 2014	MIIT helped to set up strategical cooperation relationships between China Mobile and Apple Inc., Apple announced next generations iPhone would support TD-LTE.
	Feb. 2015	One and half a year later from TD-LTE licensed, FDD-LTE licenses were granted to China Unicom and China Telecom.

8.2.1 TD-LTE development process

As early as in November 2004, 3GPP decided to launch the long-term-evolution of 3G mobile system on the Ad Hoc meeting in Quebec, and named the project as LTE. In March 2005, the idea of 4G TD-LTE was first time proposed by CATT/Datang in China. With the support from Chinese government, Datang took the lead in presenting a basic structure of TD-LTE in 3GPP LTE Ad Hoc meeting and submitted a proposal to 3GPP in June 2005. According to the proposal, TD-LTE would partially derive and evolve from current deployed TD-SCDMA, and two evolutional strategies based on OFDM and Multiple-carriers were suggested, respectively. In November 2005, on the 3GPP LTE Ad Hoc meeting held in Seoul Korea, the proposal was approved, and the OFDM solution was selected by 3GPP for both FDD and TDD.

Then the *Ministry of Information Industry (MII)* mandated its affiliate *Research Institute of Telecommunication Transmissions (RITT)* to respond for TD-LTE standardization (GA_M3, RD_TR2). By the end of 2005, several technology vendors and mobile operators were invited to participate in the TD-LTE standardization, such as Datang Telecom, ZTE, Huawei, Ericsson, Samsung, and China Mobile. Meanwhile, national universities including Tsinghua University, Beijing University of Posts & Telecom and Shanghai Jiaotong University were also invited to provide technology solutions. At the end of 2006, in the 4G Workgroup Meeting held at Jeju Korea holding by the ITU, Datang Telecom submitted the technical proposal of TD-LTE to the community for consideration on behalf of Chinese government. Later on, in March 2007, MII set up the IMT-Advanced Promotion Group to facilitate the evolution of TD-LTE in ITU's 4G standardization.

Initially, TD-LTE standardization started from a research on the frame structures. The contemporary LTE frame structures included both Type 1 (including FDD and UTRA HCR TDD) and Type 2 (based on TD-SCDMA, proposed by Datang in November 2005). They were different mostly because of different parameter designs in the physical layer. Nevertheless, there was no further benefit in future standardization for TDD in the Type1, in contrast, TDD in the Type2 would co-exist and compatible with current deployed TD-SCDMA system. In the objective of simplifying the development and diffusion of TDD in future, Datang and other Chinese enterprises then suggested to integrate two frame structures into one frame structure (TV_D1). After a period of intensive R&D and discussion, in September 2007, China Mobile cooperating with many operators proposed a simplified TDD frame structure and suggested to keep this one-frame-structure as the only optimized frame structure for LTE TDD mode. This China Mobile proposed TDD frame structure would not only maintain higher compatibility with FDD systems, but also allow smooth optimization and evolution of earlier deployed TDD systems, for instance, TD-SCDMA (RD_S2). In November 2007, this proposal was accepted by 3GPP. It is turned out later that simplifying two frame structures into one was a significant achievement not only for establishing the foundation for future FDD and TDD convergence, but also for creating an effective paradigm of international cooperation between domestic enterprises from China with influential MNEs from developed nations.

Apart from frame structure, smart antenna technology is another crucial part for TDD systems (RD_S2). As elaborated in 3G development, first introducing by Xinwei, the smart antenna technology was an advanced technology only adopted in TD-SCDMA. Therefore, it could be and should be inherited as the technology enabling TD-LTE. Nevertheless, worrying about impact on the common design between TDD and FDD, most enterprises that support FDD were refusing to introduce smart antenna technology in the overall design of LTE initially. The agreement was finally reached after several times of negotiation. In April 2007, 3GPP held a special LTE TDD Ad Hoc meeting in Beijing, to focus on specific TDD solutions. As the result of this meeting, 3GPP accepted smart antenna technology but with specific technology requirements, including adopting a short antenna distance, pre-process in spatial section, and a specific reference signal (beamforming) in LTE Release 8 (UN_BU2).

In September 2007, ITU approved the Chinese proposal to develop TD-LTE as the 4G system through deriving from the contemporary 3G TD-SCDMA system (TV_D1). In June 2008, 3GPP announced both FDD-LTE and TD-LTE were included in the LTE standard scheme, which later in October 2010 was approved by ITU (3GPP, 2012, ITU, 2013). Release 8 as the first and most significant achievement in LTE standardization was finished at the end of 2008 (TV_D1). Later, aimed to enhance the performance of LTE systems, several new features were introduced into the contemporary systems by 3GPP, and the improved LTE systems were named as LTE Release 9 and finished in June 2009. After then, 3GPP was focusing on preparing the development of IMT-Advanced, which was former triggered by ITU-R in late 2008 (ITU, 2013).

As elaborated in section 7.2.4, neither TD-LTE nor LTE FDD (including both Release 8 and 9) could satisfy the initial 4G minimum technique requirement that proposed by ITU. Thus in February 2008, during the finalization of Release 8, ITU-R defined the minimum technique requirement for further enhancement, named as IMT-Advanced. In June 2008, before ITU-R publishing the official technology defining document for IMT-Advanced, Datang suggested to add 8x2 *(eight antennas for transmission and two for receiving)* for smart antenna technology as a requirement for IMT-Advanced technology evaluation (RD_S2). This suggested was accepted by ITU-R and written in the circulation letter when call for IMT-Advanced candidates.

In the meeting held by ITU-R in October 2009, China independently submitted the candidate proposal, named as TD-LTE-Advanced. This 4G Advanced technology was the joint efforts of Chinese enterprises leaded by Datang. Moreover, Chinese enterprises also dominated several key sections in the LTE-Advanced TDD parts in 3GPP, such as technology description and performance evaluation. In November 2010, ITU announced that both LTE-Advanced and Wireless-MAN-Advanced were accepted to IMT-Advanced 4G (ITU, 2013). LTE-Advanced enclosed two systems – FDD and TDD, which were designed to operate in paired and unpaired spectrum, respectively. The TDD mode of LTE-Advanced was also known as TD-LTE Release 10 or TD-LTE-Advanced, later became a dominating TDD 4G technology due to its strong competitiveness in unpaired spectrum (CCID, 2013, Song, 2014). Release 11 was started when LTE-Advanced R10 finished standardization in March 2011. Release 12 as the final version of LTE-Advanced was finished in September 2014. To illustrate the evolution process more intuitive, Figure 8.1 illustrates the milestones of TD-LTE standard evolution based on a year divided time line.

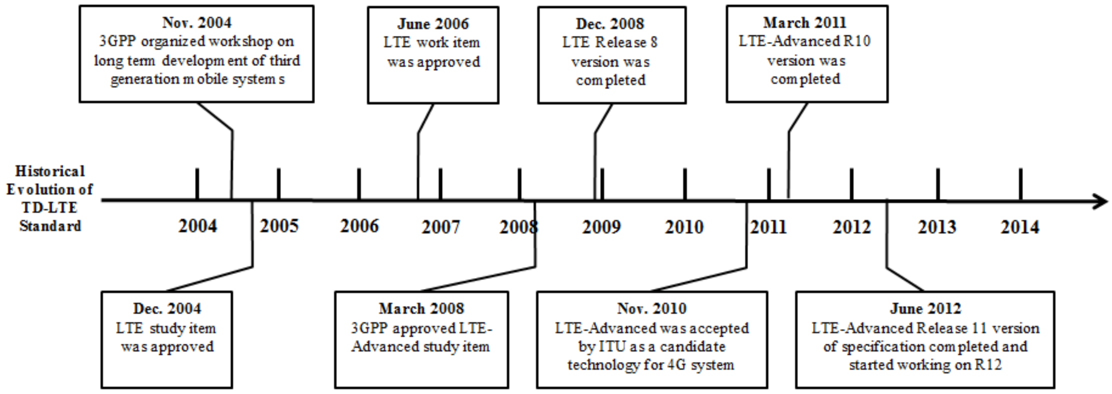

Figure 8.1 The evolution path for TD-LTE standard (Source: author illustrated based on *TDIA, 2014*)

8.2.2 TD-LTE diffusion process

In China, TD-LTE technology entered into the diffusion stage since 2008, when LTE Release 8 was completed. Most Chinese firms participated in TD-SCDMA innovation also participated in the development and diffusion of TD-LTE. After Release 8 was finished, these Chinese firms and several major international vendors soon started the equipment R&D and system tests for TD-LTE. Leaded by *China Academy of Telecommunication Research (CATR)*, the TD-LTE Promotion Group was established to ensure the smooth diffusion of TD-LTE in every single segment along the value chain.

At the beginning of 2008, as a result of the sixth governance system reform, MII was replaced and constructed into *Ministry of Industry and Information Technology (MIIT)*, which responded for issuing industry policies, supervising, promoting innovation, managing telecommunication industry, as well as protecting information security (MIIT, 2009). With the support from MIIT, on the February's Mobile World Congress in Barcelona, China Mobile declared to cooperate with UK Vodafone and US Verizon Wireless to join the TD-LTE system conducting and testing (UMTS Forum, 2008). It was turned out that collaborating with such experienced global technology giants had indeed tremendously quickened the TD-LTE development (TDIA, 2014).

By the end of October 2008, the premier Wen Jiabao had four times written instructions for TD-LTE standardization. The development of TD-LTE was listed as one of the most significant approaches for stimulating domestic. In November 2008, the vice president of China Mobile Sha Yuejia was reappointed as the Chairman of NGMN[15]. He had stressed several times of showing the determination to forge China's TD-LTE into a world-compatible mobile wireless system standard (CENA, 2012).

After a year's intensive research and development, at the end of 2009, MIIT launched the first time technique tests of TD-LTE utilization. During the tests and trials, in 2010, Huawei supplied a TD-LTE system for the Shanghai Expo in April, and then conducted

[15] NGMN: the Next Generation Mobile Networks Alliance, a mobile telecommunications association of mobile operators, vendors, manufactures and research institutes, with aim to ensure the successful commercial launch of future mobile system.

large-scale commercial tests in at least two cities with more than 100 base stations in November (TDIA, 2013). Also in November 2010, Qualcomm started participating in the scale field trial for TD-LTE on 2.3GHz chaired by MIIT, and later joined the China Mobile leaded 2.6GHz large scale test (UN_BU1). The Scale field trial in six cities was conducted from early 2011 to mid-2012, and the final stage large scale field trial in 15 cities was conducted during early 2012 to 2013.

On 15th October 2012, at the *World Telecommunication Conference (WTC)*, the deputy director of State Radio Administration, Xie Cun disclosed that Chinese government had decided to grant in total 190MHz spectrum to TD-LTE. In contrast, only 40MHz for FDD-LTE, which has obviously shown the preference toward China leaded TD-LTE (Sina, 2012). In November 2012, China Mobile published the result of procurement bidding for TD-LTE multi-mode multi-frequency terminals, and several influential MNEs such as Ericsson, Siemens and Qualcomm were included (ChinaMobile, 2014, TDIA, 2014). In 19th December 2012, China Mobile first launched TD-LTE commercialization at Hong Kong, and achieved the data roaming with Shen Zhen's TD-LTE network. Since then, China Mobile soon started pre-commercialization services in other big cities in China.

Compared with 3G era that no technology vendors and network operators interested in China's TD-SCDMA, in 4G era, they have shown enough enthusiasm to participate in TD-LTE's diffusion. In 27th February 2013, on the China hosted GTI Summit (Global TD-LTE Initiative), China Mobile published 4 TD-LTE smartphones and 4 TD-LTE MIFI products cooperated with HTC, LG, Huawei, and ZTE (Sina, 2013). As participating in the development of TD-LTE and appointed as the potential major operator, China Mobile had invested heavily in building up infrastructure, including bases and core networks. According to the annual report of China Mobile, the company had invested over 200 billion RMB in procurement TD-LTE infrastructures, with more than 207 thousand TD-LTE bases were purchased just in 2013 (ChinaMobile, 2014).

Compared with China Mobile, the other two major operators China Unicom and China Telecom, as well as current 3G system subscribers, still put their emphasis on

FDD-LTE system, and no wonder, still took the strategy of "wait and see" as in the 3G era (MO_CTS; MO_CUB2). On 14th August 2013, the State Council issued a "Red tape" document to promote the conception of "Information Consumption", named as "Several opinions for expanding domestic demand via promoting the information consumption" (Decree No. 32). It requested to promote the development of domestic mobile telecommunication, optimize the network structure, and accelerating the industrial development of TD-SCDMA and TD-LTE. Followed on, three days later, on 17th August 2013, the State Council issued a national strategy as "Broadband China", with the aim to establish a "Broadband, Convergence, and Security" information network, in which TD-LTE located in the central position (StateCouncil, 2013).

In October 2013, SASAC and MIIT jointly launched TD-LTE Industrialization Special Program (TISP) to improve the TD-LTE R&D capability and industrialization. With a budget of 34 billion RMB, TISP offered subsidy for domestic firms, joint ventures, and research institutes to invest in TD-LTE industrialization. Initially, TISP has highlighted eight key technologies for TD-LTE's industrialization, and encouraged capable actor to participate (IA_TD2). The formation of TISP had shown the determination of Chinese government on promoting indigenous 4G development, which had also passed a significant signal to the TD industry and financial market as well.

On 4th December 2013, MIIT officially issued TD-LTE licenses to three network operators but with different spectrum allocation (TDIA, 2013). China Mobile was granted with 130MHz bandwidth in total *(1880-1900MHz, 2320-2370MHz, and 2575-2635MHz)*, China Unicom and China Telecom each had 40MHz bandwidth *(China Unicom: 2300-2320MHz, 2555-2575MHz; China Telecom: 2370-2390MHz, 2635-2655MHz)*. In the 3G era, the diffusion of TD-SCDMA was lagging over 8 years behind with WCDMA and CDMA2000; while in contrast, TD-LTE from development to diffusion was basically keeping same pace with the other one – LTE FDD (RD_TR1). Moreover, the TD-LTE industry is current developing within the global scale robustly, as by the end of May 2013, 104 TD-LTE licenses were issued to 40 operators with 3 billion users' coverage (TDIA, 2013, Song, 2014, ITU, 2015).

On 15th January 2014, arranged by the MIIT minister, the chairman of China Mobile XI Guohua and Apple Inc.'s CEO Tim Cook met at Beijing. They announced a strategic partnership agreement during the meeting, and Tim confirmed that iPhone for TD-LTE would be available (Sohu, 2014; ChinaMobile, 2014).

Since 2014, the deployment of TD-LTE system started to gain momentum in both domestic and global 4G market. By the end of July 2014, over 1 million TD-LTE base stations were constructed, nearly 210 million TD-LTE handsets were sold, and more than 230 million subscribers registered for TD-LTE service with China Mobile (ChinaMobile, 2014). In terms of global market, by the end of 2014, 42 TD-LTE commercial networks were operated in 26 nations, 117 operators and 97 vendors participated in the construction and deployment of TD-LTE system (TDIA, 2014). A year later, the license of FDD-LTE was granted to China Telecom (30MHz bandwidth) and China Unicom (20MHz) by MIIT at 27th February 2015, with the aim to support them to upgrade their 3G systems into 4G FDD-LTE system (Sohu, 2015).

8.3 STUCTURE OF TD-LTE INNOVATION SYSTEM

8.3.1 TIS institutions: more cognitive motivation based institutional environment

As summarized in the case of TD-SCDMA innovation, the institutions within the TIS were featured as highly government controlled and obviously indigenous innovation favored. Among all the institutional influences that government had made, regulative institutional intervention was the most powerful approach in promoting both the development and diffusion of TD-SCDMA. Besides, normative institutional interventions like advocating national pride, as well as cognitive institutional interventions like persuading to achieve national goals had also played significant roles in promoting the 3G TD-SCDMA innovation.

Nevertheless, a different institutional environment of the TD-LTE TIS was perceived according to the data that collected. It has been indicated that regulative institutions in the TD-LTE TIS still played significant roles in stimulating and steering the innovation mainly in the diffusion stage, while a decline in the frequency and the degree of regulative interventions was obvious. Besides, national pride as one of then the most significant normative institutions also contributed mostly in diffusion stage. Furthermore, the significance of cognitive institutions had largely improved in both development and diffusion. In following sections, the institutional environment within the TD-LTE TIS was descripted from these three dimensions respectively.

Regulative institutions

Regulative institutions within the TIS are capable to impact the future behaviors of enrolled actors through building the rules, manipulating sanctions, and inspecting their conformity (Scott, 2001). In the TD-LTE TIS, regulative institutions that controlled by the government, had been manipulated into indigenous technology favored and played significant roles in promoting the innovation. Besides, if compared with the TD-SCDMA TIS, the regulative institutions in TD-LTE TIS were found to take effect mainly in the diffusion stage, but not in both stages. Furthermore, the frequency of government conducting regulative interventions was much lower than previous.

For instance, as early as March 2005, the idea of developing 4G TD-LTE was first time raised by Datang, and later China Mobile participated and then played the lead in both TD-LTE development and diffusion. They were supported by the government in many ways, both financially and technologically. Nevertheless, no direct industrial regulations, rules, or laws were published for stimulating the R&D on TD-LTE in this stage. The only policy might have potential incentives on TD-LTE development was the publication of “Ten Major Initiatives” by MIIT in November 2008. Among them, the seventh “Initiative” recognized TD-LTE R&D as a core national S&T project, required relevant organizations to accelerate the speed of TD-LTE development, and listed TD-LTE as one of the most promising approaches to drive domestic economic (MIIT, 2009).

In the diffusion stage, three influences on the regulative institutions in TD-LTE TIS had significantly promoted the diffusion of technology. Firstly, in September 2012, the government granted 200 MHz spectrum to TD-LTE for commercial use, not mentioned LTE FDD in contemporary (MIIT, 2012). Secondly, in December 2013, MIIT issued TD-LTE licenses to three operators, China Mobile, China Unicom and China Telecom, respectively. The licenses were given with bias spectrum allocations, as China Mobile held in total 120 MHz, while China Unicom and China Telecom each held 40 MHz, respectively (MIIT, 2013). What is more, the LTE FDD licenses were not issued to operators until February 2015, nearly one and half a year later from TD-LTE licensed (TDIA, 2015). At last, after TD-LTE licenses were issued, in October 2013, NDRC published a document to push the regional level government authorities to conduct the special project for promoting TD-LTE industrialization. The project targeted to enhance the R&D and industrialization especially in the TD-LTE terminal field. Accordingly, NDRC provided in total 30 billion funds for this project and requested national banks to provide primary loan for involved enterprises, with no more than 2/3 of normal commercial loan rate (GA_NF; GA_NB1). These policies had jointly manipulated the regulative institutions of the innovation system into particular TD-LTE favored ones.

Normative institutions

Normative institutions, including both values and norms, normally help both to define objectives and to designate ways to achieve such objectives (Scott, 2001). As elaborated by the former case, normative institutions had significantly promoted the diffusion of 3G TD-SCDMA in China, as the government advocated the sense of national pride towards adopting this indigenous innovated 3G technology. Launched TD-SCDMA during Beijing Olympic Games was a good case to illustrate how national pride could be perceived through showing the latest national high-tech achievement in such an international mega-evets.

Similarly, national pride in high-tech achievements was also a significant normative institution that contributed to TD-LTE innovation, especially that in the diffusion stage. However, the perception of nation pride had been shifted from reaching significant national high-tech achievements and getting rid of dependency on foreign technologies in the 3G era, to catching up with the international technology frontiers in the 4G era.

For instance, the most typical case was to name the technology as TD-LTE in China, but not as international standardized LTE TDD. In fact, as early as 2005, when Datang first raised the idea of developing TD and OFDM based 4G technologies, the name was LTE TDD as corresponding with existed LTE FDD. Actually, as introduced in section 7.2, the 4G technologies, including both LTE FDD and LTE TDD were developed based on OFDM, not on CDMA as adopted in 3G technologies, which means it is inappropriate to view TD-LTE as a TD-SCDMA evolved technology. Therefore, to name it as LTE TDD would be more proper. In fact, TD-LTE was a name for LTE TDD to commercialize in China, which was named by China Mobile initially. According to the interviews, the reason for China Mobile to adopt a different name in 4G commercialization was no others but to remind the customers the evolutionary relationship between TD-SCDMA and TD-LTE. As China Mobile believed this would potentially facilitate the diffusion of TD-LTE in China, if customers perceive TD-LTE as *"the 4G technology completely innovated by our own"* (MO_CMB4; RD_S1).

Cognitive institutions

Cognitive institutions could contribute to innovation if the common shared social meanings could be mobilized to favor the expected innovation outcomes (Kshetri et al., 2011). As former elaborated, the cognitive institutions within the TD-SCDMA TIS been expressed in achieving national goals, including reducing IPRs payments and enhancing the national security, respectively. It is evidenced that cognitive institutions, to large extent, had promoted TD-SCDMA mainly in diffusion stage.

In terms of 4G TD-LTE innovation, the cognitive institutions also contributed in both technology development and diffusion stages. If compared with the cognitive institutions in 3G TD-SCDMA TIS, the differences were the contents, or interpretations. In TD-LTE TIS, the national goals including reducing IPRs payments and enhancing national securities still existed, but no longer performed as the key cognitive institutions any more (RD_S2; UN_BE; IA_TD1).

Apart from national goals, a more persuasive cognitive institution was originated from the commonly held positive expectations towards TD-LTE. Such positive expectations not just originated from the promising technology itself, more importantly, were shaped and cultivated by the perception of strong government support in TD-SCDMA in the 3G era. Thus took for granted, it was believed that the Chinese government would still insist in supporting the TD-LTE with great efforts, and several signals that sent out by the government also confirmed such kind of expectations as well (IA_TD2; UN_BU1). As observed, several high-level officials including then the Premier Minister had voiced to support TD-LTE, and several preferential policies were granted to TD-LTE as well. Such positive expectations, in reality, had played significant roles in motivating the potential actors, both domestic and foreign, to join in the TIS and to invest in TD-LTE development and diffusion. As a TDIA interviewee indicated:

> *"... Some firms did not participated in TD-SCDMA had felt regret on the huge amount of subsidies for these active firms; while for firms who had tasted the sweetness of government support in 3G still wanted to keep on tasting the candy in 4G…in China no matter GSEs or SMEs, even some MNEs, to follow political instructions is the best way to make money." (IA_TD1)*

8.3.2 TIS actors: diversified actors in opened innovation system

TD-LTE innovation system was constituted by several groups of actors. The actors were much more diversified if compared with the 3G TD-SCDMA TIS, as more international technology firms were enrolled and more international organizations had played significant roles in the 4G TD-LTE innovation. They jointly undertook the TD-LTE innovation but with heterogeneous interests and resources, but the degree of such heterogeneity was much lower if compared with TD-SCDMA innovation, which to some extent had reflected the positive expectations towards this 4G standard. During TD-LTE innovation, they were observed to both cooperate and compete with each other.

Besides, similar with analyzing the TD-SCDMA TIS, government authorities are categorized as the actors in the regulatory system, and application providers, 4G content/service providers and subscribers are categorized as the actors in the market place, rather than TIS components. Based on the different roles that played, key actors in TD-LTE TIS are summarized in the Table 8.2 as followed.

Table 8.2 Key actors in the TD-LTE innovation system

Groups	Key Actors	Key Activities
Mobile operators	• GSEs: China Mobile; China Unicom; China Telecom • MNEs: Softbank; Bharti; STC; UKB	• Operate mobile networks (TD-LTE) • Provide basic and advanced 4G services • Perform as a platform linking all groups of actors
Technology Vendors	• Chipsets: Spreadtrum; Leadcore; CYIT Qualcomm; MTK; Marvell; Datang • Network: Huawei; ZTE; Ericsson; Siemens; Alcatel; Samsung • Devices: Huawei; ZTE; Lenovo; HTC; Coolpad; Apple; Samsung	• Participate in developing TD-LTE standard • Conduct R&D on TD-LTE system components • Provide network equipment, chipsets, terminals and handsets for TD-LTE mobile system
R&D Institutes	• PRIs: 3GPP; RITT; CATR; CAS; • Firm-based: China Mobile; ZTE; Datang; Huawei; Siemens; Ericsson; Alcatel; Samsung; Qualcomm	• Conduct R&D to develop TD-LTE standard • Conduct R&D on TD-LTE system components • Conduct research on TD-LTE related policies
Universities	• National Universities: Tsinghua; BUPT; SJTU	• Jointly provided technological solutions for TD-LTE development
Industrial Alliances	• Initiated by international participants: 3GPP; LSTI; GCF; NGMN • Initiated by China: TDIA; GTI	• 3GPP: conducted R&D and defined standard • LSTI: tested telecommunication technologies • GCF: certificated and qualified the tests • NGMN: raised functional and commercial demands • TDIA: promoted TD industrialization • GTI: promoted TD commercialization

In the 3G era, few foreign actors were enrolled, and Chinese GSEs were leading and dominating the TD-SCDMA innovation system in both development and diffusion. Few actors held positive attitudes towards TD-SCDMA and most of them were negative to participate. Even for enrolled actors, their interests and resources for TD-SCDMA innovation were largely heterogeneous. Nevertheless, the heterogeneity degree of actors in TD-LTE TIS was much lower if compared with TD-SCDMA TIS and the 4G system was much more opened than the former one. Both domestic and foreign actors from different groups, such as R&D institutes, mobile operators, technology vendors, industrial alliances, as well as universities were positive to participate in the 4G TD-LTE innovation. The government in China also impacted the TIS actors and their behaviors to coordinate and balance their interests and mobilize the innovation resources, thus affected the TIS functions, and the TIS performances in sequence.

Different actors played different roles, thus they normally participated into the TD-LTE TIS and took effects in the innovation at the different stages. Such a mode of collaboration in TIS had been evidenced in the case of TD-SCDMA innovation: R&D institutes and vendors, like CATT and Datang, were mainly responding for technology development; while operators and industrial alliance, like China Mobile and TDIA, were particularly affecting in the diffusion stage.

Nevertheless, in the case of 4G TD-LTE innovation, such a collaboration mode was replaced by a completely new paradigm, as many actors were observed to be active in both stages of technology development and diffusion. For instance, actors that formerly played significant roles in the diffusion stage were observed to participate in the development of TD-LTE, such as China Mobile, who not only leaded the R&D by proposing the later adopted “Type-2 based TDD frame structure” for TD-LTE, but also took a leading position in establishing the networks and operating the 4G TD-LTE mobile system in China. Similarly, the industrial alliances such as 3GPP, LSTI, NGMN as well as TDIA all participated into the throughout innovation process of TD-LTE. At last, another highlight was the participation of national universities, such as BUPT, who submitted in total 31 technical proposals to 3GPP with 7 actual adopted (UN_BU1).

8.4 TD-LTE INNOVATION SYSTEM FUNCTIONS, CHALLENGES AND GOVERNMENT INTERVENTIONS

As introduced, for seeking the legitimacies, actors within the TIS could play different roles and then several TIS dynamics could be observed. The inside TIS dynamics that capable to impact the innovation goals, no matter positive or negative, are learnt as the TIS functions (Johnson, 1999). Therefore, based on the delineated TD-LTE innovation system structure, we could interpret how TIS contributed to TD-SCDMA development and diffusion through undertaking seven system functions (Hekkert et al., 2007).

Achieving the TIS functions need to use and coordinate a variety of resources and capabilities (Chaminade et al., 2009). Nevertheless, as introduced, of different system actors, they normally hold different interests towards innovation, and control different resources and capabilities (Chaminade and Edquist, 2010, Samara et al., 2012). This could become challenges to the achievement of TIS functions, thereby hinders the success of innovation (Bergek et al., 2008). Furthermore, challenges could also arise due to deficiencies in resources or capabilities that required (Gao, 2015). Therefore, when understanding how each TIS function is achieved, in this section we also pay attention on identifying the challenges that faced in TD-SCDMA innovation.

To ensure the success of TD-SCDMA innovation, several government interventions were taken to address the challenges that identified. Similar as TD-SCDMA innovation, the government was also observed to support TD-LTE innovation through impacting on the system institutions and manipulating system actors with regulative, normative and cognitive interventions. Drawing upon the developed framework, the TIS functions along with TD-SCDMA development and diffusion, challenges faced in TIS functions in each stage, and the relevant government interventions are summarized in Table 8.3.

Table 8.3 TIS challenges and government interventions in TD-LTE innovation

Innovation Stages	**TD-LTE Development**	**TD-LTE Diffusion**
Challenges in TIS functions	*Knowledge diffusion* • Difficult to generate major industry participators' interests for TD-LTE *Research guidance* • Difficult to unite technological divergences towards TD-LTE, like smart antenna adoption and frame structure unification *Resource mobilization* • Attract both influential domestic and foreign firms to invest in TD-LTE R&D	*Entrepreneurial experiments* • Organize efficient network and system tests • Reduce scepticism towards TD-LTE to succeed in market *Market formation* • Difficult to convince major vendors and operators to invest in TD-LTE • Establish comparative advantages for TD-LTE against the LTE FDD
Government interventions	**Interventions on TIS Institutions** *Cognitive* • High level officials including Premier Minister voiced support to TD-LTE • Government listed TD-LTE innovation as a core national S&T project and a reliable approach to drive domestic economic • Advocated reducing IPRs payments and enhancing national security **Interventions on TIS Actors** *Regulative* • Datang Telecom was assigned to lead TD-LTE standard development • MIIT-affiliate RITT was designated to respond to TD-LTE development • ZTE was assigned to lead the development of core equipment manufacturing • China Mobile was chosen to construct pilot network and leaded testing of TD-LTE • National universities were invited to offer technological solutions for TD-LTE • 30 billion credit assigned to Datang for supporting TD-LTE R&D • China Mobile established TD-LTE special project to subsidize R&D on TD-LTE with direct government funding	**Interventions on TIS Institutions** *Regulative* • Preferential policies were granted to TD-LTE in allocating radio frequency and timing of issuing 4G licenses • Low rate primary loan and high rate VAT refund were granted to support TD-LTE • Government listed TD-LTE innovation as a national strategy and issued national programs like "Broadband China" to promote TD-LTE industrialization *Normative* • Advocated catching-up in high-tech through indigenous innovation as national pride *Cognitive* • High level officials including Premier Minister voiced support to TD-LTE • Advocated reducing IPRs payments and enhancing national security as national goals • TISP program was formed and provided 34 billion RMB to subsidize TD-LTE equipment production **Interventions on TIS Actors** *Regulative* • Datang Telecom, ZTE and China Mobile jointly were in charge of TD-LTE test and led TD-LTE industrialization • China Mobile was supported to led the diffusion of TD-LTE and formed GTI • CATR formed TD-LTE Promotion Group • Far expended TDIA provided the arena for firms to exchange concerns on TD-LTE technology and market • Foreign firms jointed in TD-LTE diffusion process independently and through forming joint ventures with GSEs • China Mobile was granted to offer TD-LTE services, and spent 200 billion RMB to construct infrastructures for TD-LTE

8.4.1 Knowledge development

The knowledge development function of TD-LTE TIS mainly contributed to the innovation in the development stage. The function was undertaken by international cooperation between R&D institutes, technology firms, mobile operators, industrial alliance and universities. Especially, Datang was the leading firm in the knowledge development of TD-LTE. As in 2004, Datang Mobile commenced its research on the TD-LTE technology and became directly involved in the 3GPP LTE standardization. In 2005, the recommendations of the 3GPP Working Group meeting in Seoul were formally adopted, thus initiating the evolution of TD-SCDMA standard. In 2007, the Group adopted proposals for LTE TDD fusion technology, spearheaded by Datang Mobile and co-signed by 27 vendors in Korea. In December 2007, Datang Mobile developed the world's first prototype, made the first air interface call and verified the theoretical peak rate of TD-LTE.

Unlike TD-SCDMA which was developed with the leading of CATT, 3GPP authorized TD-LTE proposal was initially developed by Datang itself. In fact, the year of 2004, when Datang commenced to conduct research on TD-LTE, the 3G TD-SCDMA had just finished system testing and were preparing to commercialize. Which means after TD-SCDMA standard was developed, Datang then immediately invested into the development of 4G TD-LTE. Experienced the development of TD-SCDMA, Datang had grown vastly in R&D capabilities. There was no significant challenge for the government intervention to address. Nevertheless, in terms of encouraging conducting R&D on 4G standard, the government still provided sufficient financial support to Datang, such as lower loan rate and special 4G R&D fund (TV_D2). As an interviewee from Datang said:

> *"Group (Datang) leaders put highly emphasize on developing TD-LTE…we started to conduct research and testing on TD-LTE technology soon after the TD-SCDMA development finished, and we kept on investing in the 5G research and testing after we finished TD-LTE…in terms of the pace of developing mobile standards, we must take the lead and synchronize with other leading countries such as the US and EU. Most importantly, we are capable to do so." (TV_D1)*

8.4.2 Knowledge diffusion

Knowledge diffusion function of TD-LTE TIS contributed to the innovation in both development and diffusion stage. The function was collectively undertaken based on international cooperation between different groups of actors who participated in the knowledge development with China Mobile took the lead especially. The primary challenge that faced in terms of diffusing TD-LTE knowledge was difficult to convince most of actors to adopt TD-LTE. Many MNEs, particularly in developed markets, have continued to favor the FDD variant of LTE. For example, FDD based devices quickly ramped up in terms of performance because US operators like Verizon Wireless and AT&T Mobility drove the deployment of the technology. In contrast, the common understanding was that TD-LTE might like TD-SCDMA that only deployed in China. In the contemporary, China Mobile was the only carrier who proactively expressed that it would provide 4G services based on TD-LTE.

To address this challenge, the government used regulative interventions to manipulate the system actors that it controlled to help diffuse the knowledge of TD-LTE. For example, Datang as both R&D institute and vendor had initially introduced TD and OFDM based technical proposal; RITT as an affiliate of MII then assigned to respond for TD-LTE standardization, and performed as the founder of TD-LTE TIS in China; University like BUPT had contributed several core technologies for TD-LTE; China Mobile as a leading operator had contributed a lot in uniting the frame structures; industrial alliances such as 3GPP had invited many influential MNEs to promote the development of TD-LTE. Thus as observed, diversified networks were established by with government support, which had jointly facilitated the knowledge diffusion in TD-LTE TIS. As result, the pace of TD-LTE development was basically synchronized with the development of LTE FDD.

Based on the networks that established with government support, more and more technological components were added to TD-LTE, and its advantages had started to be recognized gradually, especially by the MNEs. Then TD-LTE knowledge diffusion was mainly facilitated by the technological advantages of TD-LTE itself. For example, TD technology advances in high efficiency of spectrum utilization (SRRC, 2013). As frequency availability is highly important for every mobile operator, particularly those who operate in countries in which a limited amount of FDD spectrum is available or only a single unpaired frequency is available (Beaver, 2012). As introduced, TD-LTE could provide extra spectrum due to its feature in technological design. Thus the advantages of TD-LTE in spectrum saving make TD-LTE suitable for markets in which the device cost is critical. Then TD-LTE was increasingly being recognized as an attractive alternative by all operators and vendors that interest in TD-LTE.

Similarly, introducing smart antennas into TD-LTE had added another advanced technology feature (Chen et al., 2014). Smart antennas enabled TD-LTE offers high-speed data connectivity at a lower cost, which means it could increase the competitiveness of emerging operators against traditional operators in a short period. For example, Softbank in Japan and FarEastTone in Taiwan have clearly expressed interest in TD-LTE as an evolutionary technology for their personal handy-phone system and WiMAX networks. Because of TD-LTE's advantages in mobile broadband coverage, countries in South America and South Asia could quickly and achieve the mobile broadband coverage by deploying TD-LTE (TDIA, 2013).

More importantly, as the US WiMAX was closer with TD-LTE in core techniques than LTE FDD, such as its backward compatibility with legacy systems such as 2G and 3G. Thus when WiMAX failed in diffusion since 2010, then the previous WiMAX vendors and operators collectively announced to invest in TD-LTE (CENA, 2012). The most significant and international influential chipsets manufacturer, Qualcomm, was one of these firms shifted their interests and investment from WiMAX to TD-LTE. Such a large scale changing to TD-LTE had brought a strong demonstration effect to the hesitating actors, and to large extent, also had enhanced the positive expectations towards TD-LTE as well (RD_S1; TV_S2).

8.4.3 Research guidance

Research guidance function of TD-LTE innovation system contributed to the innovation in both development and diffusion stage by positively affecting the visibility and clarity of demands, thus help to define the specific foci for mobilizing limited and heterogeneous distributed innovation resources and capabilities that required. The function was collectively undertaken by R&D institutes, industrial associations and the influential technology firms. Nevertheless, still several challenges were faced in both development and diffusion stages. To address the challenges, it is observed that the government took strong regulative interventions to manipulate both TIS institutions and TIS actors to guide the TD-LTE related research.

For example, in terms of intervention in institutional environment, at the early stage of TD-LTE development, the State Council has listed TD-LTE as one of 16 key state science and technology projects (TDIA, 2013). The primary loan was provided by the national banks for participants in TD-LTE development based on government order; more than 30 billion lines of credit was assigned to Datang in 2009 for developing TD-LTE; high-level government officers like Premier Minister and leader of NGMN publically announced to support TD-LTE, and recognized it as the domestic technology which evolved from 3G TD-SCDMA (Sina, 2012, TV_D1; GA_M4, TDIA, 2013). Associating with the memory of how government supported TD-SCDMA in 3G era, such kind of positive expectations, as cognitive institutions in TD-LTE TIS, had played significant roles in guiding the TD-LTE research.

Moreover, high level government officials voiced strong support to TD-LTE. In October 2008, the Chinese Premier Minister in his speech had mentioned for four times that the government would count TD-LTE development as a key national strategy of stimulating economic growth. Besides, in November 2008, then the Chinese President, in his speech had expressed the value of indigenous TD-SCDMA innovation, and shown the determination of promoting the standardization of TD-LTE. The MIIT minister publically stressed several times that, different from TD-SCDMA mainly used in China, TD-LTE would be deployed globally and become a truly-global standard (TDIA, 2014).

Besides, the government also intervened directly to support system actors in TD-LTE related research, in development stage, most enterprises that support FDD were refusing to introduce smart antenna technology in the overall design of LTE because of worrying about impact on the common design between TDD and FDD. The agreement was finally reached after several times of negotiation, the financial support from the government to Datang and China Mobile was the key for negotiation to success (GA_M2). Furthermore, invited by MITT, 3GPP held a special LTE TDD Ad Hoc meeting in Beijing, to focus on specific TDD solutions. As the result, 3GPP accepted smart antenna technology, but with specific technology requirements.

More importantly, the government created GTI at the Mobile World Congress (MWC) 2011 was a smart move to guide TD-LTE related research and promote its diffusion in later stages. Established in February 2011, the GTI is a virtual open platform that advocates cooperation among global operators to promote TD-LTE. The GTI was formed to create value for TD-LTE stakeholders for early adoption of the technology and convergence of LTE FDD and TD-LTE. GTI positioned TD-LTE as a complementary solution to LTE FDD, thereby ensuring broader support at the global industrial level. As an interviewee indicated:

> *"The GTI at initial was designed by the government to support TD-LTE diffusion especially in devices manufacturing. However, the GTI neither announced only to support TD-LTE nor advocated TD-LTE as a China-centric technology. This was smart because in the TD-SCDMA era, over emphasizing on China-centric technology in global market had resulted in the struggle and leaded to negative effect on TD-SCDMA rollouts." (UN_BU1)*

The GTI guided the TD-LTE related research through a series of activities such as hosting conferences and workshops, sharing development and technology strategies, and aimed to create a device ecosystem for TD-LTE (MO_CMB2; IA_TD1). As device is always a crucial factor for any type of technology, especially for TD-LTE. Because most TD-LTE plans were designed to deploy into emerging markets such as China, India and Russia, which means the low-cost devices would serve as a critical role in cultivating these markets (UN_BU1).

8.4.4 Entrepreneurial experimentation

Entrepreneurial experimentation function of TD-LTE innovation system contributed to the innovation in both development and diffusion stage. TD-LTE as a new technology in nature involved a considerable degree of uncertainty both in technology and commercialization, the function of entrepreneurial experimentation contributed to reduce these uncertainties. In TD-LTE innovation, it was observed most entrepreneurial experimentation were undertaken by active firms such as Datang and China Mobile, and normally organized by the leading industrial alliances like 3GPP, NGMN and GTI, etc.

Similarly as Datang who quite active in developing TD-LTE, China Mobile was also active in both developing and diffusing the technology. The government just provided necessary supports to these two GSEs, no obvious challenge was identified for the government to address in particular.

For example, at the end of 2009, the first time technique tests of TD-LTE utilization was organized by MIIT. Besides, the firms former invested in TD-SCDMA were more active to conduct the entrepreneurial experimentation. As during MIIT organized system tests and trials, Huawei in 2010 supplied a TD-LTE system for the Shanghai Expo; later during 2011 to mid-2012, the final large scale field trial was conducted by China Mobile; moreover, in 2013 GTI Summit, China Mobile collaborating with several vendors jointly published the TD-LTE devices. As an interviewee from China Mobile indicated:

> *"As a GSE, operating TD-SCDMA was the result of following government order… Unicom and Telecom benefiting from operating the other two systems have successfully caught up with us in market… we started so early on investing in TD-LTE, with the hope to take back the leading position, we have strong motivation in the R&D and commercializing TD-LTE…"(MO_CMB1)*

In fact, China Mobile as an entrepreneur to promote TD-LTE also organized a series of activities to showcase the fast-growing TD-LTE global system and to further increase the confidence of international operators. For example, at the GTI conference, China Mobile and Vodafone set up a live demonstration of the first TDD/LTE FDD converged network to showcase the performance of the TD-LTE network in an outdoor environment and its convergence with the LTE FDD network (MO_CMB1). Moreover, China Mobile also held bilateral face-to-face meetings separately with high-level officers from more than 20 operators from all over the world. This action represented a significant milestone which demonstrated that China is now focusing on standards and technologies and the development of ecosystem, partnerships and public relationships.

Furthermore, as a strong supporter and active promoter of TD-LTE, China Mobile has aggressively driven the domestic industry forward through its network deployment targets and active test plans. It has specifically announced that it would upgrade all of its existing TD-SCDMA assets into TD-LTE (MO_CMB3). It has conducted numerous trails with various infrastructure vendors, device manufacturers and chipset suppliers to optimize the TD-LTE in both technology and the devices ecosystem (MO_CMB2). It has been observed that, before Chinese government issued TD-LTE licenses, by the end of 2013, China Mobile had already installed 22 thousand TD-LTE base station, procured 1.2 million TD-LTE devices and 1.1 million TD-LTE base stations (TDIA, 2014). As interviewees from China Mobile indicated:

> *"Although our Group (China Mobile) has already invested more than 190 billion, it seems huge; however such investment could help the overall telecommunication industry in our country to save the money and to generate the value, which could be several times more than our investment." (MO_CMB2)*

Supported by the government, China Mobile coordinated with a broad range of firms from China and abroad has significantly contributed to the standardization of TD-LTE. Consequently, numerous MNEs had expressed interest in the Chinese 4G technology. As in September 2011, 24 international technology vendors had joined the global TD-LTE development initiative, and 10 international operators had released the plan for TD-LTE commercialization. In the earlier stage, most MNEs did not join the initiatives to invest in Chinese standard with the consideration of their limited adoption in the global market. Nevertheless, they could not ignore the huge potential of telecommunication market in China. The huge investment of China Mobile and its wide range partnership, to some extent, had demonstrated government support and convinced them to adopt.

8.4.5 Resource mobilization

Resource mobilization function contributed to the TD-LTE innovation in both development and diffusion stage. The function was crucial as the success of innovation is heavily depending on whether the resources are available, or efficiently applied to core actors. In this case, the TIS played significant roles in mobilizing requested resources, such as financial capital, human capital and complementary assets to support the TIS actors to develop and to diffuse the TD-LTE. Function of mobilizing resources was mainly undertaken by the government authorities like MIIT and the influential industrial associations such as 3GPP and IEEE who had control on the resources.

In the case of TD-LTE, through impacting on regulative institutions and shaping cognitive institutions, Chinese government was observed to mobilize resources for supporting TD-LTE in development and diffusion. For example, MIIT launched TD-LTE industrialization Special Program (TISP) in October 2013, which offered 34 billion RMB subsidies to participating domestic firms to work on the 8 key projects of TD-LTE industrialization (TDIA, 2013). Despite of financial support, complementary resources were also provided by the government to support TD-LTE. For instance, by introducing preferential policies, nearly 4 times more spectrums were allocated to TD-LTE than LTE FDD, and the TD-LTE licenses were issued to operators nearly two years early than LTE FDD (TDIA, 2014, Sohu, 2015).

IPR agreement was arranged by MIIT between Datang Telecom and other TD-LTE market stakeholders. This happened during later 2012 to early 2013, after allocating the 4G spectrum, which was helpful for forming an industrial value chain of TD-LTE diffusion (DatangTelecom, 2013). The government encouraged GSEs to invest on TD-LTE. For example, according to annual reports of these leading GSEs in 2013, Datang Telecom invested over 790 million RMB in developing TD-LTE chips, terminals and networks; ZTE spent nearly 530 million RMB in producing TD-LTE devices; and China Mobile invested more than 200 billion RMB in TD-LTE network construction and terminal procurement (TDIA, 2014; China Mobile, 2014).

8.4.6 Market formation

Market formation function of TD-LTE innovation system contributed to the innovation mainly in the diffusion stage. The function helped articulate the demands for potential customers and create competitive advantages. In the TD-LTE innovation, the activities of market formation were mainly undertaken by firms in different industrial sector who had invested or held interests in deploying TD-LTE.

Nevertheless, several challenges were faced to form the TD-LTE market, especially how to convince the industrial participators to select TD-LTE. Initially, the government had planned to issue TD-LTE licenses to all three domestic mobile operators to collaboratively promote the industrialization and commercialization of TD-LTE. While the problem that faced was only China Mobile wanted the TD-LTE license, and China Mobile has constantly expressed the hope that more than one TD-LTE operator exist in China (GA_M3; MO_CMB1). China Unicom had an HSPA based network thus wanted to deploy an LTE FDD network (MO_CUB2). China Telecom had a CDMA2000 network and also wanted to deploy LTE FDD because of the more matured device ecosystem than that of TD-LTE (MO_CTB2). Besides, in the contemporary, only China Mobile adopted the TD-SCDMA and had invested huge in establishing TD-SCDMA infrastructure, which means if China Unicom and China Telecom shifted their paths from FDD based network to TDD, the cost would be a significant consideration.

To address the challenges that faced in market formation, it has been observed that the government not only took strong regulative interventions on TIS actors, but also used regulative, normative and cognitive instruments to create and shape the institutional environments for TD-LTE.

For example, TDIA formed in the 3G era continued serve as a platform for participated firms to exchange viewpoints on TD-LTE standardization and to improve their collaboration. Besides, MIIT also formed a TD-LTE working group in 2008, all three operators were invited as core members, and the itinerary for TD-LTE industrialization was made to ensure an efficient diffusion of TD-LTE. Furthermore, in

December 2013, MIIT issued TD-LTE licenses to three services operators (TDIA, 2014), but it was later until February 2015 when two FDD-LTE licenses were issued (Reuters, 2015). Benefiting from the early-mover advantage and more bandwidth, TD-LTE system deployment gained momentum in both domestic and global 4G market.

Moreover, promoting by the government and leading companies, more and more international firms were invited to participate in the standardization of TD-LTE. For example, in February 2008 at TD-LTE industry summit in Barcelona, China Mobile announced that UK Vodafone and US Verizon Wireless would participate in the system test. Further, in February 2011, at GSMA summit, China Mobile jointly with many international operators have established the Global TD-LTE initiative (GTI), which aims to facilitate the cooperation between international firms in terms of TD-LTE development and diffusion. By the end of 2011, GTI has become one of the most influential organizations by enrolling 114 international operators and 95 vendors.

To pursue a larger-scale diffusion of TD-LTE in both domestic and overseas markets, China Mobile also collaborated with Apple Co. in providing TD-LTE services through TD-supported Apple devices (TDIA, 2014). In fact, both China Mobile and Apple faced the need of collaborating with each other. Interestingly, Apple had not adopted China's homegrown 3G standard, but its sales in China in 2011 had increased nearly four times than in 2010. In 2012, Apple's revenues from China even contributed more than 15% of its overall revenue. Seeing such a huge market potential, Apple also seek to partake in China's TD-LTE diffusion by collaborating with China Mobile to provide terminals and content for the market.

In addition, TD-LTE is gaining significant traction in emerging markets, such as Africa, which lack a fixed-line infrastructure. TD-LTE could help provide an efficient and effective solution for last-mile connectivity in Africa. Domestic technology firms such as Huawei and ZTE have specifically contributed to TD-LTE's market formation in less-developed regions like Africa with strong support from the government. As result, by the end of 2015, TD-LTE has taken more than 50% market share in the EU and dominated the market in less-developed regions (TDIA, 2014).

8.4.7 Creating legitimacy

Creating legitimacy function of TD-LTE innovation system contributed to the innovation mainly in the diffusion stage. The related activities were jointly undertaken by mobile operator, technology vendors and R&D institutes who had invested in the TD-LTE. By creating legitimacy, the function undertakers helped counteract the resistance to change and facilitate TD-LTE to merge into the incumbent regime.

In fact, after the market formation with government support, the situation for TD-LTE to commercialize was far better than that of TD-SCDMA in contemporary. For example, the 4G market was relatively well articulated, more and more released 4G needed services, contents as well as applications were available (Huawei, 2015). In addition, more and more global influential vendors and mobile operators have started to invest in TD-LTE, like Samsung, Apple, Ericsson, etc. Their participations and investments in TD-LTE had largely legitimated TD-LTE in a global scale.

Even so, it was observed that Chinese government also supported to create higher level legitimacy for TD-LTE in a large scale. For example, through regulative intervention in TIS institution, all the three mobile operators in China were granted with TD-LTE licenses 2 years before FDD, and China Mobile was selected to take the lead in TD-LTE diffusion by giving bias TD-LTE spectrum (MIIT, 2014). As in October 2012, the Radio Regulatory Bureau of MIIT announced 2.6GHz spectrum planning in China, with allocating the 2500-2690MHz (190MHz) band for TD-LTE (ibid.). The announcement was also designed to be in favor of Clearwire, which planned to use the same band for its TD-LTE network in the US. Clearwire and China Mobile jointly worked to build global support for TD-LTE in this band through the GTI (MO_CMB1).

Besides, the government also encouraged domestic technology firms to participate in developing the ecosystem for TD-LTE. As result, the domestic firms were the key beneficiaries in the equipment market, and thereby, virtually dominated the TD-LTE equipment market. For example, in terms of the overall equipment market of TD-LTE, by the end of 2012, Huawei took 25%, ZTE took 23%, Datang took 13%, and all the others including Ericsson and Alcatel took the rest 39% (TDIA, 2014, Huawei, 2015).

Among all the domestic firms, Huawei was actively involved in both development and diffusion of TD-LTE. To develop its own TD-LTE based equipment ecosystem, Huawei have established many research institutes to conduct R&D in equipment manufacturing, such as the joint TD-LTE interoperability testing labs in Xi'an, Shenzhen, Shanghai and Beijing (Huawei, 2014, TV_HB, TV_HS2). Through years of R&D, its wholly-owned subsidiary – Hisilicon has already grown into an international influential TD-LTE chipsets manufacturer (TDIA, 2014).

As former introduced, Huawei and ZTE were also the leading domestic firms that largely promoted the TD-LTE diffusion in the oversea market, thus the enhancement of their competitiveness in the market could also significantly help create legitimacy for TD-LTE to commercialize. For example, in 2012, in total 29 global mobile operators signed 45 TD-LTE commercial contracts with Huawei and in total 64 TD-LTE laboratory networks were constructed in this year (Huawei, 2015); in 2013, Clearwire in the US procured the first batch of 2000 base stations from Huawei to construct its commercial TD-LTE network (Huawei, 2014). Huawei is a private technology firm but with highly government support through industrial policy and officials' voice. Comparatively, ZTE is a GSE thus the government could support it through regulative interventions like administrating and direct subsidizing (ZTE, 2014; RD_S1; RD_TR2). Through supporting these key TIS actors, the legitimacy for TD-LTE was well created.

To sum up, the case of TD-LTE innovation in this section has demonstrated that how the TD-LTE TIS structural components could decide the system functions with government intervention. Whether the system could be well functioned or not then could decide whether the system targets could be achieved or not. In the following section, we summarized the performance of TD-LTE innovation system in both development and diffusion stage.

8.5 PERFORMANCE OF TD-LTE INNOVATION SYSTEM

8.5.1 Technology development: creating competitive international 4G technology

According to data collection, there at least existed two major expectations towards developing 4G TD-LTE: to create a competitive international 4G standard, and at the meanwhile, to enhance the sustainability in high-tech development through continuous promoting the indigenous innovation capabilities (Stewart et al., 2011, Xia, 2012b). For example, then the President Jiang Zemin demonstrated the significance of TD-LTE as:

> *"... since our indigenous developed 3G TD-SCDMA has already started to commercialize, then we should pay highly attention on its technology evolution... to grasp the chance in the development of next generation mobile technology, and to strengthen the R&D in TD-LTE, and to develop our TD-LTE into the world's leading technology..."(Xinhua, 2008)*

If assessed from these perspectives, then China's initiative of developing TD-LTE could be viewed as a tremendous success. For instance, in terms of the target to create comparative international 4G standard, TD-LTE had been well developed and authorized as one of two international 4G standard by ITU. Besides, with a large scale of international collaborations, the overall development process was leaded by Chinese enterprises like China Mobile and Datang. Unlike TD-SCDMA development, which was mostly conducted by CATT/Datang and Siemens, there were 8 Chinese domestic firms and more than 10 MNEs from nearly every single segment of the 4G industrial value chain had contributed to the TD-LTE development. As a result, TD-LTE has not only narrowed the technological distance with the LTE FDD, but also highlighted the advantages that TD-based system has a higher spectrum efficiency (Yang and Li, 2014).

Furthermore, experienced the throughout TD-SCDMA innovation process, the enhancement of R&D capability in Chinese domestic enterprises had been obviously expressed. For instance, the first TD-LTE concept was proposed by Datang, and China Mobile had leaded the R&D and proposed the "Type-2 based TDD frame structure", which would tremendously promote the integration of LTE FDD and TD-LTE in future. Besides, as mentioned, when enterprises that support FDD were refusing to introduce smart antenna technology in the overall design of LTE, 3GPP held a special LTE TDD Ad Hoc meeting in Beijing to focus on specific solutions, and the positive agreement was reached at last under the strong promotional efforts by domestic firms.

Either efficient R&D conductions or skilled standardization negotiations have both evidenced that the indigenous innovation capabilities of Chinese domestic enterprises were largely enhanced. The domestic enterprises have not only broken the dependencies on foreign technologies, what is more, the sustainable indigenous innovation capability was gradually established. Taking Huawei as example, by the end of 2014, Huawei had 14000 research staffs, 4000 engineers and 11 huge R&D centers to respond for TD-LTE R&D. Ranked in the first place, in total over 260 core LTE standard proposals from Huawei were approved, nearly 20% of the total in the world. The products from Huawei could cover every single segment of the TD-LTE industrial value chain, from chipsets, terminals to antennas and base stations (Huawei, 2014). Therefore, assessed from these aspects, performance of TD-LTE TIS in development was a great success. As an interviewee from MIIT indicated:

> *"Technology innovations in our telecommunication industry in China, especially in mobile systems standardization, have entered the fast track. We are changing the strategy from initially imitative innovation, to indigenous innovation, and now start shift to collaborative innovation within the global scale…" (GA_M3)*

8.5.2 Technology diffusion: promoting industrialization, commercialization and economic growth

In terms of technology diffusion, expectations could be expressed from three dimensions as: to further improve and strengthen the TD-LTE industrial value chain, to achieve large scale and high profit of commercialization, and further to better drive the overall economic growth in China (TDIA, 2013, Chen et al., 2014). As an interviewee from MIIT expressed the significance of TD-LTE diffusion as:

> *"...promoting TD-LTE innovation is not only a key to enhance the capability of indigenous innovation, but also a strategic solution to 'increase domestic demand and maintain high rate of growth'… China Mobile is expected to drive*

the whole industry to achieve breakthrough in core fields like smart terminals and multichip, and enhance the international influence of TD-LTE."(GA_M1)

If assessed from these perspectives, then China's initiative of diffusing TD-LTE could also be viewed as a remarkable success. Firstly, the 4G TD-LTE industrial value chain has been tremendously improved in every single segment along with TD-LTE diffusion. For instance, in terms of spectrum, from 2009 to 2011, the auction price of 2.6 GHz TD spectrum in EU had increased 13 times; for purchasing TD spectrum, Softbank in Japan had acquired Willcom and Optus in Austria had acquired Vividwireless (CCID, 2013). In terms of chipsets and terminals, seven-module multichip for TD-LTE was introduced by Qualcomm; five-module multichip was introduced by Hisilicon; by the end of 2012, in total 116 TD-LTE terminals from 67 vendors were introduced.

Secondly, a large scale and high profit commercialization was achieved during the diffusion of TD-LTE. For example, in the domestic market, by the end of July 2014, over 1 million TD-LTE base stations were constructed, nearly 210 million TD-LTE handsets were sold, and more than 230 million individual customers registered for TD-LTE services with China Mobile, the leader of TD-LTE industrialization (ChinaMobile, 2014). In oversea markets, by the end of 2014, 42 TD-LTE commercial networks were operated in 26 nations, 117 operators and 97 vendors participated in the construction and deployment of TD-LTE system (TDIA, 2014).

At last, in terms of economic growth, according to incomplete statistics, by the end of 2013, the direct increased employment number was over 2.2 million, and the indirect number was about 4.5 million; the increased investment was about 1000 billion, and increased consumption over 1500 billion; the contribution of TD-SCDMA to the GDP was about 2.3% in total (MIIT, 2014, Song, 2014).

So far, according to the data that been collected, the case of TD-LTE innovation in China has been illustrated through understanding the structure of its innovation system, the system functions, challenges and government interventions, as well as the system performance in technology development and diffusion. To conclude the elaboration, we summarized the key system features in the Table 8.4 as followed.

Table 8.4 Features of TD-LTE innovation system

Stages	TD-LTE Development	TD-LTE Diffusion
Milestones	*March 2005 to October 2010* • System development was mostly finished • TD-LTE was written in 3GPP Release 8 • TD-LTE was authorized by ITU	*February 2010 - Now* • TD-LTE equipment was available • Network and system tests were finished • Spectrum with 200 MHz was allocated • Commercial trial and license were launched
System components	*Key actors* • R&D institutes: Datang; RITT; CATR; • Vendors: Datang; Huawei; ZTE; Ericsson; Siemens; Nokia; Qualcomm • Operators: China Mobile; Softbank • Universities: Tsinghua; BUPT; SJTU • Industrial Alliances: 3GPP; LSTI; GCF; *Key networks* • Government – R&D institutes • Universities – R&D institutes • Industrial Alliance – R&D institutes • R&D institutes – Vendors – Operators *Key institutions* • Cognitive: commonly held positive expectations towards TD-LTE; reducing IPRs payments; enhancing national security.	*Key actors* • R&D institutes: CATR; CAS; R&D in firms • Vendors: Datang; Huawei; ZTE; Qualcomm Ericsson; Siemens; Alcatel; Samsung; Apple; • Operators: China Mobile; China Unicom; China Telecom; Softbank; UKB; STC • Industrial Alliances: NGMN; TDIA; GTI; *Key networks* • Government – Operators – Vendors • Industrial Alliance – Operators – Vendors *Key institutions* • Regulative: Gave Spectrum and funds with bias; Issued TD-LTE license 1.5 years before FDD; NDRC promoted TD industrialization • Normative: National pride in catching-up • Cognitive: commonly held positive expectations towards TD-LTE; reducing IPRs payments; enhancing national security.
System functions	*Knowledge development & diffusion* • TD & OFDM based proposal from Datang • Type-2 frame structure from China Mobile • BUPT submitted 22 technical proposals *Research guidance* • RITT was designated to lead TD-LTE R&D with full government authorization • High-level officer voiced support to TD-LTE *Entrepreneurial experiments* • Datang leaded R&D and testing TD-LTE • 3GPP, LSTI, GCF organized testing TD-LTE *Resource mobilization* • 30 billion credit assigned to Datang for R&D • China Mobile established TD-LTE special project to subsidize R&D	*Entrepreneurial experiments* • China Mobile leaded testing and commercial trial of TD-LTE • NGMN, TDIA, GTI, MIIT organized testing *Resource mobilization* • MII launched TISP with 34 billion RMB as the budget to subsidize domestic firms to work on key TD-LTE industrialization project • National banks were asked to offer loans with privileged interests rates for TD-LTE • Offered high rate of VAT refunds for vendors • Allocated 200 MHz spectrum to TD-LTE *Market formation & Legitimation* • TD-LTE licenses issued nearly two years earlier than FDD • Most TD spectrum gave to China Mobile, the operator invested heavily in TD-LTE.
System performance	*Created comparative international 4G* • TD-LTE with higher spectrum efficiency was developed and authorized by ITU • TD-LTE attracted WiMAX vendors to join *Promoted sustainable innovation capability* • Domestic R&D institutes and vendors grew, started to lead international standardization, and started to catch-up with influential MNEs	*Promoted TD-LTE industrialization* • TD-LTE industrial value chain was further developed and improved in every segment *Promoted TD-LTE commercialization* • 230M CN users; 1 million base stations; 210 million handsets; 42 networks in 26 nations *Promoted national economic growth* • Over 6.7 million employment • about 2500 billion revenue • over 2.3% GDP contribution

8.6 SUMMARY

In this section, we elaborated the cases of 4G TD-LTE innovation in China. Through summarizing the key events in both technology development and diffusion stages, we first generated a chronology and illustrated the process of China's TD-LTE innovation. Then followed the theoretical framework, we elaborated how the government in China promoted this indigenous technology innovation by intervening on the institutional environment and the activities undertakers in the innovation system.

Specifically, associating with the data collected from documentary research and semi-structured interviews, we first delineated the structure of TD-LTE innovation system, as a conclusion, we summarized the feature of institutional environment of the system and identified that the system actors. Compared with TD-SCDMA, it was observed that cognitive institution replaced regulative institution performed as the major influential forces; system actors were more diversified, more MNEs were active in the TD-LTE innovation. Besides, we also found that system actors in different groups no longer just undertook innovation activities in a single stage: more developers were active to help diffuse TD-LTE, and more operators and vendors had taken part in the development stage at the start, such as China Mobile and ZTE. The government still firmly supported the domestic firms to contribute to TD-LTE innovation.

Based on understanding the structure of TD-LTE innovation system, we also captured each of the seven TIS functions along with the innovation process. It has also been observed that seven functions were not independent from each other but interact and influence each other. Several challenges still faced in fulfilling each system function. Nevertheless, unlike TD-SCDMA innovation, the challenges that hindered TD-LTE development were mostly caused by heterogeneity of actors but not deficiencies. As completely experienced the development and diffusion of 3G standards, the mobile industry have been well established and cultivated. Domestic technology firms like ZTE, Huawei, Lenovo and Datang had grown into leading MNEs in global market, and few deficiencies were faced in terms of resources and capabilities.

For TD-LTE innovation to success, it has been observed that China's government also provided firmly support to address these challenges in both development and diffusion. On the one hand, the government took regulative, normative and cognitive interventions to create and shape the institutional environment in the innovation system to favor the TD-LTE innovation; on the other hand, the government also took regulative interventions like directive and administrative orders, to manipulate the system actors. Compared with TD-SCDMA innovation, it was obvious that the regulative interventions were still there and significant in both stages, but the degree and frequency were largely declined. More cognitive interventions were taken and most functions were actively undertaken by the TIS actors especially those with the government supports.

Furthermore, the performance of TD-LTE innovation system was also assessed with the consideration of specific initiatives of developing and diffusing TD-LTE. For example, in the development stage, the major expectations were to create a competitive international 4G standard, and at the meanwhile, to enhance the sustainability in indigenous high-tech research and development; in the diffusion stage, the expectations were to further improve and strengthen the TD-LTE industrial value chain, to achieve large scale and high profit of commercialization, and to better drive the national economic growth. No matter evaluated from which dimension, the TD-LTE innovation in China could be viewed as a remarkable success. Associating with the case of TD-SCDMA innovation, the overview of China's 20 years' catching-up in mobile system innovation has been well demonstrated: since 1995 when MPT first ordered CATT to develop 3G standards, to 2015 that TD-LTE has been deployed in 26 nations with more than 0.3 billion subscribers all over the world.

CHAPTER 9: DISCUSSION – COMPARATIVE STUDY OF CHINA'S MOBILE SYSTEM INNOVATIONS

9.1 INTRODUCTION

Based on the theoretical framework and the case studies, this chapter conducts a synthetic analysis of to understand the mechanism of government intervention in the TIS to promote the technology innovation, especially that in the catching-up context. Specifically, in section 9.2, we summarize the characteristics of TD-SCDMA and TD-LTE innovation system. Through analyzing the structure, functions and performances of TD-SCDMA and TD-LTE TIS, part of the first question (SQ1) – TIS features in the catching-up context, the second question (SQ2) – how technology development and diffusion are achieved in relation to the TIS, and the third question (SQ3) – main challenges that faced in TIS functions in catching-up are elaborately addressed. Besides, in section 9.3, through analyzing the government interventions in the TD-SCDMA and TD-LTE innovation, we answer the other part of the first question (SQ1) – the characteristics of government intervention in the catching-up context, and the fourth question (SQ4) – the instruments that government used for addressing identified challenges in innovation. Then section 9.5 concludes this chapter at the end.

9.2 PERFORMANCES OF TD-SCDMA AND TD-LTE TIS

Table 9.1 summarizes the comparison between TIS performances in TD-SCDMA and TD-LTE development and diffusion, and thereby evidences the conclusion that TIS of TD-LTE performs better than TD-SCDMA. Specifically, in the stage of technology development, TD-SCDMA and TD-LTE were both developed with new added technology features and authorized by ITU as international standards. Nevertheless, despite of similar outcomes, TD-SCDMA was developed based on Cwill's SCDMA technology and Siemens' TD-CDMA technology, but TD-LTE was developed based on Datang's proposal and leaded by China Mobile with wide range of international vendors and operators collaboration. Thus as Table 9.1 indicated, TD-SCDMA TIS helped domestic technology firms and R&D institutes to reduce the dependencies on foreign technologies, but TD-LTE TIS enabled them to take the lead in international standardization and catching-up influential MNEs.

Table 9.1 Performances comparison between TD-SCDMA and TD-LTE innovation system

Innovation Stages	Technology Development	Technology Diffusion
TD-SCDMA TIS performance	*Created comparative 3G technology* • TD-SCDMA with new added technological features was created • successfully authorized by ITU as one of the three international 3G standards *Promoted indigenous innovation capability* • Held 43 core patents for TD and 35 for SCDMA • Domestic R&D institutes and vendors grew, and started to reduce dependencies on foreign technologies.	*Promoted TD-SCDMA industrialization* • TD-SCDMA industrial value chain was formed by domestic firms and a few MNEs • Few MNEs interested in participant • Key components like chipsets are still produced by MNEs like Qualcomm *Promoted TD-SCDMA commercialization* • 87.9 million users was attracted in 3 years • Only 1 TD-SCDMA license issued • Only implemented in mainland China *Promoted national economic growth* • 3.9 million employment increased • Generated about 875 billion revenue • Over 0.5% GDP contribution
TD-LTE TIS performance	*Created comparative international 4G* • TD-LTE with higher spectrum efficiency was developed and authorized by ITU • TD-LTE attracted WiMAX vendors to join *Promoted sustainable innovation capability* • Held over 22% core patents for TD-LTE • Domestic R&D institutes and vendors grew, started to lead international standardization, and started to catch-up with influential MNEs	*Promoted TD-LTE industrialization* • TD-LTE industrial value chain was further developed and improved in every segment *Promoted TD-LTE commercialization* • 230M CN users; 1 million base stations; 210 million handsets; 42 networks in 26 nations *Promoted national economic growth* • Over 6.7 million employment • about 2500 billion revenue • over 2.3% GDP contribution

The real gap between TIS performances in TD-SCDMA and TD-LTE innovation is reflected in the diffusion stage. In terms of industrialization, TD-SCDMA industrial value chain was mainly constructed by domestic firms; few MNEs were interested in investing the technology; and several core and high value-added system products like chipsets were mainly produced by MNEs. In the contrast, TD-LTE attracted great enthusiasms from 97 vendors and 117 mobile operators worldwide. Besides, in terms of commercialization, TD-SCDMA license was only issued to China Mobile and only operated in mainland China, while TD-LTE has been deployed in 26 nations with 42 commercial networks; TD-LTE has attracted 230 million subscribers in China within 2 years, comparatively, TD-SCDMA only has 87.9 million users in the first three years' deployment. Furthermore, in terms of promoting national economic growth, TD-LTE diffusion provided double employments, three times of revenue generation, and five times of GDP contribution than that of TD-SCDMA. Thus, we can conclude that the TD-LTE innovation system performed much better than the TD-SCDMA innovation system, especially in the diffusion stage.

9.3 FUNCTIONS OF TD-SCDMA AND TD-LTE TIS

As indicated by Bergek et al. (2008), the performance of a technological innovation system in technology development and diffusion could be viewed as the collectively reflections of system functions fulfillments in each stage. In TD-SCDMA and TD-LTE innovation, the system functions were observed to be different mainly in two dimensions: TD-LTE TIS functioned better than the TD-SCDMA TIS in every single sub function; TD-SCDMA TIS function worked more independent from each other and followed a linear manner along with the sequential order of technology development and diffusion, while TD-LTE TIS functions were more likely to interact and influence each other, and collaboratively contributed the technology innovation with many positive cycles. Thus with aim to understand how TIS functions were different in the two innovation cases, we summarized the comparison between TIS functions in TD-SCDMA and TD-LTE innovation in Table 9.2 as followed.

Table 9.2 Functions comparison between TD-SCDMA and TD-LTE innovation system

Innovation Stages	Technology Development	Technology Diffusion
TD-SCDMA TIS functions	*Knowledge development & diffusion* • Xinwei was formed to focus on SCDMA • Siemens was invited to focus on TD *Research guidance* • CATT was designated to lead TD-SCDMA R&D with full government authorization • MII offered over 1 billion RMB fund to R&D *Entrepreneurial experiments* • Datang was formed to take lead in developing and testing TD-SCDMA *Resource mobilization* • MPT spent 20 million RMB to support the formation of Xinwei, 1.3 billion RMB to Datang for TD-SCDMA development • Moved TD-SCDMA R&D group to Datang	*Entrepreneurial experiments* • China Mobile was ordered to take lead in the diffusion of TD-SCDMA *Research guidance* • MII launched TRIP with 708 million RMB *Resource mobilization* • National banks were asked to offer loans with privileged interests rates for TD-SCDMA • Offered high rate of VAT refunds for vendors • Transferred IPRs from Datang to key vendors • Allocated 155 MHz spectrum to TD-SCDMA *Market formation & Legitimation* • Advocating national pride and national goals to cultivate and establish normative and cognitive institutional environment
TD-LTE TIS functions	*Knowledge development & diffusion* • TD & OFDM based proposal from Datang • Type-2 frame structure from China Mobile • BUPT submitted 22 technical proposals *Research guidance* • RITT was designated to lead TD-LTE R&D with full government authorization • Mainly leaded by 3GPP in further R&D *Entrepreneurial experiments* • Datang leaded R&D and testing TD-LTE • 3GPP, LSTI, GCF organized testing TD-LTE *Resource mobilization* • 30 billion credit assigned to Datang for R&D • China Mobile established TD-LTE fund	*Entrepreneurial experiments* • China Mobile leaded testing and commercial trial of TD-LTE • NGMN, TDIA, GTI, MIIT organized testing *Research guidance* • MII launched TISP with 34 billion RMB • GTI leaded R&D on devices *Resource mobilization* • National banks were asked to offer loans with privileged interests rates for TD-LTE • Offered high rate of VAT refunds for vendors • Allocated 200 MHz spectrum to TD-LTE *Market formation & Legitimation* • TD-LTE licenses issued earlier than FDD

TIS functions comparison between TD-SCDMA and TD-LTE

Individually looking at the seven identified TIS functions, TD-LTE TIS has presented a better fulfillment in each of them than that of TD-SCDMA TIS. Specifically, knowledge of TD-SCDMA was mainly developed by later invited actors – Cwill and Siemens, but TD-LTE was initiated and developed by existed actors – Datang and China Mobile with higher efficiency and lower cost. TD-SCDMA knowledge was mainly diffused to a few domestic R&D institutes and vendors, but TD-LTE knowledge was diffused into wide range of firms almost covered every single segment of the industry, which had largely facilitated the technology diffusion in later stage. Besides, the function of research guidance of TD-SCDMA TIS was mainly undertaken with government orders and financial incentives, but TD-LTE TIS guided related research on

TD-LTE mainly based on the positive expectations, voiced government support and leading TIS actors. Moreover, there was no real sense entrepreneurial experimentations in TD-SCDMA, as Datang leaded technology development and China Mobile leaded technology diffusion were both ordered by the government and the risks were also taken by the government. Furthermore, the function of resource mobilization of TD-SCDMA TIS was mainly enabled by the government authorities, but TD-LTE TIS attracted more private capitals to invest in the technology. In addition, in terms of market formation and legitimation, the better performances of TD-LTE TIS have been well elaborated when assessed the performance of two innovation systems in the diffusion stage.

TIS functions and process of technology innovation

Based on such understandings, it is observed that the process of how seven system functions contributed along with the technology development and diffusion are very different in TD-SCDMA and TD-LTE innovation. We made two timelines to allocate the sequential order of TIS functions in TD-SCDMA and TD-LTE innovation in Figure 9.1 and Figure 9.2, respectively. As the figures showed, the difference is that the TD-SCDMA TIS function worked more independent from each other and followed a linear manner along with the sequential order of technology development and diffusion, while TD-LTE TIS functions were more likely to interact and influence each other, and collaboratively contributed the technology innovation with many positive cycles.

For example, as Figure 9.1 showed, TD-SCDMA started from the research guidance function in 1995, when CATT started to develop Chinese 3G; then knowledge diffusion started from 1998 when 3G R&D Team was formed; after that, entrepreneurial activities emerged in 2000 when small scale system test was conducted; market formation started in 2002 when TDIA was built; then legitimation, as the final system function, started since 2006 when the government granted TD-SCDMA as the national 3G standard.

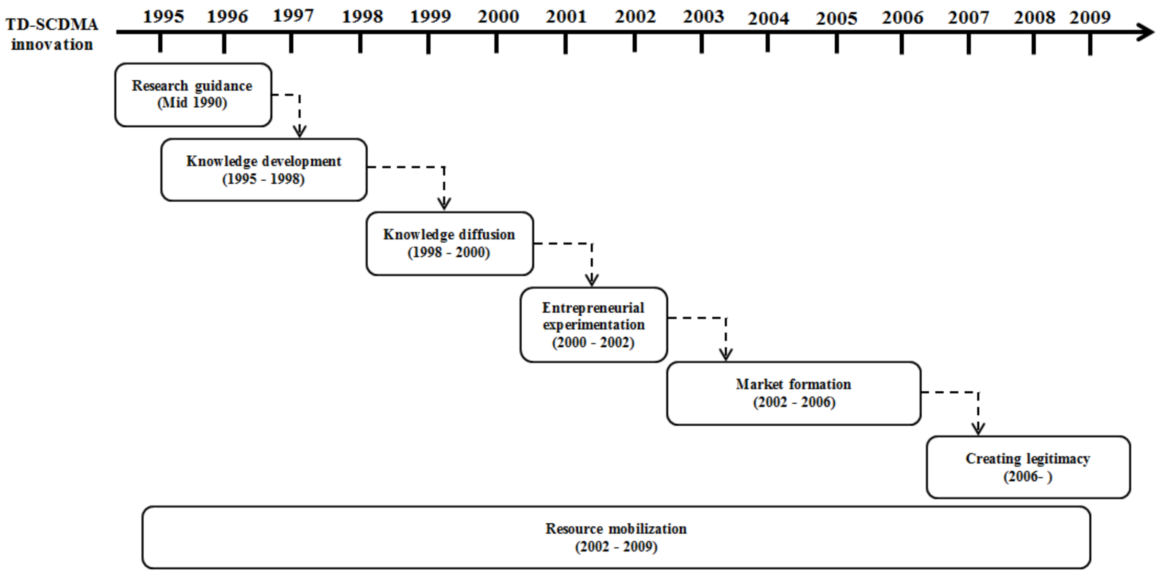

Figure 9.1 TD-SCDMA innovation system functions in the innovation process

Comparatively, TIS functions in TD-LTE innovation were not fulfilled in the linear order. As Figure 9.2 showed, the functions interacted and influenced each other quite often: TD-LTE innovation started from Datang's entrepreneurial R&D in 4G TD-LTE in March 2005; then research guidance and knowledge development process commonly lasted from November 2005 when MII decided to support development of Datang's proposal, to December 2008 when first version TD-LTE for commercialization – Release 8 was finished; knowledge diffusion function was achieved mostly along with the knowledge development, as it started from November 2006 when Datang submitted TD-LTE proposal to the ITU, until ITU accepted it as official international 4G standards in October 2010; entrepreneurial system test was conducted in 2008 until November 2010 when MII approved official plan for TD-LTE commercial trial in large scale; then research guidance function worked again in February 2011 when GTI was formed, and expended in September 2012 when TISP was introduced to guide industrialization; resource mobilization function worked every time when needed; market formation also started from 2011 when GTI was established; and the function of creating legitimacy was observed to emerge since MIIT issued TD-LTE licenses in December 2013.

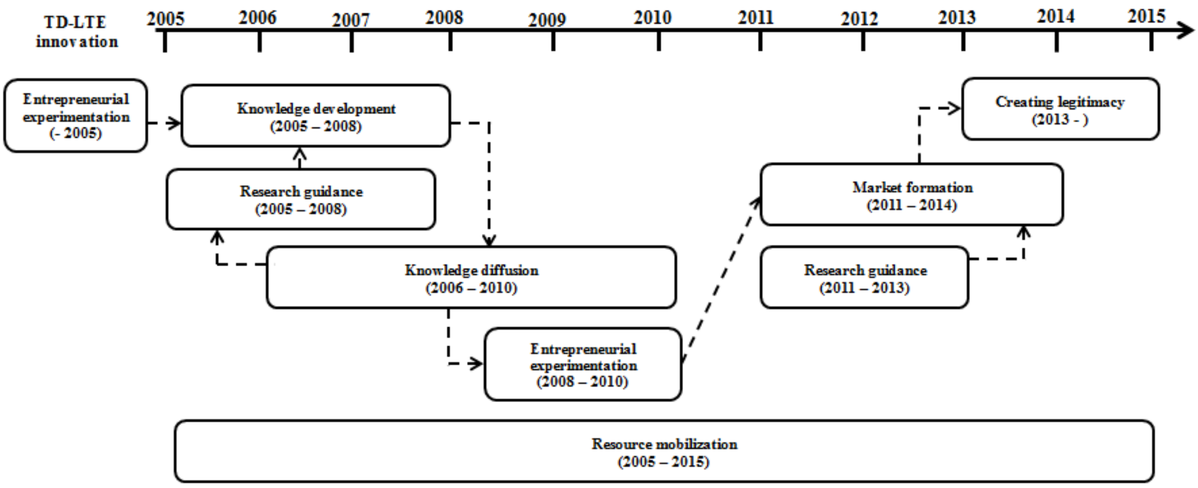

Figure 9.2 TD-LTE TIS functions in innovation process

Despite of differentiated degree of fulfillments in TIS functions, the similarity of how TIS functions contributed to innovation has indicated a temporal model as shown in Figure 9.3: some TIS functions are particular significant in the stage of technology development, like knowledge development and diffusion; some TIS functions play significant roles in both development and diffusion stage, like entrepreneurial experimentation, resource mobilization and research guidance; also some TIS functions contribute more in the technology diffusion stage, as market formation and legitimation.

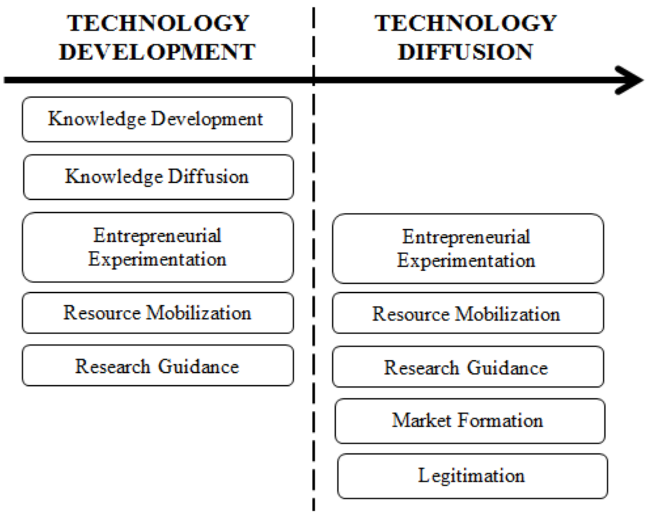

Figure 9.3 TIS functions distribution in stages of technology development and diffusion

Nevertheless, it should be noted that, functions that mainly contributed in one stage does not necessarily mean that they cannot contribute in the other stage. For example, it has been observed in both case studies that if a firm contributed to fulfill the function of knowledge development, then it is very possible that this firm would like to contribute to deploy the technology in later stage. Besides, as observed in the case studies, seven TIS functions could influence each other, to achieve one specific system function might has further effects on other functions. For example, the function of research guidance has contributed to knowledge development in TD-SCDMA and TD-LTE innovation; then after knowledge was created, the market might have expectations towards the new technology thus to diffuse the knowledge; and eventually might facilitate the function fulfilment in terms of market formation and creating legitimacy for the new technology. Therefore, as observed in the cast studies, the seven TIS functions are not independent with each other, but normally interact with each other, and in consequence could impact the outcomes and reflected the process of innovation.

Through comparing the performance and the functions between TD-SCDMA and TD-LTE innovation system, we suggest that Technology development and diffusion are enabled logically by seven TIS functions, namely knowledge development, knowledge diffusion, research guidance, entrepreneurial experimentation, resource mobilization, market formation and legitimation in an effective TIS. Seven TIS functions interact and influence each other with a temporal model, and with positive cycles created during the innovation process.

9.4 THE STRUCTURE OF TD-SCDMA AND TD-LTE TIS

As Hekkert et al. (2007) suggested, TIS functions refer to innovation activities that able to affect the technology development and diffusion. The functions are undertaken by system actors and determined by actors' behaviors, which is normally affected by the institutional environment within the innovation system (Liu and White, 2001). Since TIS actors, networks and institutional environments are collectively recognized as the three fundamental TIS components, thus the differences in terms of TIS functions are normally linked with the differences in terms of TIS structural components. With aim to understand how TIS structural components were different in the two innovation cases, we first summarized the comparison between two systems' structure in Table 9.3.

Table 9.3 Structure comparison between TD-SCDMA and TD-LTE innovation system

Innovation Stages	Technology Development	Technology Diffusion
TD-SCDMA TIS	<u>*Key actors*</u> • R&D institutes: CATT/Datang • Vendors: Datang; Xinwei; Siemens <u>*Key networks*</u> • Government – R&D institutes • R&D institutes – Vendors <u>*Key institutions*</u> • Regulative: Datang's proposal was recognized as national one; Subsidized to TD-SCDMA development project with funds and low rate loans;	<u>*Key actors*</u> • R&D institutes: CATR; CAS; R&D in firms • Vendors: Datang; ZTE; Huawei; Potevio • Operators: China Mobile • Industrial Alliances: TDIA <u>*Key networks*</u> • Government–Vendors; Government–Operator • Operators – Vendors <u>*Key institutions*</u> • Regulative: MII announced TD-SCDMA as the national 3G standard; Spectrum was allocated with a bias strategy; subsidies; • Normative: National pride in High-tech area • Cognitive: reducing IPRs payments and enhancing national security.
TD-LTE TIS components	<u>*Key actors*</u> • R&D institutes: Datang; RITT; CATR; • Vendors: Datang; Huawei; ZTE; Ericsson; Siemens; Nokia; Qualcomm • Operators: China Mobile; Softbank • Universities: Tsinghua; BUPT; SJTU • Industrial Alliances: 3GPP; LSTI; GCF; <u>*Key networks*</u> • Government – R&D institutes • Universities – R&D institutes • Industrial Alliance – R&D institutes • R&D institutes – Vendors – Operators <u>*Key institutions*</u> • Cognitive: commonly held positive expectations towards TD-LTE; reducing IPRs payments;	<u>*Key actors*</u> • R&D institutes: CATR; CAS; R&D in firms • Vendors: Datang; Huawei; ZTE; Qualcomm Ericsson; Siemens; Alcatel; Samsung; Apple; • Operators: China Mobile; China Unicom; China Telecom; Softbank; UKB; STC • Industrial Alliances: NGMN; TDIA; GTI; <u>*Key networks*</u> • Government – Operators – Vendors • Industrial Alliance – Operators – Vendors <u>*Key institutions*</u> • Regulative: Gave Spectrum and funds with bias; Issued TD-LTE license 1.5 years before FDD; NDRC promoted TD industrialization • Normative: National pride in catching-up • Cognitive: commonly held positive expectations towards TD-LTE

Comparison between TD-SCDMA and TD-LTE TIS actors

Several differences in terms of system actors between TD-SCDMA and TD-LTE TIS were observed in the case studies. Firstly, as Table 9.3 showed, a most obvious difference is that the key actors in TD-LTE TIS were far more abundant in quantity and diversity than the TD-SCDMA. For example, in the development stage, only CATT and Datang leaded R&D activities for TD-SCDMA; in the contrast, public R&D institutes like RITT and CATR, domestic technology firms like Huawei, ZTE and Datang, MNEs such as Siemens, Nokia and Ericsson, mobile operators like China Mobile, Clearwire US and Softbank Japan, national universities like BUPT, SJTU and Tsinghua, and industrial alliance like 3GPP and LSTI all contributed to the TD-LTE development. Similarly, in the diffusion stage, TD-SCDMA was mainly deployed by a few domestic TDIA members like Datang and China Mobile; in the contrast, TD-LTE diffusion was collectively undertaken by a wide range of organizations and firms, both domestic and overseas, almost in every single segment of the industry.

Secondly, another significant difference is that the key actors of TD-LTE TIS are mostly enrolled at the beginning stage of technology development, while the actors of TD-SCDMA were mostly established or invited when facing the need. It has been observed that many technology adopters were involved in TD-LTE development rather than just wait until the technology is ready to use, meanwhile, technology developers were also active in TD-LTE diffusion. For example, several key actors in TD-SCDMA diffusion, such as the technology vendors like Huawei and ZTE, and service provider like China Mobile were not involved in technology development; in the contrast, in the case of TD-LTE, apart from R&D institutes and universities that traditionally undertook R&D activities, a number of participants that traditional functioned in diffusion stage, such as technology vendors i.e. Huawei, ZTE, Qualcomm, Samsung and mobile operators i.e. China Mobile, Softbank, UKB were mostly enrolled in the system for technology development. The early enrollment of key actors in TD-LTE innovation, especially key technology adopters, has been proved to be significant in facilitating the system functions such as knowledge diffusion, market formation and legitimation.

As discussed in former section, TIS functions in TD-SCDMA followed a sequential order along with technology development and diffusion, but TD-LTE TIS functions were more dynamic and interact with each other. This difference could be interpreted by the differences in TIS actors that elaborated, as TIS functions were undertaken by the actors, thus earlier enrollment of key system actors could enable the system functions to be fulfilled in a more dynamic manner. For example, a most obvious difference in terms of TIS functions between two innovation cases is that TD-SCDMA innovation started from CATT's research guidance then knowledge developed after enrolling Siemens, Xinwei and Datang; TD-LTE innovation emerged from Datang's entrepreneurial R&D on 4G mobile system standard and then guided by RITT and 3GPP for further development. Obviously, there was no way that TD-SCDMA innovation could start from a domestic firm's entrepreneurial experimentation, because the TIS initially was built up by CATT who was the only actor in the beginning stage, and no domestic actor was capable to fulfill the function of entrepreneurial experimentation in contemporary.

As we concluded in the section 9.2.2 that independent and interacted TIS functions in fulfillment could lead to a better TIS performance in technology development and diffusion, and exhibited in this section that how TIS functions fulfilled are determined by what and how TIS actors are enrolled, thus we could draw another conclusion in relation to the system actors that sufficient number of actors with key resources and capabilities must be enrolled into the TIS to ensure the success of technology innovation; enrolling key actors in the TIS at the early stage of technology innovation could reduce the uncertainty thus facilitate both technology development and technology diffusion.

Comparison between TIS networks between TD-SCDMA and TD-LTE

Apart from differences in system actors, the TD-SCDMA and TD-LTE TIS also presented many differences in terms of networks in the innovation system. Networks in TIS are established based on the interactions between the actors in the system. To capture all the networks in such a complicated technology innovation is unrealistic and meaningless, as some interactions might be established based on business relationships between firms in private, and have neither implicit nor explicit relationship with the innovation targets. Therefore, with aim to capture the related networks in innovation, we took the strategy to redistribute the TIS functions among the TIS actors (Figure 9.4).

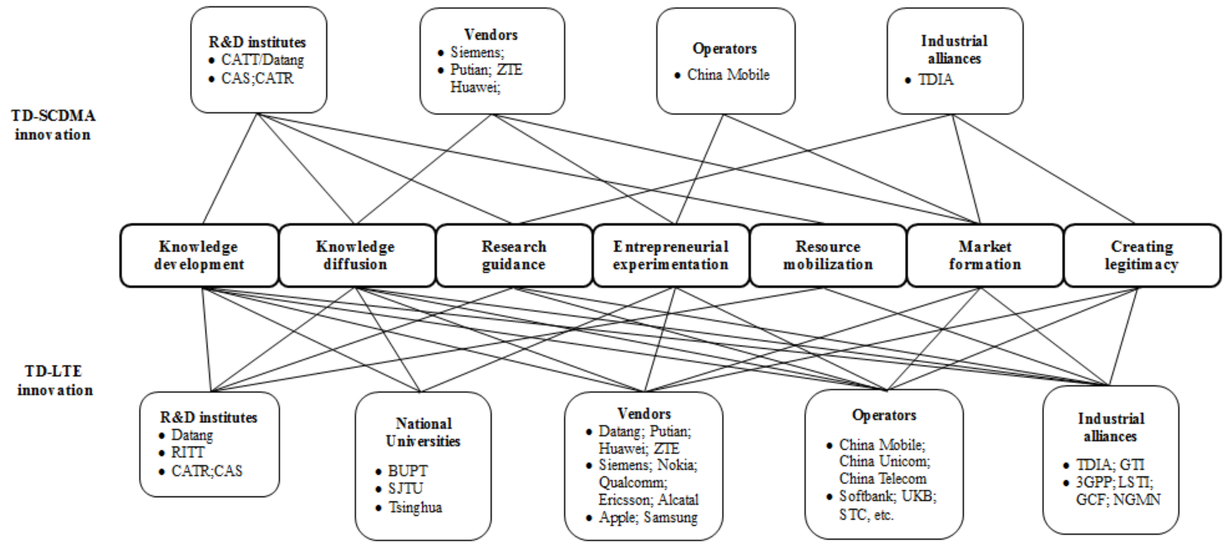

Figure 9.4 Redistributing TIS functions among actors in TD-SCDMA and TD-LTE innovation

Networks in TD-SCDMA TIS are mostly composed by formal networks i.e. problem-solving and buyer-supplier and relatively deficient if compared with that in the TD-LTE TIS. For example, in the case of TD-SCDMA innovation, most innovation networks were initialed and controlled by the government with the primary target to address faced innovation challenges. In the contrast, the relationships in TD-LTE innovation system are much more abundant and diversified, and many informal networks were also established i.e. conferences and solons in addition with formal networks. For example, many key participants were enrolled in the 3GPP, TDIA and GTI, with a massive number of networks established.

Furthermore, in case of TD-LTE innovation, it is also observed that the core networks were mostly built up at the early stage of technology development, even if the networks functioned mainly to serve the technology diffusion. For example, key vendors such as Huawei, ZTE and Datang all established strategic partnerships with China Mobile – the most possible mobile operator to run TD-LTE since the development of TD-LTE. In fact, the early establishment of key networks could also help reduce the uncertainty of innovation, thus to enhance the TIS performance in both technology development and diffusion. Therefore, based on the discussions, we suggest that sufficient formal and informal networks must be established to ensure the success of technology innovation; building up core networks in the TIS at the early stage of technology innovation could reduce the uncertainty thus facilitate both technology development and diffusion.

Comparison between TD-SCDMA and TD-LTE TIS institutions

It has been observed that institutional environment in the innovation system had played significant roles in shaping actors' behaviors in both innovation cases. Regulative, normative and cognitive institutions together composed the institutional environment for both innovation systems, and impacted innovations in different stages.

In terms of regulative institutional environment, for example, at the early stage of TD-SCDMA development, the proposal raised from Datang was authorized as the only 3G mobile system standard that China was about to develop; In diffusion stage, before TD-SCDMA commercialization, MII announced TD-SCDMA as the only national 3G standard in 2006, and issued bias spectrum to it. Such kind of preferential regulative policies had no wonder well demonstrated the preference towards indigenous innovated TD-SCDMA, which to large extent, had created a well regulative institutional environment for the technology to develop and diffuse. Similarly, regulative institutional environment also facilitated the TD-LTE innovation based on bias policies.

In terms of normative institutions, both cases present its significance in facilitating technology innovation through defining innovation objectives, designating ways to achieve them. It has been observed that valuing the national pride in high-tech achievements had constructed the normative institutions for both TD-SCDMA and TD-LTE. Launched TD-SCDMA during Beijing Olympic Games was a good case to illustrate how national pride could be perceived through showing the latest national high-tech achievement in such an international mega-evets.

In terms of cognitive institutions, both cases demonstrate its value in facilitating technology innovation through mobilizing common shared social meanings to favor the targeted innovation. For example, cognitive institutions that constructed based on achieving national goals including enhancing national security and reducing IPRs payments to promote TD-SCDMA in diffusion. Moreover, cognitive institutions that originated based on the commonly held positive expectations had largely promoted the TD-LTE in both development and diffusion.

Nevertheless, as Table 9.3 showed, the TIS institutions also demonstrated many differences between two innovation cases. For example, in technology development stage, TD-SCDMA innovation was initiated and pushed by regulative institutions with strong government interventions; while in the case of TD-LTE, the development of technology was mainly promoted by cognitive institutions, which based on wide range of positive recognition from innovation participants. In stage of technology diffusion, although all the three kinds of institutions contributed in both cases, the degree of influence on system actors and the construction of institutions were different. For example, less coercive forces based regulation, laws and policies were find in TD-LTE TIS if compared with TD-SCDMA; normative institutions in TD-SCDMA TIS was mainly constructed based on pursuing national prided in high-tech achievement, although it still lasted to facilitate TD-LTE innovation, yet the degree was much lower and participating and leading in international cooperated standardization became more significant; at last, cognitive institutions in TD-SCDMA TIS mainly worked based on common understandings in reducing IPRs payments and enhancing national security, while TD-LTE TIS cognitive institutions were mainly constructed based on the positive expectations towards the technology.

We suggest that such differences were mainly caused by differences in technology characteristics. As TD-SCDMA case showed, for a country catching-up in technology innovation, when in the early stage of pursuing indigenous technology innovation, it is more likely to have to take path-breaking trajectory, but at the same time challenges were extremely severe, thus as observed, regulative institutions took the lead and played significant roles in both development and diffusion. As the TD-LTE cases showed, along with TD-SCDMA innovation, the experience is accumulated and capability is improved, thus China moved to path-dependent trajectory in 4G innovation. The strong government support in TD-SCDMA and the technological advances of TD-LTE had collectively established positive expectations towards TD-LTE innovation, thus as observed, cognitive institutions took the lead and played significant roles in both technology development and diffusion. Therefore, based on discussion, we suggest that in TIS, regulative, normative and cognitive institutions should be properly aligned for both technology development and technology diffusion; in the catching-up context, for path-breaking innovation， regulative is more important than cognitive.

9.5 CHALLENGES IN TD-SCDMA AND TD-LTE TIS

China's innovation cases showed that the fulfilment of different TIS function requires specific system actors to work with different resources and capabilities. Because of the deficiencies and the heterogeneities in terms of system actors' interests, resources and capabilities in the innovation, several challenges were faced when achieving system functions in the process of TD-SCDMA and TD-LTE innovation. In each case, it has been observed that the challenges that faced were varied in different innovation stage, and were mostly addressed by the government to ensure the success in technology development and diffusion. Furthermore, we also observed that the challenges identified in two innovation cases were also different. The differences in terms of challenges in TD-SCDMA and TD-LTE are summarized in Table 9.4 as followed.

Table 9.4 Challenges comparison between TD-SCDMA and TD-LTE innovation

Innovation Stages	Technology Development	Technology Diffusion
Challenges in TD-SCDMA innovation	*Knowledge development* • Develop a 3G standard within the time schedule requested by ITU *Knowledge diffusion* • Lacking of matured R&D networks *Research guidance* • Chose innovation path for Chinese 3G • Reverse negative expectations on indigenous introduced 3G TD-SCDMA *Entrepreneurial experiments* • Reduce high uncertainty in perceptions • Select surrogates to lead R&D activities *Resource mobilization* • Weak R&D capability in contemporary • Lacking of experts in R&D	*Entrepreneurial experiments* • Reduce high uncertainty in perceptions for TD-SCDMA to succeed in market • Select a surrogate to lead test and diffusion *Resource mobilization* • Few domestic and foreign firms are interested to invest in TD-SCDMA *Market formation* • Persuade 2G users to upgrade to 3G • Select a surrogate to operate TD-SCDMA • Persuade vendors to invest in TD-SCDMA *Creating legitimacy* • Establish comparative advantages for TD-SCDMA against the other two alternatives
Challenges in TD-LTE innovation	*Knowledge diffusion* • Difficult to generate major industry participators' interests for TD-LTE *Research guidance* • Difficult to unite technological divergences towards TD-LTE, like smart antenna adoption and frame structure unification *Resource mobilization* • Attract both influential domestic and foreign firms to invest in TD-LTE R&D	*Entrepreneurial experiments* • Organize efficient network and system tests • Reduce scepticism towards TD-LTE to succeed in market *Market formation* • Difficult to convince major vendors and operators to invest in TD-LTE • Establish comparative advantages for TD-LTE against the LTE FDD

As Table 9.4 showed, different challenges were faced in fulfilling specific system functions in different stages. Nevertheless, all the challenges that faced could be grouped into two categorizations in generic. As observed in the case studies, on the one hand, some challenges were faced because of deficiency in compulsory resources and capabilities, which in ultimate was caused by deficiencies in key actors. On the other hand, some challenges were faced because of improper address heterogeneity of key actors' interests, since fail to align key actors' interests could lead to failures in aligning key resources and capabilities with the targeted innovation.

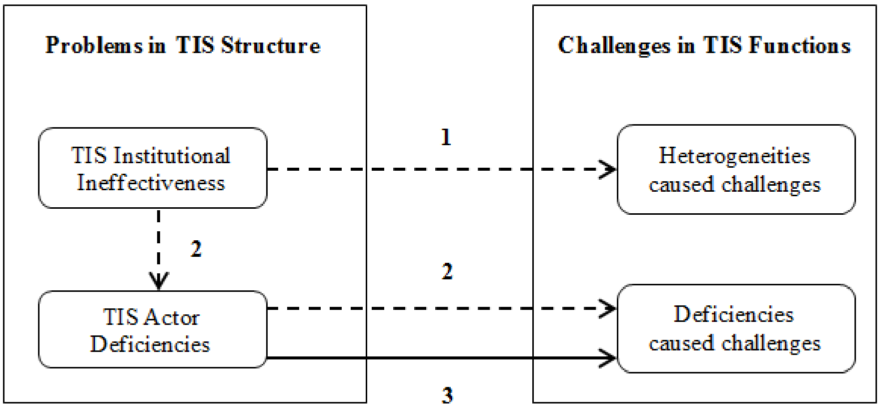

Figure 9.5 TIS challenges and problems in TIS structure

Based on the innovation system perspective, we suggest that identified two kinds of challenges could be viewed as the result of TIS institutional ineffectiveness and TIS actor deficiencies (Figure 9.5). TIS institutional ineffectiveness could also result in TIS actor deficiencies. First of all, in terms of institutional ineffectiveness, as Freeman (1995) indicated that the institutions must be well aligned to ensure the success of innovation, thus when the institutional environment in the TIS could not properly align, or mobilize, key actors' interests with the targeted innovation, then high heterogeneity in actors would result in challenges (type1). Besides, when the institutional environment in the TIS fails to attract, or persuade, the actors who hold key innovation needed resources and capabilities to join in the innovation system, then the deficiency caused challenges would rise (type2). Nevertheless, apart from TIS institutions failing to attract the necessary actors, the case of TD-SCDMA innovation also showed that in the contemporary, there was no resourceful and capable domestic actor could be attracted when CATT started to develop Chinese own 3G technology. Such kind deficiencies are not caused by TIS institutional effectiveness (type3).

Furthermore, Table 9.4 also showed that challenges faced in same TIS function are different in TD-SCDMA and TD-LTE innovation. For example, in terms of knowledge diffusion, TD-SCDMA was facing the challenge that lacking of reliable R&D networks to diffuse the knowledge, while TD-LTE was facing the difficulty in generating positive perspectives for the technology; in terms of entrepreneurial experimentation and knowledge development, TD-SCDMA was facing the actor deficiencies that no existing R&D institutes or firms could undertake the activities, but TD-LTE innovation did not face such problem; in terms of resource mobilization in the development stage, TD-SCDMA faced deficiencies in capabilities and sufficient resources, while TD-LTE mainly faced challenges in mobilizing key actors' interests.

We suggest that such differences were mainly related with different characteristics of TD-SCDMA and TD-LTE technology. As the TD-SCDMA case showed, for a country catching-up in technology innovation, when in the early stage of pursuing indigenous technology innovation, it is more likely to have to take path-breaking trajectory, but normally face the challenges of aligning heterogeneous interests and the deficiencies in innovation capability, experience and relevant resources. As the TD-LTE cases showed, along with TD-SCDMA innovation, the experience is accumulated and capability is improved, thus the country will naturally move to path-dependent trajectory based on the former achievements. Compared with path-breaking innovation, path-dependent innovation normally face less challenges in deficiency, but still need to address the heterogeneities. Therefore, associating with the former discussions, we suggest that in TIS, institutional ineffectiveness and actor deficiencies can challenge TIS functions in both technology development and diffusion; in catching-up context, path-breaking innovation faces severer challenges caused by both deficiencies and heterogeneities than path-dependent innovation.

9.6 THE MECHANISM OF GOVERNMENT INTERVENTION IN TD-SCDMA AND TD-LTE INNOVATION SYSTEM

In response to our research question, both innovation cases have presented that the government can take various instruments to promote technology development and diffusion. Moreover, TD-SCDMA and TD-LTE innovation system presented different features, thus the government intervention was also observed to be different in two different innovation cases. Thus this section aims to answer the research questions about the mechanism of government intervention in innovation, and the characteristics of that in the catching-up context.

The government intervention in TD-SCDMA and TD-LTE innovation

Based on the theoretical framework, the mechanism of government intervention in technology innovation could be expressed as facing challenges in the TIS functions in technology development and diffusion stage, how to take what intervention instruments to promote the fulfillment of the TIS functions. In generic, as both TD-SCDMA and TD-LTE case showed, the strategies that government took for addressing the challenges could be categorized into two groups: to intervene on TIS institutions thus to influence the TIS actors indirectly, or intervene on the TIS actors directly. Two strategies can either work independent with each other, or collectively functioned.

Both TD-SCDMA and TD-LTE innovation case presented that China's government took both strategies together in both technology development and diffusion stages. For example, in the development of TD-SCDMA, the government took indirect strategy to impact the regulative institutional environment in the innovation system i.e. recognized TD-SCDMA as national 3G innovation path, provided low rate primary loan and high rate VAT refund to support TD-SCDMA R&D; and direct strategy to invite, create and shape the system actors i.e. ordered CATT to lead, constructed Xinwei, invited Siemens, provided 1.3 billion R&D funding to Datang. In the diffusion of TD-SCDMA, indirect strategies were taken to impact regulative institutions i.e. issued preferential policies for

TD-SCDMA, normative institutions i.e. offered TD-SCDMA services during Olympic and cognitive institutions i.e. high level official voiced for TD-SCDMA; direct strategies were taken to order and subsidize the system actors to promote TD-SCDMA diffusion i.e. formed TDIA for industrialization, transferred IPRs, assigned China Mobile to operator TD-SCDMA, offered subsidies to vendors, etc.

Similarly, in terms of TD-LTE development, indirect strategies were taken to impact cognitive institutional environment i.e. high level officials voiced support and listed TD-LTE as core national S&T project; and direct strategies to mobilize system actors to support TD-LTE development i.e. assigned Datang and RITT to lead R&D, assigned ZTE to lead core equipment manufacturing, invited national universities to participate. In TD-LTE diffusion stage, indirect strategies were taken to impact regulative institutions i.e. bias industrial policies to TD-LTE, normative institutions i.e. advocated national pride in high-tech catching-up and cognitive institutions i.e. voiced support from government and advocated national securities; and direct strategies to order and subsidize system actors to promote TD-LTE diffusion i.e. formed GTI, invited MNEs to form joint ventures, subsidized China Mobile in network construction, etc.

Both TD-SCDMA and TD-LTE cases evidenced the effectiveness of two strategies in addressing challenges. Selecting direct or indirect strategy should be based on the specific challenges that faced in TIS functions. As discussed in the former section, deficiencies and heterogeneities caused most of challenges in innovation, and TIS actor deficiencies and TIS institutional ineffectiveness are exhibited as the mechanism for them, respectively. Furthermore, as showed in the cases, direct strategies normally adopted to create, invite and shape system actors, which could be more effective in addressing deficiencies caused challenges; indirect strategies normally used to impact institutional environment in system, which could be more effective in aligning the heterogeneous interests with innovation. Therefore, in general, direct strategies are suggested when facing deficiencies caused challenges, and indirect strategies could be considered primarily when facing heterogeneities caused challenges.

Nevertheless, it should be noted that, direct strategies and indirect strategies not work independent with each other. If adopted two strategies as the same time, they are more likely to interact and influence each other, which might lead to reinforcements in the effectiveness. For example, when the government directly ordered or subsidized the TIS actors in innovation, the interventions are very much likely to “release” the signal that government is supporting the innovation, which might contribute to both regulative and cognitive institutional environments based on mimetic mechanisms. Therefore, as showed in the cases that China’s government normally took a mix strategy to address the challenges with both direct and indirect interventions. Based on the discussions, we suggest that, to address challenges in technology innovation, government can intervene on TIS actors directly, or intervene in TIS institutions thus to impact TIS actors indirectly; direct interventions can better address deficiencies caused challenges, indirect interventions can better address heterogeneities caused challenges; a mixed strategy can be more effective as two strategies can reinforce each other.

The instruments of government intervention in TD-SCDMA and TD-LTE innovation

Apart from varied strategies that identified for government intervention, in both cases, we also identified several regulative, normative and cognitive instruments of government intervention that promoted the technology development and diffusion, as summarized in Table 9.5 as followed.

Table 9.5 Instruments of government intervention in TD-SCDMA and TD-LTE innovation

Intervention type	Instruments in TD-SCDMA innovation	Instruments in TD-LTE innovation
Regulative	<u>*Development stage*</u> • Path-breaking innovation was decided • Ordered CATT to explore Chinese own 3G • Recognized Datang's proposal as national 3G • Low rate primary loan and high VAT refund • Publish technology specifications on R&D • Xinwei was formed by CATT and Cwill • Moved TD-SCDMA R&D group to Datang • MPT spent 20 million RMB to support the formation of Xinwei, 1.3 billion RMB to Datang for TD-SCDMA development • MII offered over 1 billion RMB fund and 2/3 normal commercial loan rate to support R&D <u>*Development stage*</u> • Preferential policies were granted • TDIA was formed for industrialization • Ask Datang Telecom, Potevio and ZTE to take system test and led industrialization • China Mobile was assigned to operate • IPRs were transferred from Datang Telecom to other TDIA members • 38 billion RMB loan were offered to TD-SCDMA vendors with 2/3 normal loan rate	<u>*Development stage*</u> • Datang Telecom was assigned to lead TD-LTE standard development • MIIT-affiliate RITT was designated to respond to TD-LTE development • ZTE was assigned to lead the development of core equipment manufacturing • China Mobile was chosen to construct pilot network and leaded testing of TD-LTE • National universities were invited to offer technological solutions for TD-LTE • 30 billion credit assigned to Datang for supporting TD-LTE R&D <u>*Development stage*</u> • Preferential policies were granted to TD-LTE in allocating radio frequency and timing of issuing 4G licenses • Low rate primary loan and high rate VAT refund were granted to support TD-LTE • Government listed TD-LTE innovation as a national strategy
Normative	<u>*Diffusion stage*</u> • Provide TD-SCDMA services during Beijing Olympic Games for national pride	<u>*Diffusion stage*</u> • Advocated catching-up in high-tech through indigenous innovation as national pride
Cognitive	<u>*Diffusion stage*</u> • High level officials including Premier Minister voiced support to TD-SCDMA • Publish technology specifications • MII launched TRIP with 708 million RMB as the budget to subsidize domestic vendors • Advocated reducing IPRs payments and enhancing national security as national goals	<u>*Development stage*</u> • High level officials voiced support to TD-LTE • Government listed TD-LTE innovation as a core national S&T project and a reliable approach to drive domestic economic • China Mobile established TD-LTE special project to subsidize R&D on TD-LTE with direct government funding <u>*Diffusion stage*</u> • Publish technology specifications • Advocated reducing IPRs payments and enhancing national security

Regulative instruments

According to literature, regulative type instrument influences technology innovation based on coercive forces. In both cases, we can observe that regulative instruments were most powerful forces that impacted the TD-SCDMA and TD-LTE innovation in both development and diffusion stages.

Regulative instruments could be adopted by both direct and indirect strategies of the government intervention in innovation, as the government published several preferential policies to shape or create the regulative institutional environment in the innovation system to favor indigenous technology innovations, and at the same time to mobilize system actors directly based on the coercive forces. In the TD-SCDMA and TD-LTE innovation, it is observed that specific regulative intervention strategies and instruments were selected based on specific challenges faced. For example, when facing challenge that few actors were interested in investing in the TD-SCDMA in diffusion, on the one hand, the government published the national regulations that granted TD-SCDMA as national 3G standard and the financial policy that provided primary loan and VAT refund to motivate the equipment manufacturing; on the other hand, the government was also observed to adopt the directives or administrative orders to the GSEs in each industrial segments like China Mobile, ZTE and Datang to take the lead in TD-SCDMA diffusion, and provided funds and subsidies directly to innovation undertaking GSEs.

In specific, we find that regulative government intervention is critical for addressing TIS institutional ineffectiveness especially in guiding research, mobilizing resources and creating legitimacy, thus to ensure the success of technology development and diffusion. In the TD-SCDMA case, as China faced tight time restriction in submitting its 3G standard to ITU, and at the meanwhile, domestic firms lacked the required R&D capability to independently develop the 3G standard, but most of the technology giants controlling the key know-hows had no interests in collaboration with them in the endeavor meant to create a GSE-controlled system that would compete with their technologies. Thus the government granted Datang’s 3G proposal as national 3G standard to develop and provided huge funds and subsidies to invite capable and resourceful MNEs to participate. This helped overcome the TIS institutional ineffectiveness in attracting system actors and guiding their R&D interests into TD-SCDMA. In the TD-LTE case, the government granted TD-LTE as the national 4G path with low rate primary loan and high rate VAT refund granted.

Government directly supported GSEs to promote innovation should be particular highlighted in China's 3G and 4G innovation. It has been observed that the GSEs support acted as a key successful factor in both technology development and diffusion. In TD-SCDMA development stage, CATT served as the intermediary for Cwill and Siemens to transform their proprietary technologies that formed the basic components of the TD-SCDMA standard. In TD-SCDMA diffusion stage, GSEs were the initiating, core members of the industrial value chain as elaborated. In the TD-LTE case, Datang Telecom was the leader of standard development. In the diffusion stage, Datang Telecom, ZTE and China Mobile led the system test, equipment manufacturing, and network construction and service provision, respectively.

Through substantial investments, GSEs translated the interests of broad ranges of key actors including both domestic and international technology firms. On the one hand, the huge investments from GSEs well demonstrated the firm support from the government, which contributed to reinforce the cognitive system institutions and thereby address the TIS institutional ineffectiveness by reducing the uncertainties in terms of technology and market of Chinese indigenous 3G and 4G; on the other hand, the active involvement of GSEs also helped solve the TIS actor deficiencies for the technology development and diffusion, which was especially significant for innovation in the catching-up context. In a word, GSEs play the role of the leading "penguins" of the "penguin phenomena" in TD-SCDMA and TD-LTE innovation. Therefore, we suggest that, regulative instrument can help overcome TIS institutions ineffectiveness in guiding research, mobilizing resources and creating legitimacy, thus to promote the innovation; regulative government intervention on GSEs can help overcome the TIS actor deficiencies in knowledge development, entrepreneurial experiments, thus ensure the success of technology development and diffusion.

Normative instruments

As introduced, normative type instrument influences technology innovation based on normative forces. Normative instruments helped defined both objectives of promoting indigenous innovations in high-tech field, and at the same time designate ways to achieve them through conducting for example TD-SCDMA and TD-LTE innovation. In both cases, we observed that normative instruments played as the complements for regulative instruments, and mainly impacted the innovation in diffusion stages. Besides, the instruments based on normative forces cultivated the institutional environment into indigenous innovation favored, and contributed to address the TIS institutional ineffectiveness especially in establishing market and creating legitimacy.

In the case of TD-SCDMA innovation, normative instruments mostly from the sense of national pride, which believed can be significantly enhanced if China could be a leader or a representative in such a high tech area, and get rid of technology dependency with foreign enterprises. For example, as observed, the government asked China Mobile to provide commercial 3G TD-SCDMA services in the 2008 Beijing Olympic Games, with the aim to demonstrate the latest achievement in the high-tech field. Combining with the regulation that TD-SCDMA rivals – WCDMA and CDMA2000 were not allowed to commercialize in contemporary, the market for indigenous 3G had been vastly developed, and TD-SCDMA as the "home-grown technology" had generated huge national pride thus largely facilitated the process of legitimacy creation. Similarly, In the 4G era, the perception of nation pride had been shifted from achieving significant national goals in high-tech innovation to catch up with the international technology frontiers in innovation. For example, Huawei was supported to provide TD-LTE trial text in Shanghai Expo in 2010, and government high-level officials have more than once voiced TD-LTE as China's latest achievement in S&T in significant international conferences like WTC. Therefore, we suggest that, normative government intervention, complemented with regulative instruments, can help overcome TIS institutional ineffectiveness in market formation and legitimate creations, thus ensure the success of technology diffusion.

Cognitive instruments

The instruments based on mimetic forces could cultivate the institutional environment into specific innovation favored. In both cases, China's government was observed to adopt cognitive type instruments to influence the cognitive institutional environment in the innovation system, and thereby to promote technology innovation based on mimetic forces in both technology development and diffusion.

For example, to promote TD-SCDMA in diffusion, the government shaped TIS cognitive with educating the social with two national goals: adopting indigenous technology could contribute to national targets of reducing high IPRs payments, reducing high degree of foreign technology dependent, and enhancing national security. Besides, the government also published several technology specifications to mobilize the research interests from potential vendors. Moreover, MII also launched TRIP with 708 million RMB as the budget to subsidize domestic vendors to produce TD-SCDMA based devices. What is more, the public voiced support on TD-SCDMA from high-level officials also critical in reducing the uncertainties thus promoted the diffusion.

In the case of TD-LTE, cognitive instruments contributed to the innovation in both development and diffusion stage. For example, the national goals including reducing IPRs payments and enhancing national securities also introduced. The speeches were given by high level officials declaring the government support on TD-LTE R&D and diffusion. Besides, government listed TD-LTE innovation as a core national S&T development project. Furthermore, TD-LTE special project for subsidizing the R&D and the manufacturing were launched by the government. Imitating the GSEs and influential MNEs, actors were active in TD-LTE innovation. Therefore, we suggest that, cognitive instruments can help to address TIS institutional ineffectiveness in research guidance, knowledge diffusion, market formation, entrepreneurial experimentation and legitimacy creation, thus ensure the success in both technology development and diffusion.

In addition, as discussed, government intervention instruments are introduced when challenges in TIS functions emerge, which are related with the features of TIS structural components. Facing varied challenges in innovation, the government intervention instruments also demonstrated differences in terms of features and the way they functioned between cases.

According to Table 9.5, through comparing intervention instruments between two cases, we find that regulative instruments were critical in both technology development and diffusion stage, in both cases. The government used regulative instruments like directive orders and financial supports to address TIS actor deficiencies caused challenges, meanwhile, it adopted regulative instruments like financial supports and regulations to address TIS institutions ineffectiveness caused challenges. The differences between two cases in terms of regulative instruments were reflected in the different degree of regulative intervention. TD-SCDMA as a path-breaking innovation faced more severe challenges in both TIS institutions and actors, thus as observed, the regulative interventions were stronger in TD-SCDMA innovation than TD-LTE.

Besides, as observed in both cases, three types of intervention instruments are not independent, they interact and reinforce each other in the actual practices. In the cases of TD-SCDMA and TD-LTE, on the one hand, the normative instruments and cognitive instruments played as complementary forces to coercive mechanism based regulative instruments; on the other hand, it is also witnessed that the regulative instruments also contributed significantly to reinforce the normative and cognitive institutions. For example, when the government supported GSEs to take the lead in different industry segments with directives and financial measures, at the same time, other innovation participants would very much likely to recognize the GSEs as success models, which could reinforce the cognitive institutions in consequence. Thus we suggest that, normative and cognitive instruments can complement regulative instruments, regulative instruments can reinforce the others; mixed regulative, normative and cognitive instruments can better promote technology development and diffusion.

Government intervention in catching-up context

Despite of intervention strategies and instructions, the macro context should also be taken into consideration when characterizing the government interventions. As Yu et al. (2012) indicated, in early stage of catching-up, China as a technology late-coming country was normally featured as weak in innovation resources, capabilities and infrastructures, and maintained a long time technology import in history. Later on, through continuous technology innovation, the resources became abundant, the infrastructure became sufficient, and the capabilities and experiences have been well cultivated. Therefore, in the catching-up context, different conditions between path-breaking innovation (TD-SCDMA) and path-dependent innovation (TD-LTE) normally lead to different challenges, which required different featured government interventions.

As suggested by Gao et al. (2014), the more challenges an technology innovation initiative faces, the stronger government intervention it requires. For technology late-coming counties with aims to catch-up in technology innovation, strong government intervention is essential to eliminate uncertainty, mobile critical resources and cultivate indigenous capability of innovation. In this case, China is a late-coming country in technology innovation, and currently in the catching-up context. Facing weak R&D capability, Chinese government has taken all efforts to promote the 3G TD-SCDMA innovation. After then, experienced through TD-SCDMA innovation, the TD-LTE innovation has enjoyed a shorten circle from creation to legitimation. This was because both government and the innovation system improved. Therefore, the history of TD-SCDMA and TD-LTE innovation indicated that the degree of government intervention and maturity of the TIS would hold a negative correlation. Thus based on discussions, we suggest that in the catching-up context, government intervention in indigenous technology innovation is necessary; stronger regulative government intervention is required in path-breaking innovation than path-dependent innovation; cognitive intervention better functioned in path-dependent innovation than the path-breaking one.

9.7 SUMMARY

Based on the theoretical framework and the case studies, this chapter conducted a synthetic analysis with the aim to understand the mechanism of how can government intervene into the technological innovation system for promoting the indigenous technology innovation, especially that in the catching-up context. In generic, the characteristics of TD-SCDMA and TD-LTE innovation system, and the mechanism of government intervention in the two innovations were emphasized. The analysis was expended based on the four sub-divided research questions that proposed. Furthermore, through answering the research questions, several related findings were summarized.

Specifically, in section 9.2, with aim to address the first three research questions, we compared and characterized the TD-SCDMA and TD-LTE innovation system in terms of system structure, functions and performances, as well as the challenges that were faced in each innovation. Through comparing the system performance, we concluded that the TD-LTE TIS performed much better than the TD-SCDMA, especially in the diffusion stage. We find the differences in system performance were the reflection of differences in the achievement of system functions. As individually looking at the seven identified TIS functions, TD-LTE TIS presented a better fulfillment in each of them than that of TD-SCDMA. Besides, the similarity of how TIS functions contributed in the process of innovation has indicated a temporal model that some functions are particular significant in technology development, some functions play significant roles in both development and diffusion stage, and some functions contribute more in diffusion. Through comparing the two cases, we find that in well performed TIS, seven TIS functions should interact and influence each other, and create positive cycles.

Based on literature, differences in TIS functions demonstrate the differences in terms of system structure. Through comparing the structural components, we addressed the first research question and concluded that a well functioned TIS normally well aligns regulative, normative and cognitive institutions, and enrolls sufficient and diversified key actors to establish abundant formal and informal networks at early innovation stage. As result, the first two research questions (SQ1 & SQ2) were collectively addressed.

Furthermore, with the aim to address the third research question (SQ3), we also summarized and compared the challenges that faced in TD-SCDMA and TD-LTE innovation. Based on synthetic analyses, we find that challenges in TIS functions could be categorized into caused by deficiencies or heterogeneities in key system actors. In TIS, institutional ineffectiveness and actor deficiencies can result in deficiencies and heterogeneities in both technology development and diffusion; in catching-up context, path-breaking innovation normally faces severe challenges caused by both deficiencies and heterogeneities, path-dependent innovation faces less challenges in deficiencies but still need to address heterogeneities.

Moreover, in section 9.3, with aim to address the first and the fourth research questions (SQ1 & SQ4), we characterized and compared the government interventions in TD-SCDMA and TD-LTE innovation. The strategy and instruments for government intervention, and the characteristics of them in the catching-up context were particularly emphasized. Based on synthetic analyses, we understood the government roles in indigenous technology innovation from a technological innovation system perspective, how the innovation policies are issued, as well as how the innovation policies actually work to impact the technology innovation. As result, we find that the rationales for government intervention was to address the challenges that faced in TIS functions; the strategies for government intervention included both direct intervention on the TIS actors and indirect intervention on the TIS institutions; in generic, three types of intervention instruments were categorized, namely regulative, normative and cognitive instruments; the specific instruments that government selected normally depend on which strategy is selected, which normally related with challenges that faced.

At last, we also focused on the context of innovation. In the catching-up context, we characterized TD-SCDMA innovation as the path-breaking innovation and TD-LTE as the path-dependent one. As result, we find that government intervention is essential in catching-up, and stronger intervention is required especially for path-breaking innovation than path-dependent innovation. Next chapter concludes this dissertation.

CHAPTER 10: CONCLUSION

10.1 RESEARCH REVIEW

To conclude this dissertation, we first have a brief review of the overall research process, including how the research aim was identified and how the research was designed and conducted. Then the answers of research questions are revisited.

10.1.1 Research process and approach

This research originated from an interesting phenomenon we had observed: with proper government support, some traditional late-coming countries in terms of technology are catching up in terms of technology innovation. Thus, in chapter 2 and chapter 3, we reviewed the innovation literature with the aim of understanding how innovation could be promoted by government intervention. Many relevant studies were reviewed and the observed phenomenon was interpreted according to various perspectives. Nevertheless, through the literature review, we also identified two research gaps and aimed to understand how government intervention in TIS can promote technology innovation, especially in catching-up context.

A theoretical framework was developed in chapter 4. Accordingly, the main question was divided into four sub-questions at the operational level. The research was designed around the framework and questions in chapter 5. Structured by the framework, the results of data collection and analysis were expressed as narratives of the two case studies in the empirical chapters. Specifically, chapter 6 introduced both the social and technological background of the case studies; details of two innovation cases in China were illustrated in chapters 7 and 8, and were discussed in chapter 9. Research questions were answered and there were several findings.

10.1.2 Revisiting the research questions

The case studies have unfolded and have delineated the fact that the Chinese government has promoted 3G and 4G technology innovation through institutionally intervening into the related technological innovation systems. Through analyzing the case studies, we can conclude that in the stages of technology development and technology diffusion, different TIS functions need to be achieved and different challenges are faced, which require government intervention. The government needs to analyse how TIS functions are achieved and how challenges are formed in relation to TIS structural components, and needs to determine the intervention strategy and instruments. This answered the main question of this research.

Moreover, at the operational level, we have divided the main research question into four sub-questions to focus on different aspects of the proposed main research question. Firstly, we asked the question (SQ1): How are the technological innovation system and government intervention characterized in China? In fact, this question has already implied that government interventions are appropriate and that the innovation system functions well, otherwise there is no way that catching-up in technology innovation could be achieved. With the aim of answering this question, we first compared the performances of the TD-SCDMA and TD-LTE innovation systems in terms of technology development and technology diffusion with the same standard. As a result, we concluded that the TD-LTE TIS functioned much better than the TD-SCDMA TIS in both stages. Then we compared the government interventions, and the TIS structure, functions and challenges between the two cases to understand how the characteristics of the TD-LTE TIS and government intervention were improved.

Based on analysis, we concluded that for a TIS to function well, it is normally well aligned with regulative, normative and cognitive institutions in the system, and enrolls sufficient and diversified key actors to establish abundant formal and informal networks at the early innovation stage. Besides, seven TIS functions normally interact with and influence each other with positive cycles created during the innovation process. In terms of government intervention, we find that government intervention is essential in technology innovation catching-up; stronger intervention is required especially for path-breaking innovation than for path-dependent innovation. The strategies for government intervention included both direct intervention on the TIS actors and indirect intervention on the TIS institutions. For appropriate intervention, the specific instruments that a government selects normally depend on which strategy is selected, which is normally related to the specific challenges that are exhibited in the fulfillment of TIS functions.

Secondly, we asked the question (SQ2): How can TIS affect the development and diffusion of a technology? To answer this research question, we compared the two cases and summarized the similarities in both cases in terms of TIS dynamics and the innovation process. As a result, we find that technology development and diffusion are enabled logically by seven TIS functions. Some TIS functions are particularly significant in the stage of technology development, such as knowledge development and diffusion; some TIS functions play significant roles in both the development and diffusion stages, such as entrepreneurial experimentation, resource mobilization and research guidance; some TIS functions contribute more in the technology diffusion stage, such as market formation and legitimation. Besides, as TIS functions are normally determined by TIS structural components, the relationships between TIS and technology development and diffusion can therefore be expressed as TIS actors that are mobilized by TIS institutions collectively undertaking TIS functions.

Thirdly, we also asked the question (SQ3): What are the main challenges for the government to address in China's catching-up in technology innovation? To answer this research question, we also summarized and compared the challenges that faced the TD-SCDMA and TD-LTE innovations. Based on synthetic analyses, we find that challenges for TIS functions could be categorized into those caused by deficiencies or heterogeneities in key system actors. In TIS, institutional ineffectiveness and actor deficiencies normally result in deficiencies and heterogeneities in both technology development and diffusion. Furthermore, we also find that challenges faced by the same TIS function are different for the two cases. We suggested that such differences were mainly related to different characteristics of technology and its TIS, thus concluding that in catching-up context, path-breaking innovation normally faces severe challenges caused by both deficiencies and heterogeneities, while path-dependent innovation faces fewer challenges in deficiencies but still needs to address heterogeneities.

Lastly, we asked the question (SQ4): What strategies and instruments can government use to promote the TIS functions in innovation, and how? To answer this research question, we compared the two cases and summarized the similarities in both cases in terms of government intervention strategies and instruments. As a result, we find that in general two kinds of intervention strategies are normally adopted: to intervene in TIS institutions, thus to influence the TIS actors indirectly, or to intervene in the TIS actors directly. Besides, strategy selection should be based on the specific challenges that are faced by the TIS functions. In general, direct strategies are suggested when facing challenges caused by deficiencies, and indirect strategies could be considered primarily when facing challenges caused by heterogeneities. Strategies can either work independently of each other, or function collectively. If two strategies are adopted at the same time, they are more likely to interact with and influence each other, which might lead to reinforcement of their effectiveness; thus, a mixed strategy is more effective.

Furthermore, both cases showed that various intervention strategies are normally used, based on three types of instruments in general, namely regulative, normative and cognitive instruments. Government can publish preferential policies to shape or create the regulative institutional environment in the innovation system to favor specific technology innovation, and at the same time to mobilize system actors directly, based on coercive forces. Besides, normative instruments play a complementary role to regulative instruments, helping to define both objectives and approaches, and mainly functioning in the technology diffusion stage. Based on mimetic forces, government can adopt cognitive type instruments to influence the cognitive institutional environment in the innovation system, and thereby to promote innovation in both the development and diffusion stages. As observed in both cases, the three types of intervention instruments are not independent; in contrast, they interact with and reinforce each other in practice.

10.2 SUMMARY OF RESEARCH FINDINGS

The findings of this research were generated from synthetic analysis of the two innovation cases. Following the objective of this research and the developed theoretical framework, research findings in general mainly focus on three aspects: the structure and functionality of the technological innovation system, the strategy and instruments of government intervention, and the characteristics of these in the catching-up context.

10.2.1 Technological innovation system and technology innovation

In terms of the technological innovation system, both cases evidenced that technology development and diffusion are enabled logically by several TIS functions, such as knowledge development, knowledge diffusion, research guidance, entrepreneurial experimentation, resource mobilization, market formation and legitimation. These functions normally present a temporal model as some of them are particularly significant in the development stage, some of them are particularly significant in the diffusion stage, and some of them contribute in both stages. Each of them is undertaken by several networked TIS actors, who are normally motivated by their own interests or guided by TIS institutions. The actors can be mobilized or guided by TIS institutions because the innovation system is an organizational field, in which actors need to pursue legitimation for long term survival, and thus follow the institutional mobilization that defines the targets and the means of acquiring legitimacy. This frames the theoretical foundation for how TIS functions are undertaken and achieved in relation to the TIS structural components.

Based on the case studies, we find that a technological innovation system that is performing well normally maintains several characteristics. Both cases evidenced that in a technological innovation system that performs well, the system functions normally interact and influence each other, with positive cycles created during the innovation process. Sufficient and diverse actors with key resources and capabilities are normally enrolled into the TIS at the early stage, which helps reduce uncertainty, thus ensuring the success of technology development and diffusion. Abundant formal and informal networks are normally established at the early stage to ensure the success of technology innovation. Regulative, normative and cognitive institutions are significant and are normally well aligned to achieve the system functions.

10.2.2 Government intervention strategies and instruments

In terms of government intervention, the fulfillment of technology development and diffusion requires the TIS functions that are undertaken by the TIS actors to be well achieved. The actors must be heterogeneous in resources and capabilities, thus providing the necessities of innovation. However, a high degree of heterogeneity in actors' interests and deficiencies among actors could lead to system failures that challenge the success of the innovation, with government interventions then being needed to address the challenges. We find that in the technological innovation system, institutional ineffectiveness and actor deficiencies can result in deficiencies and heterogeneities in three ways.

In terms of government intervention, we find that two kinds of intervention strategies are mostly adopted, as the government can intervene in TIS actors directly, or intervene in TIS institutions and thus impact TIS actors indirectly. Direct interventions can better address challenges caused by deficiencies, and indirect interventions can better address the challenges caused by heterogeneities. Three types of intervention instruments, including regulative, normative and cognitive instruments, are normally used.

Specifically, we find that regulative instruments can help overcome TIS institutions' ineffectiveness in guiding research, mobilizing resources and creating legitimacy, thus promoting the innovation; regulative government intervention on GSEs can help overcome the TIS actor deficiencies in knowledge development, and entrepreneurial experimentation, thus ensuring the success of technology development and diffusion. Normative instruments, complement regulative instruments, and can help overcome TIS institutional ineffectiveness in market formation and creation of legitimacy, thus ensuring the success of technology diffusion. Cognitive instruments can help to address TIS institutional ineffectiveness in research guidance, knowledge diffusion, market formation, entrepreneurial experimentation and legitimacy creation, thus ensuring success in both technology development and diffusion.

Based on the case studies, we also find that effective government interventions normally maintain several characteristics. For example, as two strategies can reinforce each other, mixed strategies are normally used in actual practice. Besides, as normative and cognitive instruments can complement regulative instruments, and regulative instruments can reinforce the others, mixed instruments are therefore normally used.

10.2.3 TIS and government intervention in the catching-up context

Despite the generally applicable findings that are summarized, there are also some findings in this research that emphasize the particularity of the catching-up context for the technological innovation system and government intervention. Based on the reviewed literature and the case studies carried out, we find that for a country that is catching up in technology innovation, when in the early stage of pursuing indigenous technology innovation, it is more likely to have to take a path-breaking trajectory. After that, along with continuous innovation, the country would move to a path-dependent trajectory based on its earlier achievements.

In this research, TD-SCDMA was a path-breaking technology compared with the incumbents, while TD-LTE could be recognized as a path-dependent technology that was developed based on the previously introduced TD-SCDMA system. Thus, based on the comparison between the two cases, we find that both TIS and government intervention presented some contextual characteristics. For example, we find that in the catching-up context, a path-breaking innovation faces severe challenges of aligning heterogeneous interests, as well as deficiencies in innovation capability, experience and relevant resources. Based on former innovation practices, experience is accumulated and capability is improved, and thus a path-dependent innovation normally faces fewer challenges in terms of actor deficiencies but still endures heterogeneities in actors' interests. Path-breaking innovation requires more regulative institutions, while path-dependent innovation requires more cognitive institutions. Besides, due to differences in structural features, we also find that the TIS functions in path-breaking innovation are normally fulfilled in a linear manner, while the TIS functions in path-dependent innovation normally influence each other with many positive cycles created in the innovation process.

As discussed, addressing challenges in TIS function during the innovation process is the rationale for and frames the standards for government intervention. Due to different challenges that are faced by catching-up innovations, we find that government intervention in technology innovation is necessary. Stronger regulative government intervention, including both direct and indirect interventions, is required in path-breaking innovation than in path-dependent innovation. Cognitive interventions are more likely to function well in path-dependent innovation than in path-breaking one.

10.3 RESEARCH CONTRIBUTIONS

10.3.1 Theoretical contributions

Firstly, it is uncovered that, catching-up as a context could significantly influence and characterize innovation exercises. The reviewed innovation studies indicated that the catching-up context should be emphasized and more related studies are needed. Actually, most knowledge employed in current innovation studies is conceptualised from the context of developed nations, while the uniqueness of innovation projects in the catching-up context are rarely considered, which may lead to unanticipated deviation between conclusions and reality. Besides, within the limited catching-up related studies, most works specifically focus on how catching-up could be achieved through technology innovation, while few of them put emphasis on how catching-up as a context could affect innovation dynamics. In this work, this divide has been addressed, since the knowledge of how NIS and TIS features, and how government roles and innovation policy are differentiated, were summarised through the literature review. Catching-up as the context has been considered when the conceptual framework was constructed, while China's indigenous technology innovation as the cases for this research were elaborately selected by considering the context of this work.

Secondly, in the literature, different theoretical perspectives are adopted to understand government intervention in innovation. Nevertheless, as Gao (2015) indicated, from one particular perspective, one piece of research normally understands a few government roles and intervention instruments, which are specifically developed from or applicable to the studied cases. Moreover, in innovation practice, the instruments that function well in a specific case might not be applicable to another, and the suggested instruments for government intervention are neither exhaustive nor exclusive. This research has provided a holistic view that exhibits the mechanisms of government intervention by introducing two strategies and three types of intervention instruments to promote technology innovation, namely regulative, normative and cognitive interventions.

Thirdly, the innovation literature has indicated that technology innovation by nature has a system feature, especially for complex technology innovations at the national level. In the literature, most existing works that have been conducted to understand government in technology innovation from an innovation system perspective adopt NIS for analysis, rather than TIS. How government as a key NIS component is capable of impacting the NIS and thereby influencing the innovation has been relatively well studied, but few studies have been conducted to understand how government, as a significant external actor, can intervene in the TIS for technology innovation. This research has bridged this research divide by contributing to extending the understanding of how government can promote technology innovation through intervening in the TIS. This is significant, because it is about how TIS can become functional and efficient under intervention, and how the mechanism that is explored can direct the government as to when and how to take what institutional measures.

Fourthly, as summarized in section 4.2.2, both the innovation system and government interventions in innovation exercises are recognized as dynamic, while most current studies normally conduct analyses in a static manner. It has been observed that, on the one hand, government interventions and innovation systems determine innovations; while on the other hand, they also learn and keep evolving along with continuous technology innovations in the process of innovations. Therefore, it is suggested that the dynamics of government intervention and innovation systems, along with the innovation development and diffusion, should be addressed, and the evolution of government interventions and the innovation system along with continuous innovations should also be emphasized. In this work, the divide elaborated was addressed through conducting comparative case studies based on the conceptual framework that was developed. In each case, the framework was adopted to express how government interacted with TIS, and how they were characterized along with the process of TD-SCDMA and TD-LTE innovation, including both stages of development and diffusion. By comparing the two cases, the differences in government intervention and TIS between the 3G and 4G innovations were summarized, and accordingly their evolutions were expressed.

At last, this work also contributes to institutional theory by extending the theory's adoption. The adoption here does not refer to the theory being adopted more widely because of enhanced utility as discussed above. Here we are talking about more ways of adopting institutional theory. In chapter 4, we have elaborated some original thinking about how institutional theory and the innovation system frame can be combined through understanding the mechanisms of "how organization seeks legitimacy in an institutional field". Actually, such original thinking and the attempt to put it into practice have, to some extent, shown an example or an approach in which institutional theory can be combined with other frames or theories when being adopted in certain analyses.

10.3.2 Practical contributions

Besides theoretical contributions, the case studies of China's 3G and 4G mobile system innovations have also enabled this research to have practical contributions. For innovation practice, China's case studies have suggested that the government can play significant roles in technology innovation. Especially in a developing country like China, with great technological and market uncertainties, but weak R&D capability, it is suggested that the government conduct institutional interventions in promoting significant innovation if the country is willing to achieve technology catching-up.

Furthermore, the disclosed mechanisms and the Chinese case studies have also provided valuable guidance and reference for other developing countries which aim to catch up through indigenous technology innovation. For instance, as discussed in the findings, government can make institutional interventions in the innovation system for promoting an indigenous technology innovation. Some systems are self-organized, while some could also be initiated by government. In both cases, institutional interventions are able to impact on the functions of system through mobilizing the system components. As summarized, within different innovation stages, the main inducement and blocking mechanisms are different. Several measures could be taken for intervention, and they should be taken according to a time sequence due to the different challenges that need to be addressed in the different stages. Besides, the sustainability of the innovation system should be particularly emphasized, especially for countries in the catching-up context. Key actors in both the innovation system and the market place should enhance their capability so that it becomes international. All of the findings and the Chinese cases have significantly contributed to innovation practices.

10.4 IMPLICATIONS FOR INNOVATION POLICY IN PRACTICE

10.4.1 Facilitating actors' participation and enhancing actors' capabilities

The Chinese innovation cases have well demonstrated the significance of enrolling capable actors for the success of the innovation. Moreover, facilitating the participation of capable foreign actors is as significant as cultivating and enrolling domestic actors, especially with the aim of catching up in technology innovation. For example, in the initial development stage of TD-SCDMA, inviting Cwill (providing SCDMA) and Siemens (providing TD duplexing) turned out to be a successful move that set the blueprint and technological foundation for later innovation. Promoting indigenous technology innovation does not necessarily mean conducting the whole innovation process completely via domestic entities. Convincing and facilitating the participation of both foreign and domestic actors that are capable is also significant. Thus, the government could issue innovation policies, such as subsidies and tax relief.

In fact, to facilitate actors' enrolment, the core value that is cherished is their capabilities in innovation. Such capabilities do not just refer to "technological congruence", but also include "social capabilities" as discussed in the section 2.6.3. For example, through comparing the 3G and 4G cases, it is discovered that, due to enhanced capabilities of domestic actors in different fields, the performance of the TD-LTE TIS is better than the TD-SCDMA TIS in both technology development and diffusion. Their capabilities are enhanced through both learning from foreign participants, and self-development. Therefore, innovation policy is suggested to enhance actors' capabilities as well, especially for countries aiming to catch up through technology innovation. When designing related policy, government should first consider which kinds of capabilities are particularly required for innovation to succeed, and then apply political instruments to achieve this. To develop general capabilities, issuing policy to support the education sector, such as universities and other training institutes, could result a long-term benefit. To develop specific capabilities that are required for specific technology innovations, issuing policy such as subsidies, attracting expertise and funding specific R&D fields could address the problems as well.

10.4.2 Facilitating actors' interactions and intermediations

The actors' interactions in innovation do not just include dynamic interplays between enrolled actors within the innovation system, but also encompass cross-boundary interactions, such as government authorities directly manipulating actors in the system and the collaborations between system actors and merchants in the marketplace. Innovation policy could facilitate the establishment of key interactions. For example, in the case of the TD-LTE innovation, led by the government, the interactions between China Mobile and international giants like Apple Inc. and Vodafone were established with the aim of facilitating technology development and diffusion in both the domestic and global market. Policy leveraging on establishing joint ventures and tax relief were initiated. Moreover, apart from facilitating the establishment of necessary and helpful interrelationships, innovation policies are also suggested to break hindering interactions, such as lock-in and harmful network effects. Addressing the challenges that are caused by harmful interactions is as significant as establishing the helpful interactions.

Besides, in terms of facilitating the relationships, the role of intermediating institutes is commonly recognised in both the innovation literature and empirical case studies. It is discovered that intermediating organisations can impact on innovation in a very broad range, including aspects of knowledge creation, knowledge diffusion, directing innovation, as well as standards setting. In cases of mobile wireless technology innovation, globally influential institutes such as IEEE in the US and 3GPP in the EU can greatly affect both the development and the diffusion of technology. TDIA in China has significantly facilitated commercialisation of TD-SCDMA and TD-LTE. To promote indigenous technology innovation, the case studies in this work have clearly demonstrated how intermediating institutes like TDIA and GTI were established by government and supported by innovation policy. However, it is also observed that many intermediaries were often "temporarily" or "voluntarily" introduced, rather than firmly and formally recognised. Considering the significant roles of intermediaries in facilitating interactions for innovations, innovation policy could help to support the establishment as well as the maintenance of helpful intermediating institutes.

10.4.3 Emphasising both regulative and influential institutions

As interpreted by institutional theory, the institutional environment in the innovation system decides how organisational actors can pursue legitimacy by performing different activities, thus impacting on the innovation. Innovation policy as a decisive institutional force should be well designed and rationalised for innovation to succeed. As observed, systems for technology innovation are not always self-organised, especially in the catching-up context in which the foundation for innovation is normally weak. Through examining the two case studies, we suggest that for existing innovation systems, innovation policy could emphasise rationalising current institutions for mobilising the outcomes. Meanwhile, if the innovation system does not exist, then innovation policies are suggested to help establish the required innovation system.

Besides, rationalising institutions in the market place has also proved to be significant, especially for countries in the catching-up context. Here, rationalising institutions in the market place does not mean that hard interventions are encouraged. For an emerging market which is requesting clear instructions or facing significant failures, strong regulatory innovation policy is suggested, while for mature markets in which the operating mechanisms for innovation function well, it is suggested that innovation policy puts more emphasis on perfecting or protecting such mechanisms.

Furthermore, it is observed that a regulative institutional environment is more likely to be emphasised when issuing innovation policy, but normative and cognitive institutional environments are normally neglected. In fact, it is evident that normative and cognitive institutions also impact on technology innovation significantly. For example, the government continued emphasising “China’s indigenous innovation” during the diffusion of 3G TD-SCDMA. The same strategy was also used in the diffusion of TD-LTE. Such “techno-nationalism” has largely promoted the diffusion of two systems. In fact, such kinds of motivation that originate from cultural-cognition can hardly be delivered by regulative institutions like law and regulation. Thus, we suggest that issuing innovation policy should not only put emphasis on regulative institutions, but the normative and cognitive institutions are also significant.

10.4.4 Differentiating and evolving innovation policy

It has been widely recognised that implementing one-size-fits-all innovation policy to promote innovation is neither feasible nor possible. To ensure effectiveness and efficiency, it is suggested that innovation policy is differentiated based on specific innovations. Following the framework and the Chinese innovation cases, several dimensions are suggested to be considered when differentiating policy. First, catching-up as a specific context for mobile system innovation has impacted both innovation activities and government intervention. Second, the innovation policy should be distinct according to the different organisational actors it focuses on. For example, innovation policy for the market place should put more emphasis on innovation diffusion, while policy for the innovation system should consider both technology development and diffusion at the same time. Third, innovation policy should be differentiated based on the challenges that it is aim at addressing. Lastly, innovation policy should also be differentiated by considering the different innovation stages.

Furthermore, apart from emphasising differentiation, the evolution of innovation policy along with transiting innovation systems and continuous innovations should also be taken into consideration. Through comparing the innovation cases, it is recognised that the government in China was improving along with the 3G and 4G system evolutions. It had learnt from past experience, whether this was success or failure, and then issued more targeted and more effective policy for promoting indigenous innovation. Therefore, it is suggested that, for governments in catching-up countries, summarising from the past experiences of issuing and implementing innovation policy, and continuously improving and evolving both capability for intervention and the quality of innovation policy issued are significant for ensuring the success of innovation.

10.4.5 Strengthening international linkages

Initially, this work did not set out to emphasise international linkages in analysing government intervention in innovation. Through analysing the process of China's 3G and 4G innovations and comparing the two different but interrelated innovation systems, the influences of international linkages on China's indigenous technology innovations were unconsciously exhibited. Firstly, it is observed in both the 3G and 4G innovation cases that establishing and consolidating linkages with foreign actors that are encouraged and facilitated by the government have significantly stimulated the development and diffusion of China's TD-SCDMA and TD-LTE innovations. For example, in the initial stage of developing TD-SCDMA technology, Siemens was enrolled with its TD duplexing technology; in the diffusion stage, foreign vendors such as Samsung, Nokia, Alcatel and Ericsson were encouraged to form joint ventures with domestic firms like Datang, Potevio, ZTE etc. Similarly, in the TD-LTE innovation, as previously elaborated, international giants like Apple and Vodafone were all invited to set up strategic cooperation relationships with domestic firms like China Mobile, ZTE, Huawei etc. The government was observed to issue inclining policy to encourage and facilitate such kinds of international cooperation in terms of promoting indigenous innovations, such as subsidies for technology export and tax relief for joint ventures. Their resources, experiences and capabilities have largely promoted the innovations.

Furthermore, through comparing the innovation systems of TD-SCDMA and TD-LTE, it has been observed that the number of foreign firms and organisations that participated in the TD-LTE innovation, including in both technology development and diffusion, was much larger than the number in the 3G era. Many international giants that did not support or were even against China's standard in the 3G era, were very active in participating in the TD-LTE innovation, and the styles of international cooperation were also more diverse. Unlike TD-SCDMA, which was only adopted in China, TD-LTE has become in a real sense an international standard which now covers 26 countries. Supported by innovation policy of "domestic firms going out, foreign firms invited in", China has gradually achieved catching-up in technology innovation.

10.5 LIMITATIONS AND FURTHER RESEARCH

10.5.1 Research limitations

Despite the contributions and implications, several limitations of this research were also identified. First, the retroductive method used in this study might lead to a limitation of this research. As discussed in the research design chapter, the prerequisite of exploring the mechanism based on the retroductive strategy is to establish a closed system, so that the proposed mechanism could then be examined, based on various events that comprise the closed system. Nevertheless, in terms of social science research, the closed system that was built up can hardly be entirely closed. Therefore, in terms of selecting case studies, biases might occur if only cases in China's telecommunication field are examined.

Second, based on the selected case studies, in terms of retroducing the mechanism, several implicit but relevant issues might also be missed and therefore not be tested. This is because the theoretical framework was initially developed based on the reviewed literature and was only revised based on selected events. The theoretical framework was exclusive, and cannot enclose all the relevant issues. As it was adopted to frame the data collection and analysis, and thereby structured the conclusions and findings, this could therefore also be considered as a limitation.

Third, biases might occur because the case studies were highly dependent on the researcher's personal understandings from documentary research and the interviewees' personal understandings about the selected events. Even though a triangulation strategy was employed to relieve such kinds of bias, they still cannot be completely erased. Besides, as most of the interviews were conducted with executive level staff, considering their personal interests, some of them might not elaborate their own real thoughts. Furthermore, the interviewed organizations were selected based on the consideration of their significance in the innovation projects and whether connections could be established. This could also be considered as a limitation because there may exist more and different details in these unvisited organizations.

10.5.2 Further research

This research also points to several topics which might be worth considering for further research. Firstly, inspired by the approach of developing the theoretical framework, further research could be conducted to extend the adoption of institutional theory as we did in this work. As elaborated, institutional theory has long been criticized as strong in interpreting but weak in structuring analysis. Nevertheless, as TIS is normally described as weak in interpreting, but functions well in structuring analysis, we therefore combined institutional theory with the innovation system frame, based on the literature, which complemented the weakness of institutional theory. Adding an analytical lens to enhance the utility of institutional theory has, to some extent, broadened the adoption of institutional theory. Thus we suggest that further research could be conducted to explore more adoption approaches for institutional theory.

Secondly, through bridging the research gaps in the catching-up context and intervention mechanism, we suggest that further studies could be conducted to adopt our framework in analyzing more and different innovation cases. As different industries or different countries face different social and technological environments, features of government interventions and innovation systems normally demonstrate huge diversity. Therefore, whether the mechanism of government intervention that is exhibited by the developed theoretical framework can fit well with different social-technical conditions in other industries or countries could be further examined. More importantly, through its adoption in more and different case studies, the framework itself could be further sharpened and perfected.

Lastly, through bridging the research gap related to understanding government intervention based on the TIS frame, we suggest that further studies could be conducted to focus on government intervention in innovation based on other innovation system frames, such as RIS, SIS, LIS etc. Government intervention in NIS has been well studied, and this work has already contributed to extending how government can promote the innovation of a specific technology based on the TIS. More studies are suggested to understand government intervention in different levels of innovation.

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Appendix 1: Systematic review on innovation literature

1. Use *"Science Direct"* and *"ABI/Inform"* as two databases (for cross-check), restrict in *"Peer-reviewed Journals"*, and limited within the field of *"Social Science, Business, Economic, and Management"*.
2. Select "Technology Innovation" as key words to search in each database.
3. Exclude obvious irrelevant results, then rank *"Top 15 Journals"* in each database, according to the number of articles that been published (Table 1 and Table 2).

Table AP1-1: Searching result from "Science Direct Database" (in total 47034 articles)

Rank	Publication Title	Count
1	Research Policy	1742
2	Technological Forecasting and Social Change	1433
3	Technovation	1207
4	Telecommunication Policy	1124
5	Technology in Society	1005
6	Industrial Marketing Management	951
7	Journal of Information Technology	851
8	Information & Management	778
9	Structural Change and Economic Dynamics	626
10	European Management Journal	588
11	International Journal of Information Management	554
12	World Development	542
13	Expert Systems with Applications	524
14	Journal of Business Research	517
15	Journal of Product Innovation Management	507

Table AP1-2: Searching result from "ABI/Inform Database" (in total 36420 articles)

Rank	Publication Title	Count
1	Research Policy	1519
2	Technovation	1226
3	Telecommunication Policy	1020
4	Technology Analysis & Strategic Management	928
5	Journal of Information Technology	906
6	Journal of Technology Transfer	851
7	International Journal of Innovation, Management and Technology	810
8	Research Technology Management	597
9	International Journal of Technology Management	435
10	The China Quarterly	407
11	European Journal of Information Systems	406
12	Economics of Innovation and New Technology	369
13	International Journal of Business and Social Science	351
14	European Journal of Innovation Management	343
15	The Journal of Product Innovation Management	332

4. Compare the results from each database, to screen out the final *"Top 15 Journals"* in this field (Table 3), mostly according to the number of articles that published.

Table AP1-3: Top 15 Journals in the field of "Technology Innovation"

Rank	Publication Title	Max Count
1	Research Policy	1742
2	Technological Forecasting and Social Change	1433
3	Technovation	1226
4	Telecommunication Policy	1124
5	Technology in Society	1005
6	Industrial Marketing Management	951
7	Technology Analysis & Strategic Management	928
8	Journal of Information Technology	906
9	Journal of Technology Transfer	851
10	International Journal of Innovation, Management and Technology	810
11	Information & Management	778
12	Structural Change and Economic Dynamics	626
13	Research Technology Management	597
14	European Management Journal	588
15	World Development	542

5. Individually review the *"Top 15 Journals"* that been selected. Within the year of *"1990-2015"*, use the strategy *"ALL"* with *"technology innovation; innovation systems; government; catching-up"* as key words to search each journal.

6. Based on the search outcome within each journal (normally within 300), to read titles, abstracts, or introductions of the articles one by one, in order to finally screen out the directive relevant literature that need to be reviewed (Table 4).

7. Use *"technology innovation; innovation systems; government; catching-up"* as key words to search the two databases, in order to double check if any relevant literature is missed. *(257 papers in total after the step 7)*

8. Go through all the articles that been found, withdraw not really relevant ones and maintain the others, then import useful articles into the *"EndNote"* (a reference management software), to form the personal database for literature review of technology innovation.

Table AP1-4: Final result of journal review (Articles count)

Publication Title	"Technology Innovation" as Keywords in the stage "2"	"Technology innovation; Innovation system; Government; Catching-up" as Keywords in "5"	After reading "titles, abstracts, or introductions" in the stage "6"
Research Policy	1742	1271	25
Technological Forecasting and Social Change	1433	1033	20
Technovation	1226	815	24
Telecommunication Policy	1124	703	23
Technology in Society	1005	657	12
Industrial Marketing Management	951	419	15
Technology Analysis & Strategic Management	928	435	23
Journal of Information Technology	906	340	20
Journal of Technology Transfer	851	378	16
Int.J of Innovation, Management and Technology	780	451	13
Information & Management	778	344	15
Structural Change and Economic Dynamics	626	237	19
Research Technology Management	597	420	11
European Management Journal	588	342	10
World Development	542	211	11

9. During reviewing the selected literature, articles in the database could be classified based on the significance in this research from *1 to 5 stars*.

10. By employing this systematic review approach, from originally selecting articles to finally reviewing them, both the accuracy and the comprehensiveness of literature review in this research then could be promised.

Appendix 2: Information pages and consent forms

Translated Example (English Version)

MANCHESTER
1824
The University of Manchester

Information Page for Interviewees Participating in Doctoral Research Projects

You are being invited to take part in a study as part of a student project. Before you decide it is important for you to understand why the study is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

Q1: Who will conduct the study?

Guanyu Liu, (Please see attached CV), second year PhD student in the Institute of Development Policy and Management (IDPM), University of Manchester, UK

Q2: Title of the study

<Government intervention in technological innovation system within the context of catching-up: institutional analysis of TD-SCDMA and TD-LTE innovation in China>

Q3: What is the aim of the study?

From the theoretical view, this research is aiming to understand government roles and functions in technology innovation catching-up. From the practical perspective, China's experience of catching-up is planning to be highlighted for other countries to learn.

Q4: Why have I been chosen?

You have overall knowledge in this professional area, which are the most cherished capability and information for this research.

Q5: What would I be asked to do if I took part?

Just sit and talk in free style, this would become a very open interview based on pre-designed guideline but flexible. You are welcomed to talk everything related with the objective of this research.

Q6: What happens to the data that been collected?

All data collected in this study will be used for writing a student dissertation, with no commercial purpose and harmful intension.

Q7: How is confidentiality maintained?

Researcher will remove all identifiers and ID numbers or pseudonyms are used as a means of breaking the link between data and identifiable individuals. Where the links need to be preserved in order to match data sets in a repeated measures design, coding frames including participant identities are to be kept securely. Under no circumstance should they be stored on the same laptop as the database, and the data base storage would be encrypted. The data will be kept for no less than six years after last publication from this data. In the case of unpublished studies, the data will be kept for no longer than 1 year after graduation. The data should then be destroyed.

Q8: Will I be paid for participating in this study?

Basically not, but small gifts not exceed £10 in a value might be provided.

Q9: What happens if I do not want to take part or if I change my mind?

It is totally up to you to decide whether or not to take part. If you decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you still free to withdraw at any time without giving a reason.

Q10: What is the duration of the study?

Two half an hour's interviews based on pre-designed guideline would be conducted in flexible.

Q11: Where will the study be conducted?

In office or school, depends on participants but should be in public place.

Q12: Will the outcomes of the study be published?

Probably will, the study is for student's dissertation, which might be published when finish.

Q13: Criminal records check

The researcher does not have any criminal records previously.

Q14: Contact for further information

If there are any further questions, please contact the researcher via email: guanyu.liu@manchester.ac.uk, otherwise you could contact the supervisor team directly also by sending email to ping.gao@manchester.ac.uk, or sharon.morgan@manchester.ac.uk.

Q15: What if something goes wrong?

If there are any further questions, please contact the researcher via email: guanyu.liu@manchester.ac.uk, otherwise you could contact the supervisor team directly also by sending email to ping.gao@manchester.ac.uk, or sharon.morgan@manchester.ac.uk.

If there are any issues regarding this research that you would prefer not to discuss with members of the research team, please contact the Research Practice and Governance Co-ordinator by either writing to 'the Research Practice and Governance Co-ordinator, Research Office, Christie Building, The University of Manchester, Oxford Road, Manchester, M13 9PL', by emailing to research-governance@manchester.ac.uk, or by calling 0161 275 7583/8093

Untranslated Example (Chinese Version)

MANCHESTER 1824
The University of Manchester

关于参与博士项目调研的背景信息

您正被邀请参与到一个学生的研究项目中。在您决定是否参与前，对此研究项目和包含的活动进行了解是十分重要的。请花几分钟时间简单了解一下以下内容，当然您也可以和其他人讨论一下此文件内容。如果您需要更多信息或有不清楚的地方请直接联系我们。感谢您的参与。

问题 1：谁在主持此次调研活动？

刘冠宇，英国曼彻斯特大学管理与发展政策研究院的在读博士生。（附件里是我的简历）

问题 2：本次调研的研究课题？

以中国 3G 和 4G 移动通讯技术的发展为例，在发展中国家进行科技赶超的背景下，探索政府干预与科技创新系统间的互动以及这种互动对科技创新产生的影响。

问题 3：为何我会被选为访谈对象？

在这个专项领域中您具有非常专业的知识和从业经验，这是本次调研最为看重的。

问题 4：我将会以怎样的形式参与其中？

仅仅是简单地坐下来进行一次访谈，根据提前发给您的访问提纲，答案会非常开放。

问题 5：被收集的数据将会被怎样处理？

所有被收集的数据将会用于博士论文的写作，不会有任何商用目的。

问题 6：怎样确保数据的保密性？

研究员会将所有身份标识从所收集的材料中剔除，以此来打破数据和可识别的个人之间的联系。但是参与人员的 ID 和材料的对应关系会用特殊的编码方式进行保存，以确保数据的吻合不被破坏，而且安全。在任何情况下这些数据和参与人的对应关系都不会被保存在同一部电脑或同一个数据库中，保存后的内容都会被严格加密。从数据被发表之日算起数据将会被保存六年以上的时间，如果用于未发表的文章，此数据将会被保存不超过一年，之后删除。

问题 7：如果我参与调研，会被支付费用吗？

基本上不会，但是我们会提供英国带来的价值 10 英镑以内的小礼品表示感谢。

问题 8：如果我不想参与或是中途更改了想法想退出可以吗？

是否参与其中以及是否中途退出完全取决于您自己。如果您确定参与，将会需要您签署一份表示同意参与的表格。中途任何时间您都可以退出，不需要有任何理由。

问题 9：访谈将会持续多久？

根据提前准备好的访谈提纲，访谈大约会由两个半个小时构成，总体在一小时左右。

问题 10：访谈将会在哪里进行？

一般会是在您的单位，当然也可以提前预约一个您方便的时间和地点

问题 11：这次调研的内容会被发表吗？

也许会，本次调研的目的主要用于学生的博士论文，在论文完成后可能部分章节会被发表。

问题 12：犯罪记录检查

参与此次调研的研究员此前没有任何犯罪记录.

联系方式

如果您有更多的问题需要了解，请致信以下邮箱：guanyu.liu@manchester.ac.uk，或者您也可以直接联系导师管理团队，他们的邮件地址如下，ping.gao@manchester.ac.uk, or sharon.morgan@manchester.ac.uk.

如果在调研过程中您有任何问题不愿与研究团队进行讨论和沟通，您可以直接联系我们在学校的管理与协助办公室，邮件或电话都可，地址，电子邮件地址和固定电话如下：Research Office, Christie Building, The University of Manchester, Oxford Road, Manchester, M13 9PL', by emailing to research-governance@manchester.ac.uk, or by calling 0161 275 7583/8093

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CONSENT FORM

If you are happy to participate please complete and sign the consent form below

1. I confirm that I have read the attached information sheet on the above study and have had the opportunity to consider the information and ask questions and had these answered satisfactorily.
2. I understand that my participation in the study is voluntary and that I am free to withdraw at any time without giving a reason.
3. I understand that the interviews will be audio/video recorded.
4. I agree that any data collected may be passed to other researchers.
5. I agree that any data collected m be published in anonymous form in academic books or journals.

I agree to take part in the above project

Name of participant_______________ Date______________

Name of person taking consent____________ Date______________

Appendix 3: Example of pre-interview questionnaire

Translated example (mobile operator)

The objective of using this questionnaire is to gain overall information about your experience and opinions about China's government intervention in TD-SCDMA and TD-LTE standardization.

1. How did you and your department/company relate with TD-SCDMA/TD-LTE development or diffusion?
2. What was your role in relation to TD-SCDMA and TD-LTE project?
3. What are your opinions or experiences regarding to the TD-SCDMA and TD-LTE development and diffusion?
4. Did you perceive any government intervention with respect to the TD project that you participated? How it worked and affected the project?
5. Can you recommend any other potential informants that might help understanding this topic?
6. Can you provide any statistics/reports about government intervention in your company? In particular, can you provide any statistics/reports including government intervention supporting or hindering the TD projects?

Appendix 4: Example of semi-structured interview protocol

Basic individual questions

1. Personal information (position, main work, education background, etc.)
2. How did you get involved in the TD-SCDMA/TD-LTE development and diffusion in the current or former company? If possible, please briefly introduce your career that related with telecommunication.
3. What is/was your role in the TD-SCDMA and TD-LTE development and diffusion?
4. Do you perceive any government impacts in relation to TD-SCDMA/TD-LTE innovation? How did they work?
5. Personally, how do you think government intervention in TD-SCDMA/TD-LTE development and diffusion?
6. Personally, please tell us how you feel about TD-SCDMA/TD-LTE innovation in China? As a participator, or a customer, can you compare these two systems with other systems that you had used?

Company questions

1. Please give a brief history of your firm (or organization). What are the main product (or mission), main market, number of employees, annual budget & sales volume, and the market position?
2. How did your company get involved in the TD-SCDMA/TD-LTE development and diffusion? If possible, please briefly introduce the history that your company related with telecommunication.
3. What were the main roles that your company played in terms of TD-SCDMA/TD-LTE development and diffusion?
4. What is your firm's perspective on China's telecommunication market (e.g.

competition, market, technology, standards, and applications)?

5. Which mobile system your company operates? Why your company chose it?
6. In history, which mobile system your company have operated? Why chose it?
7. What effects have your company had on the development and diffusion of TD?
8. What is/was your company's strategy in China's telecommunication filed in terms of products, standards, services and markets?
9. What is/was your company's strategy in the telecommunication field in terms of R&D, IPRs and standardization?
10. During your participation in the project, did government intervention impact your company in the development and diffusion? How?

Identifying innovation system structure

1. What other companies, or organizations, do your company interact with in terms of TD-SCDMA/TD-LTE development and diffusion?
2. What roles did they play in terms of TD-SCDMA and TD-LTE innovation?
3. What was your relationship with those companies that you just mentioned?
4. Who are the key individuals of these companies or organizations? Can you introduce these key individuals to us for further interviews?
5. How was your company impacted by any policies in relation with the development and diffusion of TD-SCDMA/TD-LTE? Did these policies or government interventions impacts the strategies of your company, or the interactions between your company with other TD project participators?
6. What challenges did your company face with respect of participating in TD-SCDMA/TD-LTE development and diffusion? How did these challenges resolved?
7. How the government helped address the challenges that you had faced?

Appendix 5: Summary of interviews and interviewees

No.	Code	Organization	Role of organization	Role of interviewees	Date	Location
1	GA_M1	MIIT	Government Authorities	Official in InfoComm Development Department	April 2014	Beijing
2	GA_M2	MIIT	Government Authorities	Official in InfoComm Administration Department	June 2014	Beijing
3	GA_M3	MIIT	Government Authorities	Deputy Director in Science &Technology Dept.	June 2014	Beijing
4	GA_M4	MIIT	Government Authorities	Official in Science &Technology Department	July 2014	Beijing
5	GA_SB	SASAC	Government Authorities	Deputy Director in Personnel Bureau in BJ Branch	April 2014	Beijing
6	GA_SF	SASAC	Government Authorities	Chief in Finance Bureau in Fuxin Branch	July 2014	Fuxin
7	GA_NB1	NDRC	Government Authorities	Deputy Director in High-Tech Department	April2014	Beijing
8	GA_NB2	NDRC	Government Authorities	Official in High-Tech Department	June 2014	Beijing
9	GA_NB3	NDRC	Government Authorities	Official in High-Tech Department	June 2014	Beijing
10	GA_NF	NDRC	Government Authorities	Chief in High-Tech Department in Fuxin Branch	July 2014	Fuxin
11	MO_CMB1	China Mobile	Mobile Operators	Senior Planning Manager in R&D Centre	April 2014	Beijing
12	MO_CMB2	China Mobile	Mobile Operators	Vice Chief Engineer in R&D Centre	June 2014	Beijing
13	MO_CMB3	China Mobile	Mobile Operators	Senior Network Manager in R&D Centre	June 2014	Beijing
14	MO_CMB4	China Mobile	Mobile Operators	Senior Manager in Marketing Department	July 2014	Beijing

15	MO_CMF	China Mobile	Mobile Operators	Vice President in Fuxin Branch	July 2014	Fuxin
16	MO_CUB1	China Unicom	Mobile Operators	Senior Manager in Strategy Department	June 2014	Beijing
17	MO_CUB2	China Unicom	Mobile Operators	Official in Marketing Department	June 2014	Beijing
18	MO_CUS	China Unicom	Mobile Operators	Researcher in Network Department	Sept 2014	Shanghai
19	MO_CUF	China Unicom	Mobile Operators	Vice President in Fuxin Branch	July 2014	Fuxin
20	MO_CTB1	China Telecom	Mobile Operators	Department Director in BJ Research Institute	August 2014	Beijing
21	MO_CTB2	China Telecom	Mobile Operators	Researcher in BJ Research Institute	August 2014	Beijing
22	MO_CTB3	China Telecom	Mobile Operators	Official in Marketing Department	August 2014	Beijing
23	MO_CTS	China Telecom	Mobile Operators	Manager in Business Strategy Department	Sept 2014	Shanghai
24	TV_D1	Datang	Technology Vendors	Manager of R&D strategy in R&D Centre	April 2014	Beijing
25	TV_D2	Datang	Technology Vendors	Researcher in Chipset Group in R&D Centre	June 2014	Beijing
26	TV_D3	Datang	Technology Vendors	Official in Marketing Department	July 2014	Beijing
27	TV_HB	Huawei	Technology Vendors	Oversea IPR Department Vice Director	July 2014	Beijing
28	TV_HS1	Huawei	Technology Vendors	Senior Manager in R&D Wireless Group	Sept 2014	Shanghai
29	TV_HS2	Huawei	Technology Vendors	Business Manager in Marketing Department	Sept 2014	Shanghai
30	TV_Z1	ZTE	Technology Vendors	Senior Project Manager in R&D Centre	July 2014	Beijing

31	TV_Z2	ZTE	Technology Vendors	Researcher in Standardization Division	August 2014	Beijing
32	TV_Z3	ZTE	Technology Vendors	Business Manager in Marketing Department	August 2014	Beijing
33	TV_S1	Siemens	Technology Vendors	Business Development Department Director	August 2014	Beijing
34	TV_S2	Siemens	Technology Vendors	Technology & Development Dept. Director	Oct 2014	Beijing
35	TV_E	Ericsson	Technology Vendors	Manager of IPRs and standardization Dept.	July 2014	Beijing
36	RD_TR1	CATR	R&D Institutes	Researcher in Telecom Policy Research institute	Sept 2014	Beijing
37	RD_TR2	CATR	R&D Institutes	Official in Telecom Equipment Centre	Sept 2014	Beijing
38	RD_S1	CAS	R&D Institutes	Professor in Policy & Management Institute	Oct 2014	Beijing
39	RD_S2	CAS	R&D Institutes	Researcher in Policy & Management Institute	Oct 2014	Beijing
40	UN_BU1	BUPT	Universities	Professor specialized in telecom research	April 2014	Beijing
41	UN_BU2	BUPT	Universities	Research Assistant focus on telecom research	June 2014	Beijing
42	UN_BE	UIBE	Universities	Professor in Competition Law Centre	June 2014	Beijing
43	IA_TD1	TDIA	Industrial Alliances	Researcher in the IPR Department	Oct 2014	Beijing
44	IA_TD2	TDIA	Industrial Alliances	Director in Industry Coordination Department	Oct 2014	Beijing