ISCTE IUL
Instituto Universitário de Lisboa

Determinants of Emerging Technology Commercialization:

Evidence from MEMS Technology

WANG Chunbo

Thesis submitted as partial requirement for the conferral of the degree of

Doctor of Management

Supervisor:
Professor Paulo Bento, Assistant Professor, ISCTE University Institute of Lisbon

Co-supervisor:
Professor Lu Yin, Professor, University of Electronic Science and Technology of China, School of Management and Economics

May, 2018

- Spine –

Determinants of Emerging Technology Commercialization: Evidence from MEMS Technology

WANG Chunbo

ISCTE IUL
Instituto Universitário de Lisboa

Determinants of Emerging Technology Commercialization:

Evidence from MEMS Technology

WANG Chunbo

Thesis submitted as partial requirement for the conferral of

Doctor of Management

Jury:
Professor Ana Simaens, Assistant Professor, ISCTE-IUL
Professor Xiao Wen, Associate Professor, UESTC, China
Professor Teng Ying, Full Professor, UESTC, China
Professor Álvaro Lopes Dias, Full Professor, Instituto Superior de Gestão
Professor Paulo Bento, Assistant Professor, ISCTE-IUL

May, 2018

This page is deliberately left blank

Statement of honor
Submission of master's dissertation or project work or doctoral thesis

I the undersigned state on my honor that:

- The work submitted herewith is original and of my exclusive authorship and that I have indicated all the sources used.
- I give my permission for my work to be put through Safe Assign plagiarism detection tool.
- I am familiar with the ISCTE-IUL Student Disciplinary Regulations and the ISCTE-IUL Code of Academic Conduct.
- I am aware that plagiarism, self-plagiarism or copying constitutes an academic violation.

Full name WANG Chunbo
Course Doctor of management
Student number
Email address Jack.wang@foxmail.com
Personal email address Building 30,No.58,Xiuxi Road,Wuxi Jiangsu China
Telephone number +8613906188021

ISCTE-IUL, 14/5/2018

Signed

王春波

This page is deliberately left blank

Abstract

The term “emerging technology” refers to new technologies that create substantial changes to industry evolution and enterprise management. Nowadays, such technologies are mainly based on the development of information technology, internet technology, biotechnology and other interdisciplinary areas with potential industrial applications. Although emerging technologies have created opportunities for technological and economic innovation, their “creative destruction” characteristics also result in a very high failure rate in their commercialization processes.

Most of the recent studies on the commercialization of emerging technology have focused on developed areas such as the United States, Japan, and the European Union, with few studies on developing countries like China. The present thesis seeks to fill this gap. Taking 112 Chinese MEMS enterprises as a sample, this thesis empirically investigated the determinants of emerging technology in China. Furthermore, a case study (Wuxi BEWIS Sensing Technology, Ltd.) was employed to analyze how these determinants affect the real commercializing process in the Chinese economy. Through multiple regression analysis, the empirical results show that technology property, market conditions, regional innovation network, and enterprise capability are determinants of MEMS commercialization, whereas social environment and policy and regulation do not have significant impacts on the performance of MEMS commercialization.

This chapter is comprised of seven chapters. Chapter 1 mainly introduces the background, the content of the research, and the contributions of the research. Chapter 2 presents a literature review on emerging technologies, including definitions, characteristics, management, and commercialization. Chapter 3 analyzes the status and developing trends of MEMS technology. Chapter 4 describes an empirical study on the determinants of commercialization of MEMS technology, before Chapter 5 reports the results of the empirical survey in Chapter 4. Chapter 6 uses Wuxi BEWIS Sensing Technology Ltd. as a case to analyze how the above-mentioned determinants affect the four stages in the commercialization process. Finally, Chapter 7 presents the main conclusions and recommendations, as well as limitations and suggestions for further research.

This thesis explores the successful methods of emerging technology commercialization in China, providing some practical guides to Chinese enterprises and helping increase their commercialization success rate. The thesis offers value to emerging technology literature, industrial development, and government policy makers.

Keywords: MEMS; emerging technology; commercialization; determinant
JEL: O33; M11

Resumo

O termo "tecnologia emergente" diz respeito a novas tecnologias que estão a gerar mudanças substanciais na evolução da indústria e na gestão das empresas. Atualmente essas tecnologias baseiam-se sobretudo no desenvolvimento da tecnologia de informação, da tecnologia de internet, da biotecnologia e de outras áreas interdisciplinares com potencial de aplicação industrial. Embora as tecnologias emergentes tenham criado oportunidades para a inovação, tecnológica e económica, as suas características de "destruição criativa" também resultaram numa elevada taxa de insucesso nos processos de comercialização.

A maioria dos estudos recentes relativos à comercialização de tecnologia emergente têm-se focado em regiões desenvolvidas tais como os Estados Unidos, o Japão, e a União Europeia, existindo poucos estudos em países em vias de desenvolvimento como é o caso da China. Esta tese procura contribuir para o preenchimento dessa lacuna. Partindo de uma amostra de 112 empresas chinesas de sistemas microeletromecânicos (MEMS), procurou-se investigar empiricamente os determinantes de tecnologia emergente na China. Além disso, foi efetuado um estudo de caso (Wuxi BEWIS Sensing Technology, Ltd.) para analisar como esses determinantes afetam o processo real de comercialização na economia chinesa. Os resultados empíricos, obtidos através de análises de regressão múltipla, mostram que a propriedade tecnológica, as condições de mercado, a rede regional de inovação e a capacidade empresarial são determinantes para a comercialização de MEMS. Por outro lado, constata-se que o ambiente social, a política e a regulamentação não têm impactos significativos no desempenho da comercialização de MEMS.

Esta tese é composta por sete capítulos. Primeiramente são apresentados os antecedentes, o âmbito da investigação e as contribuições da mesma. Depois, é efetuada uma revisão de literatura sobre tecnologias emergentes, incluindo definições, características, gestão e comercialização, seguindo-se uma analise à situação atual e às tendências de desenvolvimento da tecnologia de MEMS. De seguida, efetuou-se uma descrição de um estudo empírico sobre os determinantes da comercialização da tecnologia de MEMS, antes de serem relatados os resultados dessa mesma investigação. Posteriormente, utilizou-se a Wuxi BEWIS Sensing Technology Ltd. para analisar como os determinantes mencionados acima afetam as quatro etapas do processo de comercialização. Finalmente, são apresentadas as principais conclusões e recomendações, bem como as limitações e sugestões para futuras investigações.

Esta tese explora os métodos de sucesso da comercialização de tecnologia emergente na China, fornecendo alguns guias práticos para empresas chinesas aumentarem a taxa de sucesso de comercialização. A tese oferece contributos à literatura sobre tecnologia emergente, ao desenvolvimento industrial e aos responsáveis pelas políticas públicas.

Palavras-chave: MEMS; tecnologia emergente; comercialização; determinantes.
JEL: O33; M11

摘要

新兴技术特指可以创造或有潜力改变一个行业管理方式的一种新型的技术，今天，主要是指信息技术、互联网技术、生物技术以及它们在其它领域的潜在应用，虽然新兴技术已经为技术和经济创新创造了机会，但是，它们创造性毁灭的特征也为商业化成功带来了高的失败率，而发展新兴技术是一项风险极高的活动。

目前大多关于新兴技术的研究集中在发达国家，如美国、日本及欧洲，很少有研究者关注像中国这样的发展中国家，为了弥补空白，本文调研了112个中国MEMS(微机械机电系统)方面的新兴技术企业，然后以无锡北微传感科技有限公司为案例分析了在中国经济背景下新兴技术商业化过程中的影响因素，通过多重回归分析和实证分析得到技术属性、市场条件、区域创新网络和企业家能力是影响新兴技术商业化成功的主要影响因素，而社会环境和政策法规因素对MEMS技术商业化成功没有显著影响的结论。

本文总共有七章。第一张主要介绍了研究的背景和主要贡献；第二章是文献综述，描述了新兴技术的定义、特征、管理方法和商业化相关研究；第三章分析了MEMS技术的发展状态和趋势；第四章为MEMS技术商业化影响因素的实证研究；第五章对实证研究结果进行了阐述；此外，第六章以无锡北微传感科技有限公司为例分析了各个因素在商业化的四个阶段影响作用；最后，第七章对全文进行了总结，同时也提出了本研究的局限性和将来进一步研究方向。

本文的目的是探索新兴技术在中国商业化成功之路，也希望能为中国的企业提供一些实践上的指导，帮助他们技术商业化道路上提高成功率和避免不必要的失败，本文以崭新的视角研究新兴技术商业化，期望对新兴技术理论研究和业界实践、包括政府政策的制定提供有价值的帮助。

关键词：MEMS；新兴技术；商业化；影响因素
JEL：O33；M11

This page is deliberately left blank

Acknowledgements

We are extremely grateful to all those who helped and encouraged me during the period of writing this thesis.

We are particularly appreciative of my supervisor Paulo Bento and my co-supervisor Lu Yin, who gave me the freedom to choose the subject of my thesis and offered me a lot of help. Their sincere advice and instructive suggestions on this thesis benefited me greatly. Paulo pointed out my mistakes and shortcomings and we are deeply thankful for his help in the accomplishment of this thesis.

Moreover, We would like to show my special thanks to all the people who were involved in the questionnaire design, including three specialists on MEMS: Mr. Jin Yufeng, Mr. Ma Shenglin, and Mr. Huang Qiang; two professors on management: Mr. Yin Lu and Ms. Wang Min; and three doctoral candidates: Mr. Xu Feng, Mr. Han Jiulin, and Mr. Lu Zhouying.

We would also like to show my sincere gratitude to the other professors – XiaoWen, SunPing and Virgínia Trigo – from whose lectures and help, we have benefited greatly. They have improved my language, writing and research method, and have provided guidance.

We also want to express my sincere gratitude to my family and friends, who gave me valuable suggestions and comforted and encouraged me during the course of writing this thesis.

Without everyone’s help, we could not have succeeded in completing my thesis.

This page is deliberately left blank

致谢

我十分感谢在我写论文的时候给予帮助和鼓励的人们。

首先，要向我的导师银路教授和 Paulo Bento 表达我诚挚的谢意。他们给了我选题的自由和空间。同时在写作阶段给予我很大的帮助。他们真诚的指导和建议让我受益匪浅。银教授指出了我论文中的不足及需要改进之处。我很感激他对我的论文完成起到了很大的帮助作用。

同时，我也要向我的任课老师 Virgínia Trigo 教授和项目负责人肖文教授表达我的谢意。他们的演讲及课堂帮助让我更好地完成论文写作。他们在语言，写作和研究方法上都为我提供了指导和帮助。

我还想要感谢项目组孙平教授、马绍壮教授以及我的家人和朋友，还有在写在上给与我协助的许许多多的人。他们为我论文的写作提供了很多支持。

最后，再一次向以上所有人表达我诚挚的谢意。在他们的帮助下，我更好的完成了论文写作。

This page is deliberately left blank

Contents

This page is deliberately left blank

List of Tables

This page is deliberately left blank

List of Figures

This page is deliberately left blank

List of Abbreviations

PDA	Personal Digital Assistant
R&D	research and development
MEMS	Micro-Electro-Mechanical Systems
NBSC	National Bureau of Statistics of China
TWB	The World Bank
SEM	Structure Equation Model
BEWIS	Wuxi BEWI Sensing Technology Ltd.
WIPO	World Intellectual Property Organization
ROA	Return on Assets
ROE	Return on Equity
SPC	Statistical Process Control
IOT	Internet of Things
CCIDCR	China Center for Information Industry Development Consulting Report

This page is deliberately left blank

Chapter 1: Introduction

1.1 Background and significance

Throughout the long history of societal evolution, new technologies have gradually become the most important engine of economic growth. It is widely believed that, to date, there have been three main technological revolutions (Yin & Wang, 2010). The first one happened in the 1760s with the invention of the steam engine by British engineer James Watt; the second one was brought on by the application of electricity in the 1870s, and the third one began in the 1940s with the wide application of information and communication technology around the world. Emerging technology, as a type of new technology, refers to technologies that are emerging and creating substantial changes to industry evolution and enterprises management. Nowadays, such technologies are mainly based on the development of information technology, internet technology, biotechnology, and other interdisciplinary areas with potential industrial applications. Recently, intelligent sensors, 3D printing, nanotechnology, grapheme material, and biological information technology have all shown the potential to reshape the entire industries or create a new sector, significantly updating established business models (Masters & Thiel, 2014).

Although emerging technologies have created opportunities for technological and economic innovation (Yin &Wang, 2005), their “creative destruction” characteristics (Day & Schoemaker, 2000) also bring about a very high failure rate in their commercialization process. Compared to the incremental technological innovation, emerging technology has a significant impact on the business model, posing new challenges to traditional managerial skills in an enterprise (Day & Schoemaker, 2000). For example, in 1998, Apple Computer launched the Newton “personal digital assistant” (PDA) product to the market after spending $500 million on research and development (R&D), but experienced poor sales. However, a tiny startup called Palm Computing, Inc. also used PDA technology to develop the PalmPilot, one of the best-selling consumer electronics products in history, and sold more than 1 million units in its first year and a half (Dillon, 1998). This case highlights the high risk of emerging technological commercialization. One of main reasons why Palm Computing succeeded while Apple failed lies in the completely new requirements for the enterprise management, including the innovations of organization structure, business model, and marketing strategy (Huang & Zhang, 2015).

For emerging technology, the failures of incumbents are so widely recognized that some traditionally managerial approaches may turn out to be a disadvantage when facing outside entrants with new ideas and vision (Huang & Zhang, 2015). Therefore, in order to increase the successful rates for both startups and incumbents, it is necessary to study the determinants of emerging technology commercialization. In the present study, we consider a typical emerging technology called Micro-Electro-Mechanical Systems (MEMS) to explore the determinants of its commercialization process.

MEMS is a micro intelligent machine or system that consists of miniature intelligent sensors, information processing and control circuits, micro-power, micro-machines, peripheral package entities, various types of data interfaces, and communication units. The origins of what we now know as MEMS technology can be traced back to April 1954, when a paper by Charles Smith was published in *Physical Review* (Smith, 1954). Pustan, M., Dudescu, C., and Birleanu, C. (2016) predicted that, by 2018, the annual global market for MEMS products will reach more than $9.96 billion. The commercialization of MEMS technology started at the end of the 20th century, with a very small market, when wireless communication technology went into the matured stage. At the beginning of the 21st century, with the rapid development of ultraprecise machining technology as well as integrated circuit micro-fabrication technology, the application MEMS began to burst out, showing a typical market feature for emerging technology. MEMS has since become one of the fastest developing high technologies in the field of information technology, maintaining at least double-digit growth every year (Mounier, 2014). Meanwhile, new markets such as consumer electronics, industrial control, and military industry have been explored quickly, showing a wide application prospect. As a type of emerging technology, MEMS has the potential either to create new industries or to subvert the competition of existing industries.

On the way to becoming the world’s second-largest economy, China has experienced high growth during the past 30 years (The World Bank [TWB], 2016). However, it has become increasingly difficult to maintain this speed by relying solely on natural resource consumption and high investment at the cost of the environment. Chinese economic structure has had to upgrade, transferring from extensive growth to intensive one (Hu, 2012). According to the National Bureau of Statistics Data, China’s GDP growth rate was 6.9 percent in 2015, the lowest in 25 years (National Bureau of Statistics of China [NBSC], 2017).

China’s economy has reached the end of 30 years of rapid growth, and the central government has announced that China’s economy has entered a “new normal”; that is, a state of medium low growth. Over the past few decades, China’s growth has primarily depended on low wages, high-polluting industries, and real-estate construction. To avoid falling into the “middle-income trap”, China must rely on new technology to upgrade industry (Hu, 2012). However, the lack of experience and knowledge for emerging technology commercialization has led to a very high failure rate for emerging technology companies in China. The distinct differences between traditional and emerging technologies make it difficult to copy the commercializing experiences in tradition technology (Li & Chen, 2015). While innovation-oriented strategy has become the national strategy of China, developing new technologies – especially emerging technologies – is a high-risk activity, which means that China must urgently improve its success rate of emerging technologies commercialization (Yin & Wang, 2010； Huang & Yang, 2014).

While some scholars have discussed the commercialization of emerging technology (Zhu J., 2015), there is still no literature focusing on MEMS technology. Different emerging technologies have their own trajectory and evolution rules, making them unique to business model design, managerial skills, or even government supporting policies (Kostoff, 2004). China’s history, policies, and political institutions have meant that Chinese companies mainly concentrate on learning and imitating the enterprises of developed countries. Previous Chinese literature on emerging technology has focused on basic characteristics and general management principles, but has seldom focused on specific technology to explore its developing trajectory and commercialization (Li, 2005; Li & Chen, 2015). Thus, current academic research cannot effectively guide the management of specific emerging technologies like MEMS. Meanwhile, since most researchers and institutes in China are greatly affected by developed countries, especially the classic theory from the Wharton School, and directly borrow research method and theory from Western countries, few studies have been conducted regarding the Chinese economic context and enterprise capabilities (Jin, 2005; Huang & Wang, 2011).

To fill this gap, this thesis will combine empirical analysis and case study methods to systematically investigate the determinants for MEMS commercialization. The results are valuable for academic research and also for enterprises, whether they are startups or incumbents in the MEMS industry. In addition, this study can provide theoretical support for government industry policies to help lower the cost and shorten the commercialization process.

1.2 Research objective, problem, and questions

The objective of this thesis is to explore the successful methods of emerging technological commercialization in China, providing a practical guide to Chinese MEMS enterprises, helping increase their success rate and avoid unnecessary losses during their technology commercialization process. The main challenge in this study is to investigate the determinants of the commercialization of MEMS technology in China. Accordingly, the main research questions are as follows:

(1) How many stages are there in the MEMS commercialization process?

(2) How can these stages of MEMS technology commercialization be identified?

(3)What are the determinants of successful commercialization of MEMS technology?

(4) To what extent do these factors affect MEMS commercialization?

(5) How do these determinants influence the commercialization of MEMS technology?

1.3 Structure of the thesis

Taking MEMS technology as an example, this thesis investigates the key factors that determine the successful commercialization of MEMS technology. Figure 1-1 illustrates the structure of this thesis.

Chapter 1 introduces the background, significance, and purpose of the thesis, along with the content of the research and its structure. The contributions of the research are also described in this chapter. Chapter 2 is the review of the literature on emerging technologies, including its definition, characteristics, management, and commercialization. Chapter 3 analyzes the status and developing trends of MEMS technology. It overviews the MEMS technology and systematically presents the characteristics of MEMS technology. In addition, the patent data are analyzed and, based on this information, common forms of MEMS technology and are identified, thus illustrating the domestic and overseas development status of MEMS technology. Finally, the prospects for the main applications and the future of MEMS technology are identified.

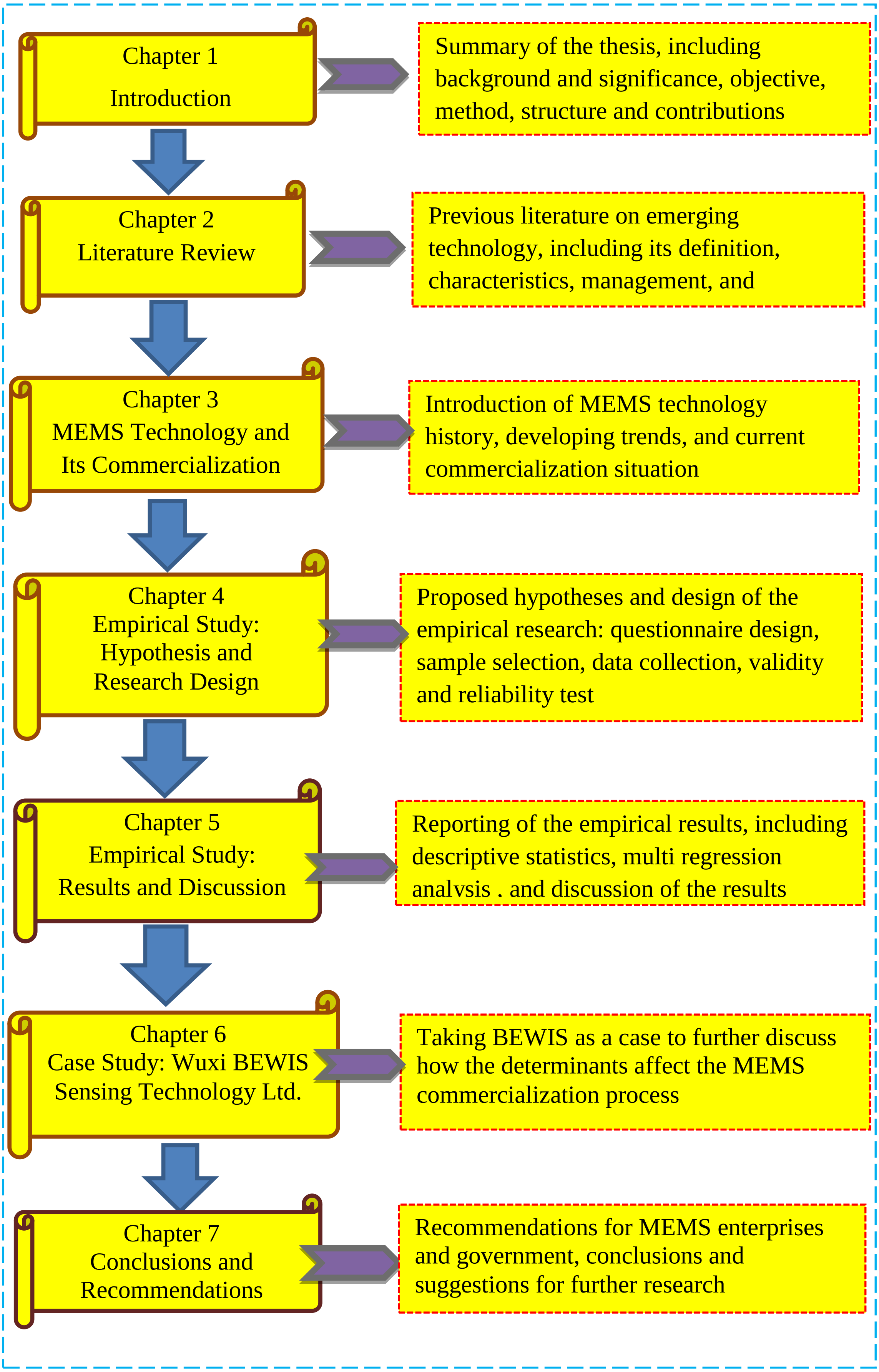

Figure 1-1 Structure of the Thesis

Based on a review of previous research on emerging technology and analysis of MEMS technology, Chapter 4 presents an empirical study on determinants of commercialization of MEMS technology. Related hypotheses were proposed and a questionnaire was designed to investigate the impact of various factors on MEMS commercialization. We then introduce the sample selection and data collection in Chapter 4, and also conduct the validity and reliability test for empirical data. Chapter 5 reports the results of the empirical survey in Chapter 4. Multiple regression was employed to analyze the statistical data, examining the extent of key factors on the performance of commercialization including technology property, regional cluster innovation network, enterprise capacity, market conditions, policy and regulations, and social environment. Related discussions are also provided in Chapter 5.

Since the empirical survey only investigated the determinants of MEMS commercialization, Chapter 6 uses Wuxi BEWIS Sensing Technology Ltd. (BEWIS) as a case to analyze how these factors affect the four stages in the commercialization process. Thus, this case study is a complementary to the empirical analysis in Chapters 4 and 5.

Finally, Chapter 7 provides conclusions and recommendations, as well as limitations and suggestions for further research.

1.4 Research method

The purpose of this study is to investigate the determinants of MEMS technology commercialization in China. To achieve this goal, multiple methods can be used to collect necessary information. In this study, qualitative and quantitative analyses were conducted to analyze the key factors that determine the success of MEMS commercialization.

1.4.1 Empirical study

This study employed empirical survey approaches like questionnaire and in-depth interview to collect the necessary data and information. The questionnaire includes basic information of enterprises and the influences of different factors on MEMS product development, which are measured by a five-point Likert scale. Structure equation model (SEM) was then used to analyze the statistical data. This empirical study will examine the extent to which the proposed factors affect the success of MEMS technology commercialization. In this empirical study, the sample covers 112 MEMS enterprises in China.

1.4.2 Case study

To further explore how these factors influence the MEMS product development, we also employed a case study to do qualitative analysis. Case analysis is a suitable means of conducting exploratory research work, especially for complex procedures (Yin, 1994). Emerging technique management is complicated. It is also novel research work that has not been sufficiently developed. Since Wuxi BEWIS Sensing Technology Ltd. (BEWIS) has passed the emerging stage and the fast-growth stage and is now at the mature stage, it is a suitable case to observe the commercialization of MEMS technology. This case study may provide some novel insights into MEMS product development, particularly the role of various factors on the commercialization, which is valuable to other MEMS enterprises.

1.4.3 Theoretical analysis

This study conducts a comprehensive literature review on emerging technology, which reveals the current theories. In addition, related analyses for MEMS technology characteristics, as well as developing trends, are also summarized in the thesis. All of these theoretical analyses provide a foundation for the following empirical study. Furthermore, recommendation to the other MEMS enterprise is discussed based on the results of the empirical examination and case study.

1.5 Contributions of this study

By combining empirical analysis and case study, this study explores the determinants for the successful commercialization of MEMS technology, especially under China’s transition economies. The contributions of this thesis are from theoretical and practical perspectives.

1.5.1 Theoretical contributions

Currently, most studies on the commercialization of emerging technology have considered the context in developed countries and regions like the United States, Japan, and the European Union, with few studies on developing countries like China. To fill this gap, this thesis takes MEMS technology as a typical example to systematically analyze the characteristics of emerging technology commercialization, especially the four stages identified during the entire commercializing process.

Taking 112 Chinese MEMS enterprises as a sample, this study empirically investigated the determinants of emerging technology in China. Furthermore, a case study was employed to analyze how these determinants affect the real commercializing process under the Chinese economic background. Through multi-regression analysis, the empirical results show that technology property, market conditions, regional innovation network, and enterprise capability are the main determinants of MEMS commercialization, whereas social environment and policy and regulation do not have a significant impact on the performance of MEMS commercialization. These findings enrich the emerging technology literature, especially for the commercialization of emerging technology under developing countries.

1.5.2 Practical contributions

This thesis empirically investigates the determinants of MEMS commercialization and discusses how they influence the MEMS product development, which is valuable for government policy making as well as the related enterprises' product development providing some guidance to the commercialization of other emerging technologies.

(1) *For government.* Through empirical study, this study finds that, during the MEMS commercialization process, regional innovation networks are among the determinants of commercialization performance. Therefore, to provide more favorable context to the MEMS enterprises, local governments should carefully make related policies to help cultivate regional innovation network. This open innovation system requires extensive cooperation among various agents such as universities, industry associations, intermediate agencies, and governments in the region. Apart from the innovation network, the case study also show the importance of various financial programs in supporting the survival of startups. How to identify prospective startups is a big challenge for local governments. To address this problem, the specific features of an emerging technology should be considered carefully since different emerging technology may exhibit quite different commercialization paths and requirements, meaning that the same policy and regulation may not be suitable for all technologies. Thus, the local government should also enhance the academic research and field survey on emerging technology before the related policy is proposed.

(2) *For enterprises*. To develop a successful product, an MEMS enterprise needs to consider four determinants including technology property, market conditions, regional innovation network, and enterprise capability simultaneously. This study also divides the commercialization into four stages and discussed the different roles of the determinants on

product developing process so as to provide necessary reference to the enterprise practice. At the early product selection stage, it is critical to make a large-scale survey and collect comprehensive information to evaluate the market conditions, finding a niche market to develop. Later in the R&D and pilot test stages, enterprise may make full use of all external supporting resources, such as various public platforms, to control the cost. During these process, how to design a product to satisfy the customer’s demand, rather than a product with the most advanced technology is a key to successful commercialization. Since the emerging technologies are changing continuously, an enterprise looking to maintain its advantage over its competitors must continue innovating in order to keep up with technological change.

(3) *For emerging technology industries*. MEMS technology is a new form of technology that has attracted global attention in recent years. Using the global MEMS patent data, this thesis discusses the MEMS product distribution as well as its geographic distribution around the world, which provides some hints with which to predict the trends of MEMS technology. This study provides six trends to MEMS industry-3D-structural, high-performance monolithic, highly integrated module, low power consumption, intelligence, and networking which may create new sectors or change existing industries dramatically. In addition, due to the common property of emerging technology, the characteristics of MEMS commercialization may be applied to other technologies to some extent, guiding their commercialization processes.

This page is deliberately left blank

Chapter 2：Literature Review

This chapter summarizes the existing literature on emerging technologies, including the definition, characteristics, management, and commercialization of emerging technology.

2.1 Definition of emerging technologies

2.1.1 Technology, high technology and new technology

2.1.1.1 Technologies

In daily work and life, the terms “science” and “technology” are often combined to form the term “scientific technology”. Science is a knowledge system that reflects the essence and laws of objective things. Science is based on practice, precisely argued logic, the rational knowledge of essential features, necessary connections, or the laws of the movement of things in the objective world (World Intellectual Property Organization [WIPO], 1977).

Technology is the set of knowledge, skills, methods, and types of planning that adjust, control, and transform nature and society according to objective laws, making it possible to engage in practical activities to increase the chances of survival. It is a resource that controls the factors of production and products as well as a system of knowledge that serves as a basis for products or services. Technology may be a product or technological invention, a type of design, a practical method or a professional type of design and managerial skills (Fu & Tong, 1996).

2.1.1.2 High technologies

The term “high technology” was coined in the classic *High-Grade Technology* in the 1960s (Bi, 2015). In 1983, the phrase “high technology” was formally included in the Merriam-Webster Third New International Dictionary. There are several definitions of high technology. According to Chen (1997), high technology is the latest knowledge-intensive scientific achievements, which dominate the development of socially productive forces. Gu and Zhao (1998) also suggested that high technology is based on modern scientific theory and can bring great economic and social benefits to society. High technology has also been viewed as a combination of cutting-edge scientific knowledge and technologies that play a revolutionary role in modern social production. Yin and Wang (2010) summarized that high technology has the following features: (1) it is based on the latest scientific theory; (2) it belongs in the class of knowledge-intensive technology; and (3) it has a profound influence on both economic development and social progress. Thus, high technology is based on scientific invention and discovery. From social economic perspectives, each high-technology product has its own features. Compared to either general or traditional technology, high technology represents not only the accumulation of human experience, but also scientific inputs and knowledge based on contemporary technological achievements.

2.1.1.3 New technologies

A new technology is a concept related to time. New technology and high technology differ in that a new technology is classified from the time of occurrence and does not have a direct relationship to the latest scientific development and the degree of knowledge intensiveness, whereas high technologies are directly and closely connected to these two factors (Chen, 1997). For example, some newly practical technologies are new technology, but not high technology. On the other hand, new technologies and high technologies overlap with each other (Day & Schoemaker, 2000) like Through Silicon Via techniques and nanometer material technology, which are the high and new technologies at well.

2.1.2 Emerging technologies

The term emerging technologies has appeared in recent years. Day and Schoemaker (2000) noted that emerging technologies are innovations and applications that have a scientific foundation and the potential to both change existing industries and create new ones. They made three key points in this regard. Firstly, knowledge for emerging technologies is spreading continuously. Secondly, applications of emerging technologies in the market are undergoing innovation. The market keeps its original status but products are in the process of upgrading. Thirdly, emerging markets are developing and taking shape. The technologies involved are pre-existing technologies that are leading to new markets.

Based on Day and Schoemaker’s (2000) definition, Li (2012) further analyzed emerging technology from the perspectives of time, content, function, and development. He suggested that emerging technologies are established based on the disciplinary development of information technology and biological technology with potential industrial prospects and high levels of uncertainty regarding development, requirements, and management. These technologies might lead to changes in industry, enterprise, the competitive environment and management thought, business flow, organizational structure, and managing modes. Meanwhile, Yin and Wang (2010) argued that emerging technology should exhibit the following three characteristics simultaneously:

(1) It is being formed or developed. Most such technologies are beginning to appear. For example, microfluidic chips, nanometer robots, and LEDs are emerging technologies that are in the process of formation. Although some technologies have been in existence for some time, they are always engaged in the developing process; an example of this phenomenon is Internet technology. Thus, researchers classify these technologies as emerging technologies.

(2) It belongs to high technology, not traditional technology. As a typical type of high technology, emerging technologies contain a very high level of technological property. If an emerging technology cannot be classified as high technology, it is only regarded as a new technology, although it is in the process of being formed or developed.

(3) It can have a great influence on economic structures or industrial development. If a recently appeared high-technology product does have an essential influence on the economic structure or on industrial development, it can be classified as general high technology or cutting-edge technology, or even as early-mature technology. Whether a technology can exert an essential influence on the economic structure or industrial development is an important standard to identify emerging technology.

2.1.3 Relationships among emerging technology, high technology and new technology

The widely accepted definition of emerging technologies in China is that it refers to recent or developing high technologies that have a substantial influence on the structure of the economy and industrial development (Li, S.M., Xiao, L. & Xiao, Y.G., 2007). Until now, most emerging technologies have focused on information technology and biological technology. However, not all recently developed high technologies are emerging technologies. Only high and new technologies that have a substantial influence on economic structures or industrial development are emerging technologies (Zhao, Z.Y., Yin, L. & Cheng, 2004; Yin & Shi, 2005). Yin and Wang (2010) asserted the following similarities and differences among emerging technologies, high technology and new technology.

(1) Similarities and differences between emerging technology and high technology

Only a few high technologies are emerging technologies. Emerging and high technologies both use the latest scientific theories, discoveries, and inventions. There are a few differences between emerging and high technologies. First, according to the present theory, high technology is a relatively stable technological group, such as information technology and biological technology. Emerging technologies refers to a specific technology such as MEMS technology, transgenic technology, or 3D printing technology. Second, high technology is usually related to a certain industry. For instance, biological technology has a corresponding biological industry. Any technology developed from this technological group would be added to the list of biological technological industries upon its commercialization. Also, high technologies are not always technologies that have appeared recently. For instance, many examples of information technology are still listed as high technology in the prevalent classifications despite the fact that they are not new. The same is true in the field of aerospace engineering and other forms of high technology. Finally, high and emerging technologies have different effects on economic development. Emerging technologies in high technology have a great influence on economic development, which is an essential feature of emerging technologies.

(2) Similarities and differences between emerging technology and new technology

Similar to high technology, only a few new technologies can be classed as emerging technologies. As mentioned above, some overlaps may exist between new and high technologies. Indeed, all emerging technologies are new technologies. The scope of emerging technologies is narrower than that of new technologies. Only a very small portion of new technologies belong to emerging technologies. Therefore, emerging technologies are a subset of the intersection of high technologies and new technologies. Figure 2-1 illustrates the relationships among the three types of technologies.

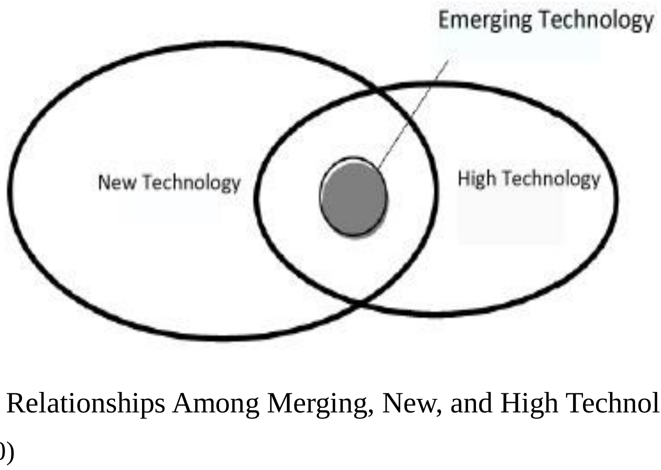

Figure 2-1 Relationships Among Merging, New, and High Technologies

Source: Yin and Wang (2010)

2.2 Characteristics of emerging technology

Table 2-1 Comparison of Emerging Technologies and Established Technologies

	Existing technology	Emerging technology
Technology:		
● Scientific basis and applications	Established	Uncertain
● Architecture and standards	Evolutionary	Emergent
● Functions and benefits	Evolutionary	Unknown
Infrastructure:		
● Value network of suppliers, channels	Established	Formative
● Regulation/standards	Established	Emergent
Customers/market:		
● Usage patterns/behavior	Well-defined	Formative
● Market knowledge	Thorough	Speculative
Industry:		
● Structure	Established	Embryonic
● Rivals	Well-known	New players
● Rules of the game	Known	Emergent

Source: Day and Schoemaker (2000)

As shown in Table 2-1, Day and Schoemaker (2000) compared emerging and existing technologies. They argued that for an existing technology, the skills, foundational structure, customers, and industries related to current existing technology are definitely known whereas emerging technologies are not clear and their networks of suppliers and channel values are beginning to grow. Market knowledge of emerging technology is insufficient. During the growing process, competitors are complex and show great uncertainty.

2.2.1 High uncertainty

Zhao et al. (2004) proposed that, unlike traditional and high technologies, emerging technologies have shown quite different features, in which high uncertainty may come from the various aspects.

(1) Market uncertainty. Since the emerging technology itself is immature and changing rapidly, especially in the early commercial stages, there is considerable uncertainty as to whether it can be accepted by the market. The demand for the emerging technology is difficult to predict, making it hard to guarantee a profit for the pioneer enterprises.

(2) Technological uncertainty. Generally speaking, an emerging technology depends heavily on many stages, which means it faces high risks of scientific uncertainty,

technological application uncertainty, R&D uncertainty (related to both time and success), and commercial uncertainty.

(3) Environmental uncertainty. The development of emerging technologies is influenced by market demand, and enterprise capacity, and other factors, but also supported by the external environment; for example, the guidance and support of the government policy environment, along with the industrial upstream and downstream enterprises. Therefore, environmental uncertainty has become an important factor that influences emerging development.

(4) Management uncertainty. The management of emerging technologies requires different processes, skills, and methods compared to the traditional one. More specifically, the investment commitment, strategy, market exploration, organizational structure, as well as learning methods related to emerging technologies, may all be different from the other technologies. Many theories and methods of traditional technological management are not adaptable to emerging technologies.

Furthermore, Liu and Li (2005) suggested that the technological uncertainty for an emerging technology is also characterized by the dynamics of a technology itself, other multidimensional factors and even unknown aspects. In the preliminary phase of an emerging technology, its nature and characteristics are uncertain. Gradually, the development of related science means that there will be fewer technological uncertainties. Meanwhile, uncertainties also come from many aspects, including technical uncertainty, scientific foundations, technical applications, standard systems, and functional interests. Moreover, technical uncertainty is uncertainty about the future, which is different from risk in that it cannot be calculated and estimated. Uncertainty is the “unknown” aspect of future events, including “partially unknown” and “completely unknown” aspects, which always inform the development path of emerging technologies.

2.2.2 Creative destruction

Schumpeter (1911) proposed the concept of creative destruction, arguing that it would substitute old and outdated methods and products with better ones. The destruction of old ways and products results in the embrace of the creativity of new ways and products. The emerging technology either creates a new industry or changes an existing industry dramatically (Li, 2012). Emerging technologies usually use a new and different scientific foundation to alter the original track of technological development. This not only creates new technological forms, but also destructively creates new competitive rules, methods of organizing, markets, management theories, and even industrial forms. Enterprises using current resources and strategies may not be able to adapt to the demand of emerging technologies, and may therefore require new capacity (Li et al., 2005). When emerging technologies creatively influence or destroy related industries, technological innovations such as mobile internet technologies can potentially influence all industries (Li, 2012). For example, internet technology has restructured the traditional media: Alipay has influenced the financial industry; Wechat has had a profound impact on mobile operators, substantially improving the convenience and quality of communication; and digital technology has changed photography, music, TV, and film. Therefore emerging technologies are also featured by creative destruction.

2.3 Emerging technology management

2.3.1 Importance of emerging technology management

The essence of emerging technologies is changing quickly, which brings forth uncertainty and creative destruction. These essential features imply that the management of emerging technology will involve the challenges presented by various aspects of these technologies. In terms of discipline classification, emerging technology management is both a branch and an important component of technology management, which can be classified into the three types (Wu & Xie, 1999).

The first type of technical management was presented in a report entitled “Technology Management: Hidden Advantages”, which was issued by the United States National Research Council in 1987. The report states that technology management is related to engineering, science, and management and is used to plan, develop, and realize technology to influence and complete an organization’s strategy and operating objectives. The second type of technical management primarily focuses on technological invention and creation. As Dreje and Kofoed (2000) argued, technological management refers to the timely creation and improvement of the company product and producing capacity. The third type of technical management considers it to be a part of strategic management. Zehner (2000) stated that technology management includes the practice of integrating the commercial strategy and technological strategy of the companies. It is an integrated process that requires refined coordination of research, production, and the market.

Emerging technologies management and technological innovation management are closely related. Emerging technologies cannot have an independent existence without technological innovation. Emerging technologies arise from technological innovation. Only enterprises with a strong technological capacity and innovation ability can continuously create new technology. Schumpeter (1911) first proposed the innovation concept and theory, but he did not explicitly provide the precise definition of technological innovation. According to Wu (2000), technological innovation refers to the entire activities that begin with new technological concepts, R&D, or technological combinations and then actual applications, economic commercialization, and social benefits.

Although the theories of emerging technological management are also mainly based on technological management and technological innovation management, traditional strategic planning, financial analyses, marketing strategies, and organization structure design, a set of new management frameworks and tools are needed in order to adapt to the creative features of emerging technological destruction (Li & Chen, 2015). The challenges of emerging technology management call for the reform of many fields, including management thought, developing strategy, marketing strategy, and value assessment. Thus, the theories and methods from related disciplines in management are insufficient.

Since the 1990s, drastic and rapid technological reforms have changed not only industrial forms of technology development, but also people’s conceptual opinions, the competitive rules of industries and the operating modes of enterprises, resulting in new research subjects for theoretical researchers. The essence of emerging technologies is technical change, which is a source of creative destruction accompanied by uncertainty. Therefore, the management of emerging technology represents a different form of managerial skills and has gradually become one of the key factors for industry success. In addition to characteristics such as uncertainty and creativity, emerging technologies are also known for their explosive growth and discontinuous changes in performance due to technical improvement as well as the structure and characteristics of network-marketing businesses (Wang, J., Ling, F. & Tang, J., 2015). This performance could help less-advanced companies reach the levels of more-advanced companies while prompting an unusual emerging-technologies race. Additionally, the discontinuous change of emerging technologies requires specific management strategies that are quite different from conventional strategies (Geels, 2002).

2.3.2 Main topics on emerging technology management

2.3.2.1 Evolution of emerging technologies

The evolution of emerging technologies has attracted the attention of scholars worldwide. There are different levels of understanding regarding the content of emerging technologies, but the following seven perspectives have been the most widely studied: a combination of biological and sociological perspectives (Geels, 2002; 2006); a quantitative perspective based on literature; patents and other objective data or indexes; influential factors evaluated from a multi-stage, multi-level perspective; the perspective of the co-evolution of technologies and associated factors (Pelikan, 2003; Mao & Liu, 2010); the perspective of the framework-element relationship; and the philosophy of the technology perspective (Cao, 2012). Some of the abovementioned perspectives share basic ideas and are therefore not completely isolated from each other. For example, Adomavicius et al. (2007) proposed the concept of a technology ecosystem, which is actually a metaphor borrowed from the field of biology that incorporates the idea of coevolution. To some extent, this term reflects the technical view of the framework-element relationship.

The findings of Huang and Yang (2014) suggest that the evolutionary powers of emerging technologies and emerging industries are mutually stimulated and constrained by (1) knowledge learning and diffusion; (2) space demands and structural changes; (3) the redistribution of values along technology supply chains; (4) technology tracks and technical standards conversion; (5) the coevolution process between the two (which includes four major stages: initial coordination, reinforced coordination, in-depth coordination, and differentiation collaboration). Meanwhile, the level of overlap between emerging technologies and emerging industries varies according to the stage.

Like many technologies, emerging technologies might have arisen out of the process of breakthrough innovation and incremental innovation. Alternatively, they might have resulted from changes in the field of innovative applications, with new technical pathways generated through the process of breakthrough innovation (Koberg et al., 2003). Incremental innovation places a stronger emphasis on the trajectories of technological evolution, along with the process of separating, grafting, and integrating related technologies; that is, the synthesis of a new system as a result of two unrelated technologies being applied in the same field (Yoffie, 1996). In addition, emerging technologies involve characteristics of disruptive technology and discontinuous innovation (Kostoff, 2004). From the point of biological evolution, emerging technologies are more like the discontinuous equilibrium process that occurs when new species are formed (Gould & Eldredge, 1977). Here, it should be mentioned that disruptive technology emphasizes enterprise and business factors, as in Bower and Christensen (1995), whereas discontinuous innovation is more concerned with customer and market factors (Glynn & Paulson, 1996).

2.3.2.2 Assessment of emerging technologies

Because emerging technologies are characterized by a high level of uncertainty, conventional static analysis techniques, such as the net present value method, are no longer applicable. Instead, dynamic assessment methods are urgently needed. Doering (2000) proposed four steps, namely, scope, research, evaluation and practice. The technology roadmap is a method that is commonly used to assess, select, and predict available technologies, searching the development trajectories of new technologies or products according to time variation when factors such as related technologies, market, and organizational links are all explicitly considered (Rinne, 2004). Because of the existence of high levels of complexity and uncertainty during the investment and decision-making process of emerging technologies, the investment process can be carried out in stages. Additionally, such investment behavior can be considered as a series of options. Only when investment uncertainty is reduced to the minimum level and the market looks promising is it possible to decide to make a large-scale investment (Zhang, 2005). The option-pricing model, real options, positioning options, and search options consider the second characteristic of emerging technologies; in other words, past decisions can affect future technology choices and development opportunities in the future with internal uncertainty (Zhang, 2005). Therefore, they are commonly used during the process of technology selection and assessment.

2.3.2.3 Managerial capability of enterprises

As Day and Schoemaker (2000) noted, because traditional management practices such as strategic planning, financial analysis, marketing strategy, and organizational design are based on sustainability, they emphasize equilibrium, rationality, and optimization. However, such assumptions are often challenged by emerging technologies that have features of non-equilibrium and extreme vagueness. Additionally, such technologies are difficult to analyze using standard analytical methods. Therefore, the establishment of new management theories and methods is required. For the management of emerging technologies, managers have to reconsider their managerial pattern due to the more flexible environment, more dynamic and adaptive strategic decision-making processes, and a discontinuous resource allocation process. Thus, experimental and exploratory approaches should be adopted for market surveys, and more attention should be paid to the development of adaptive technology. When companies confront a continuously changing and unpredictable market environment, traditional modes of strategic thinking are out of date. Therefore, researchers begin to focus on the internal resources (Barney, 1991) and dynamic capabilities (Teece et al., 1997) of companies.

Yin and Wang (2010) found that a multilayer pyramid structure is unsuitable for the development of emerging technologies. The natural choice for the vast majority of emerging technologies is a flat, matrix-like, separated organizational structure. It is also necessary to establish strategic alliances and new types of organizations. Based on an in-depth analysis of the organizational characteristics of emerging technologies, Jin (2005) discussed the abilities that are necessary for emerging technologies and organizational strategies and established a theory-based cognitive model of emerging technologies management. Meanwhile, Zhang (2005) noted that corporate governance structure can have a significant influence on technology innovation and a well-established governance structure can help promote business innovation activities. Chen (2005) and He and Raymman-Bacchus (2010) analyzed the diffusion characteristics and dynamic process of technology innovation in an industry cluster, finding that because an industry cluster represents a cluster of associated regional companies, industry clusters and technology innovation diffusion can facilitate and promote each other.

2.3.2.4 Identification of emerging technologies

Considering that the development of science and technology at the beginning of the 21st century has been rapid, it is important to identify emerging technologies characterized by creative destruction property among the large number of technologies. Currently, most studies are based on the complexity and uncertainty of emerging technologies, with a focus on qualitative analysis. Jin et al. (2006) analyzed the selection and cognition process of emerging technologies from the perspective of business organizations. They studied the critical capabilities of organizational strategies and established a theory-based cognitive model for emerging technologies, testing the validity of the model by using the case studies from IBM Corporation and Seagate Technology, Inc. Based on the uncertainties and risks associated with emerging technologies, Tan and Huang (2007) suggested a recognition and selection framework model that combines a technology roadmap and a real-option approach. Wei (2006) tested the recognition accuracy of emerging technologies based on experts' marking methods.

Huang and Lu (2009) proposed a synthetic attribute measure model and decision-making system based on attribute measures and the theory of attribute clustering. They assessed a set of techniques and provided a theoretical basis for the identification, assessment, and selection of emerging technologies. However, all these methods rely on the experts' background knowledge and personal preferences, which will inevitably affect the identification accuracy.

2.4 Commercialization of emerging technology

2.4.1 Definition of emerging technological commercialization

Studies on the commercialization of emerging technology have mainly focused on three aspects: definition, process, and factors affecting the successful commercialization. Webster (1986) defined commercialization as the process of production, marketing, and application that enables enterprises to gain potential added value and profit. Cooper and Kleinschmidt (1995) suggested that commercialization covers a series of valuable activities involving product testing, product selling, and marketing. Kalaitzandonakes (1997) argued that commercialization is the process of gaining profit from an investment in innovative technology.

Table 2-2 Differences Between Technical Product and Technology Commercialization

	Technical product	Technology commercialization
Object	Single function	Comprehensive function
Time span	Concept of the products (1–3 years)	Proposal of the concept of potentially valuable technology (5–20 years)
Risk participants	End users	In many ways, they change with the development of technology
Property of demands	Concrete object	Changing
Competition	Other products of same function	Other technology in different stages
Market challenge	Explore the products' selling advantages	The object obtained from mining technology in a timely fashion
Time	Opportunities for end-market users	Timetable of competitors, applicators, and resource providers
Opportunities to create and strive for value	Produce and sell products	Multilateral common interest in product selling or technology during product life-cycle

Source: Jolly (2001)

Furthermore, Yang and Tong (2004) divided commercialization into two concepts: “broad sense” and “narrow sense”. While narrow commercialization primarily refers to the formation of products and technology and the process of creating profit, generalized commercialization is defined as the process that begins with the study of basic theory and ends at industrial product production, a core stage of which is technology transfer (Yang & Tong, 2004).

Based on the definition of commercialization, Sui and Wang (1998) argued that the ultimate goal of emerging technologies commercialization is to achieve business value, including a series of completed activities that begin with the idea of new products or new technologies, then experience R&D, engineering, commercial production, and finally launch products to market. This is a comprehensive technological and economic behavior in a profit-driven world with high management, technical, and market risks, which is based on transferrable research achievements, a production stage, and achieves final products for profit. Chen and Wang (1995) wrote that emerging technology commercialization is an essential process for technology diffusion, in which adopters of innovative technology obtain their technology from diffusion through various approaches.

Emerging technology commercialization and technical products are two related and different concepts, as Table 2-2 shows. The table shows that technology is the carrier of products and that one technology can apply to different products. Products are the embodiment of technology and media that bring technology to market and realize its value. Technology commercialization is profitable as a result of the stages of development, production, marketing, and application. Technical production involves designing, producing, and introducing a product, while technology commercialization is much broader.

2.4.2 Process of emerging technological commercialization

Research into the commercialization of new technology began in the 1980s. Some scholars have discussed the process of transition from technology to realistic productivity to technological achievements, which involves follow-up testing, developing new products, and promoting valuable technological achievements until new products, new technology, and new materials are developed in new industries. The emerging technology commercialization is a complex, continuous, and long process that has its own rules and must be divided into different stages. Scholars divide it into different stages based on different criteria.

2.4.2.1 Longitudinal four-stage model

Nie (2002) first proposed the longitudinal four-stage model for emerging technology commercialization during the research period of the technical transmission mode in universities. He proposed four main stages that emerging technology commercialization must pass through, covering the initial innovation to the final commercial product: (1) the experimental and creative invention stage, (2) the product prototype and pilot stage, (3) pilot production, and (4) the marketing and mass-commercialization stage. The experimental and creative-invention stage advances new achievement through experiment and forms inventions or patented technology based on practical or theoretical innovation. The goal of the product prototype and pilot stage – that is, the transition from technical innovation to the product – is to break through the lab environment. This transition must pass the pilot-scale test so that it can adapt to the production environment and process conditions. The subsequent new technology commercialization is based on the pilot stage; therefore, this stage plays an essential part in the process. In the pilot production and marketing stage, significant investment is needed to prepare for the mass production of a new or expanded production line in light of products with certain market prospects. In addition, marketing network construction must be conducted simultaneously. The mass marketing commercialization stage includes improving the marketing network, establishing the logistical system, standardizing production process management, and engaging in brand-building activities.

2.4.2.2 Five-stage sequential model

Liu, C.Y., Duan, J. & Wu, F.Y., (1996) divided emerging-technology commercialization into five stages in accordance with different degrees of maturity. (1) Concept stage: this stage establishes the product design as its main object and does not create a complete product prototype. (2) Start-up stage: the products have not been listed and only a product prototype and business plan has been completed. (3) Growth stage: the first batch of products finishes and launch to market. Stable customers are not gained yet, and only the break-even point is achieved. This stage should improve product quality continuously to lay the foundation to the next large-scale market exploration. (4) Expansion stage: after a period of development, the products have achieved certain market share and can obtain a return on investment (ROI). (5) Maturity stage: The operation conditions for technology commercialization have reached the original expectation and the technology has entered a matured stage.

2.4.2.3 Multi-stage model

Jolly (2001) pointed out that emerging technology commercialization is the value-added process of achieving effective links between stages. Added value is achieved through five stages of the child processes. These stages include technology market insight, ensuring feasibility, technology demonstrations, promoting acceptance, and continuous commercialization. Five stages and four child processes comprise the technology value chain. As illustrated in Figure 2-2, the multistage process stresses the resources that each stage must acquire. The goals of the child processes are to solve marketing and technology problems, to hatch technology, and to determine commercialization potential. The primary goal is to achieve the commercialization of the technology and management strategy. Five stages are committed either to solving marketing and technology problems or to playing a direct role in technology, whereas four child processes input resources around the five stages. Connecting links are resources to ensure the smooth progress of the process stage. If resource input cannot be guaranteed at a specific link, link failure will eventually lead to the failure of technology commercialization.

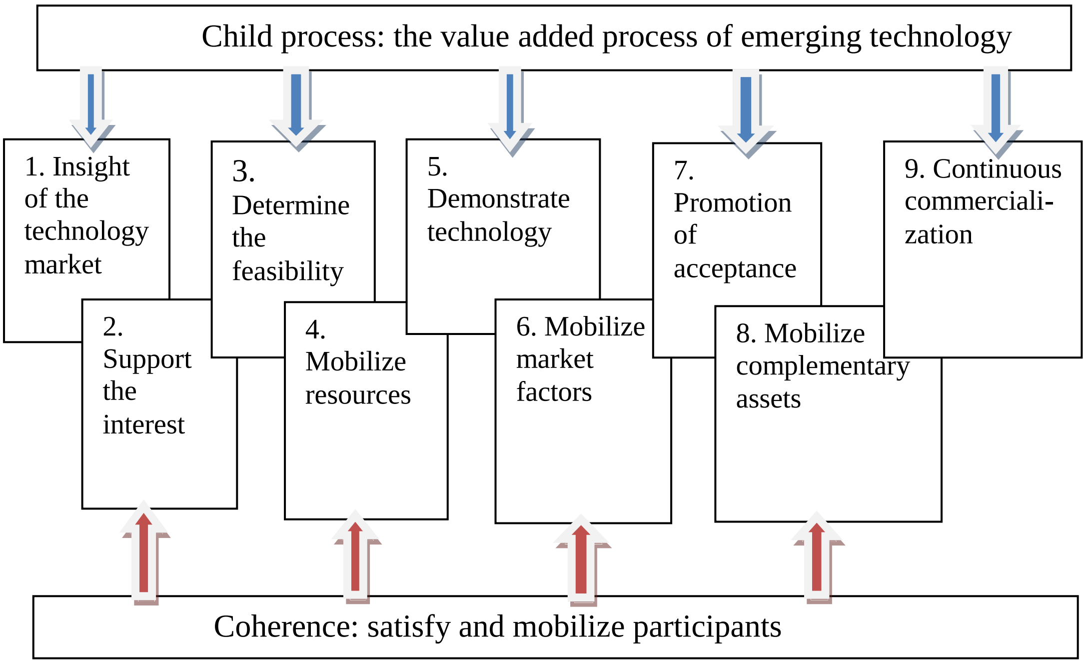

Figure 2-2 The process of Emerging Technology Commercialization

Source: Jolly (2001)

2.4.3 Factors affecting the commercialization of emerging technologies

Some scholars have identified a list of comprehensive factors that would affect the commercial success of emerging technologies. For example, Watkins (1990) considered commercialization capability, technical effectiveness, capability to manipulate technology, and technical support as the key factors in assessing technology transformation; Hatch and

McKay (1996) showed that the essential elements for emerging technology commercialization include technical demand, technical capability, technical values, and technical feasibility. Olayan (1999) considered techniques, regulations, economics, competition, and markets to be major factors affecting the commercial success of technologies.

In addition, some researches have considered successful commercialization from an internal enterprise perspective. They have suggested that factors affecting the commercialization of potential emerging technologies should trace back to when selection plans were created to assess project feasibility and help decision makers choose appropriate technologies for their level of risk (Duan, L.M., Du, Y.P. & Meng, L., 2012). Such practices can help establish a commercial evaluation system, provide necessary tools for enterprises to choose emerging-technologies projects, and offer quantitative techniques for commercial operations. As Cooper and Kleinschmidt (1995) pointed out, a product development team with strong technical capacity has a significant impact on the commercial process to obtain economic benefits. In other words, the team’s formation and function would play a significant role in influencing the outcome of the project implementation. Additionally, internal members’ knowledge and wisdom are more likely to be integrated by commercialization teams with a wealth of new technologies, which could then be better used to develop relevant products suitable for a competitive market environment.

By contrast, recent studies have tended to focus on the refinement of a specific factor impact on emerging technology commercialization. For example, Munir and Phillips (2002) analyzed the impact of market uncertainties on the commercialization process of emerging technologies. They found that customers postponed the use of new products or services because they were concerned about either the performance of new products or the quality of new technical services. In other words, customers are worried about the problems that might arise when using new products or services. Spinelli (2002) tested the impact of organizational information-collecting capacity on the decision-making process during the commercialization of emerging technologies. Their research shows that the extent of understanding of collected information, the degree of attention to specific information sources, and companies’ risk predictions based on available information will significantly affect businesses’ strategic decisions. They conducted a case study based on empirical research using two communication equipment manufacturers as the study object, finding that different understandings of the same information could lead to different commercialization practices. Linton (2004) proposed models that can predict market capacity and demand, in which elements affecting market supply and demand, government policy orientation, strategic planning, intellectual property rights, and other factors can also influence the commercialization process of emerging technologies. These studies are helpful for conducting an early-stage market analysis of emerging technologies. Crawford and Benedetto (2006) pointed out that factors contributing to the failure of new products include market collapse, technical constraints, and organizational barriers. Thus, to avoid the risk of commercial practice, companies must learn to implement effective risk management during the process of commercializing emerging technologies.

In addition, Chinese scholars consider the commercialization process of emerging technologies to be a continuous, systematic process with a high level of complexity and also examine the factors that affect the commercialization process of emerging technologies by means of theoretical analyses and empirical research (Song & Chen, 1999; Yin & Wang, 2010). Song and Chen (1999) established an index system to assess the factors affecting the commercialization process of emerging technologies. In their system, the first-grade indexes include project characteristics, enterprise capability, and macroeconomic environment, among which project characteristics are further divided into four secondary indexes: technical element, market element, product element, and profitability. Enterprise capability is further divided into seven secondary indexes: technical capability, production capability, sales capability, management capability, financial capacity, risk tolerance capability, and strategic enterprise alignment. Macroeconomic environment is further divided into two secondary indexes: the degree of prosperity, along with social, cultural and psychological factors. Fan and Li (2002) further divided the indexes into several categories, such as enterprise capability, potential risks, market assessment, and financial analysis, from the perspective of venture capital investing. They argued that products and related technologies, comprehensive management capability, development and production capacity are all key elements in the commercialization success of emerging technologies. However the most important factors are comprehensive management capability, including the entrepreneur quality, corporate management quality, business management skills, corporate marketing skills, corporate finance skills, and corporate sector coordination. Hou and Wang (2003) provided an evaluation index system from the perspective of the sustainable development of high-tech companies and proposed four first-grade indexes (entrepreneurs, product chain, enterprise capabilities, and macro environmental factors), 11 second-grade indexes, and 34 third-grade indexes.

Using a Delphi survey, Huang et al. (2007) established an assessment index system regarding the commercial potential of new technologies. Five aspects are considered: technical factors, market factors, elements of commercial conditions, elements of conformance conditions, and effect factors. There were sub-indexes under each criterion, with 25 indicators in total. Wang et al. (2008) and Zhou and Lv (2010) argued that technical advancement, technical uniqueness, marketing prospects, market growth rate, business conditions, commercial conditions, and conformance conditions are all important factors that affect the commercial potential of emerging technologies.

Meanwhile, some Chinese scholars have identified key factors through empirical studies. Based on a study of the biopharmaceutical industry, Zhou (2008) concluded that although a lot of factors may affect the commercialization process of emerging technologies – including national policies and regulations, external cluster innovation networks, capital investments, internal collaborative innovation, R&D capability, the management team, government industry policy, production equipment and capacity, sales network, and capacity – only four factors play an important role in influencing industrialization pathways: national policies and regulations, external cluster innovation networks, capital investment, and internal collaborative innovation. Zhao’s (2004) study was based on interviews with industry experts and proposed a series of hypotheses from eight aspects: technical characteristics, inventor personality, intellectual property, market conditions, business owners, financial situations, business modes, and production conditions. His empirical survey on 113 companies found that the success of technology commercialization depends largely on non-technical factors. During the laboratory stage, technical factors seem the most important. During the pilot stage, preliminary market testing and technology maturity are equally important. During the small-scale production stage, factors such as irreplaceable techniques, technology maturity, strategic technology, and the scale of alliances all represent important elements. During the large-scale production stage, the product’s competitive advantage and direct technological marketing are important elements.

By applying a four-dimensional model, Wang (2004) used an empirical study to test the factors that would affect the commercial performance of emerging technologies. He pointed out that during the laboratory stage, companies should not pay a great deal of attention to certain financial indexes, such as return on investment and net present value, which may be important in other stages. During the laboratory, pilot, and production stages, the degree of importance of the applied assessment indexes regarding technology commercialization potentials varies. Additionally, for each stage, factors that represent four major elements (including the technology, market, business, and management) should occupy equally important positions. Based on the analysis of the macroeconomic environment, Huang and Wang (2011) provided an empirical analysis of various external environmental elements that affect the commercialization process of emerging technologies. They found political and economic factors to be equally important in influencing the commercial success of emerging technologies. To some extent, political, economic and technical factors are interactive and could affect each other.

Meanwhile, from the perspective of the strategic development of new emerging industries, Fang, R.G., Yin L., and Wang M.X. (2010) pointed out that when engaging in the strategic development of emerging industries, support from emerging technologies is a priority, and the entire commercialization process of emerging technologies, including each developmental stage, is full of uncertainties. They examined the factors that might affect the commercialization success of emerging technologies at varying stages, highlighting the role of government policies in commercializing process. They found that the government plays a key role in affecting the commercialization process of emerging technologies at varying stages. Moreover, the effectiveness of government policies can not only efficiently reduce potential risks when the emerging technologies are evolving toward strategic emerging industries, but also help improve the success rate of the commercialization process (Wang & Su, 2016).

2.5 Summary

This chapter has reviewed the literature on emerging technology from definition, characteristics, management, and commercialization perspectives. We may find that previous studies have primarily focused on the industry level of emerging technologies, as well as discussing general principles, without a systematic analysis from micro-enterprise viewpoints, especially for the specific technology. Meanwhile, current studies have concentrated on developed countries or regions like the US, the EU, and Japan, with very few on the developing countries, which may explain why nearly all emerging technologies are from these countries.

Therefore, it is necessary to explore the commercialization of emerging technology in developing countries from an enterprise perspective. To fill this gap, the present thesis tries to investigate the determinants of emerging technology in China, which may enrich the emerging technology theory and provide practical recommendations to the different stakeholders during the commercialization process. Furthermore, considering the present situation of emerging technology commercialization in China, MEMS technology was chosen to be a typical example to study. Therefore, MEMS technology will be discussed in details in the following chapter.

Chapter 3：MEMS Technology and its Commercialization

In Chapter 2, we reviewed the related literature on emerging technology. Since the aim of this study is to investigate the determinants of MEMS commercialization, it is necessary to explore the property of MEMS technology. Therefore this chapter will focus on MEMS technology, discussing its history, characteristics, developing trends, market application, as well as the commercialization process.

3.1 Overview of MEMS technology

3.1.1 MEMS technology

MEMS is an emerging technology that builds on micro/nanotechnology technology including the design, processing, manufacturing, measurement, and control of micro/nanotechnology materials. MEMS is a technology that, in its most general form, can be defined as miniaturized mechanical (micro/nanotechnology) and integrated circuit (IC) elements or, in other words, a technology consisting of microsensors, an information processing and signal-control circuit, micropower, and micromechanical elements. Together, these parts form a solid structure in which various data-interface entities and communication units are integrated into a miniature intelligent device or system (Tian, 2009). Figure 3.1 shows the structure of a typical MEMS.

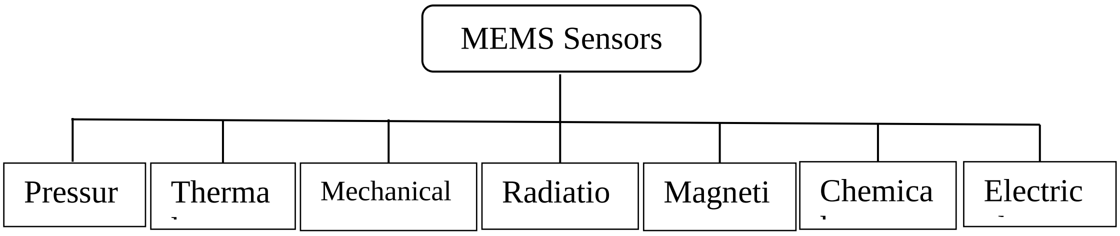

Figure 3-1 Diagram of Information Links of a Micro-electromechanical System

Source: Jin (2007)

The technologies involved in MEMS are extremely complex (for example, both sensors and actuators), draw upon a wide range of research fields (such as an interdisciplinary research area like optical, mechanical, electrical, biological, or chemical research), and include a variety of products (Shaeffer, 2013). For purposes of convenience, this study categorizes the MEMS technology according to design, production, packaging, and application techniques, as shown in Figure 3-2.

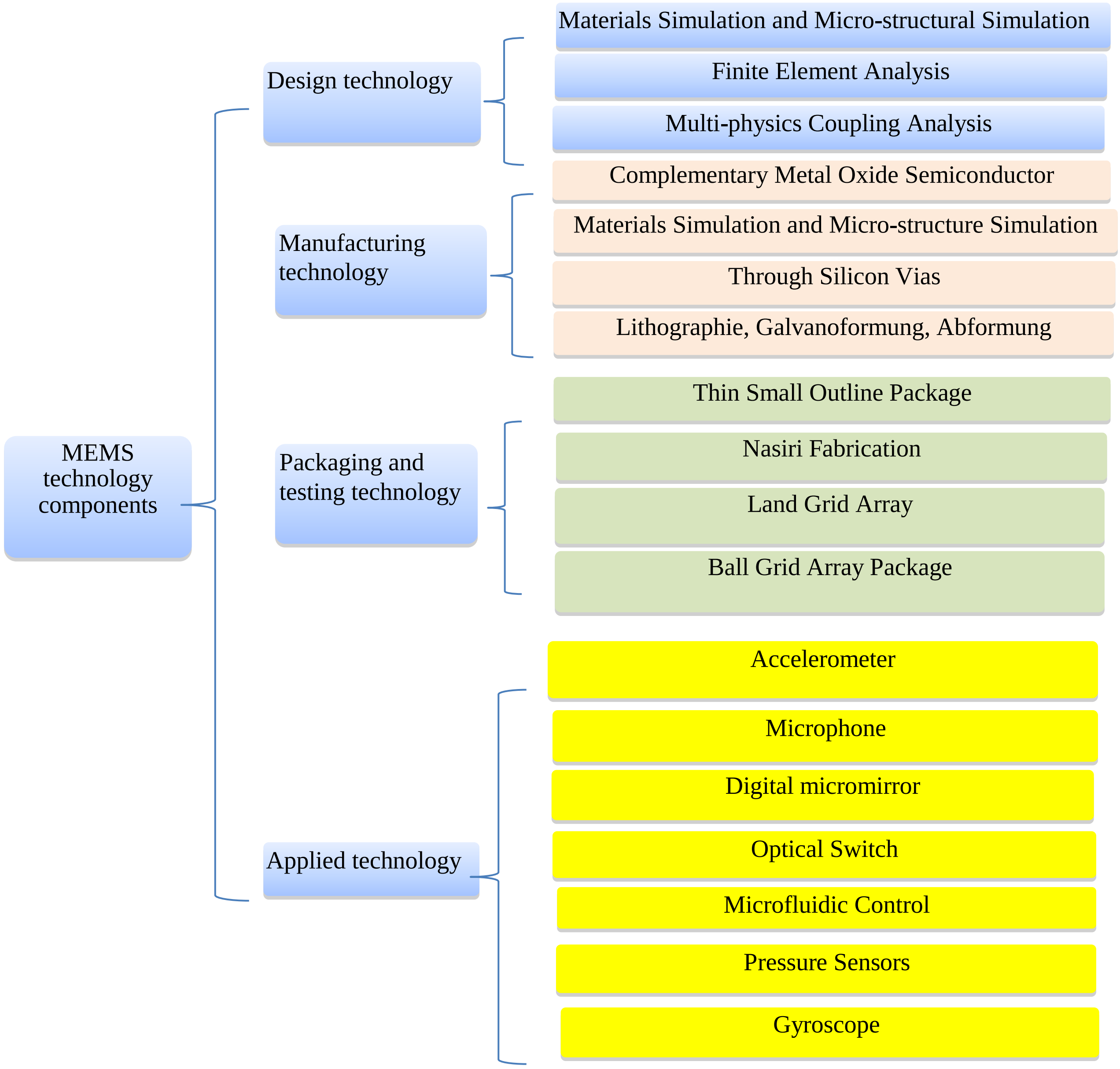

Figure 3-2 MEMS Technology Components

3.1.1.1 Design technology

Design is the first step for the MEMS products, including the configuration and design of the circuit in terms of functional definition, framework design, module collocation, and pin assembly in the context of the commercial circuit-design environment with a software platform setting. After the design work is completed, simulation software is used to test the function of the chip, and all simulation and design work is carried out within a virtual platform setting.

3.1.1.2 Manufacturing technology

The mainstream MEMS manufacturing process is currently based on silicon and non-silicon-based materials（For example, carbon nanotubes）to produce MEMS devices. However, MEMS devices could be separated by the microstructural characteristics of such devices, namely body-processing and surface-processing technology. Traditional semiconductor manufacturing processes, such as lithography, etching, and bonding, are not unusual in the production of MEMS devices. Because the movable micromechanical structure of MEMS devices is not applicable to IC, each MEMS device has to correspond to a specific technical process.

3.1.1.3 Packaging and testing technology

Packaging and testing technology represents one of the key steps in the manufacturing process of MEMS devices. Generally, the packaging and testing technique is based on microelectronic packaging technology. Although MEMS and microelectronic packaging technologies have some similarities, MEMS packaging technology has its own properties because MEMS devices usually contain a movable micromechanical structure that contains stress isolation, insulation, airtightness, and other features.

3.1.1.4 Applied technology

The combination of MEMS technology with various technologies related to the design, production, and packaging processes could yield different products such as accelerometers, gyroscopes, and pressure sensors. In general, such products could be applied to industry, information and communications, national defense, aviation and aerospace, navigation, medical care, biotechnology, agriculture, environmental monitoring, family services, and almost any other area. Thus, the applications have enormous potential.

3.1.2 History of MEMS technology

MEMS technology originated in countries that have advanced technology and mature industries, including the US, Japan, and Germany. Bell Laboratories physicist Richard Feynman first proposed the basic theories of MEMS in the 1950s.

Table 3-1 Milestones of MEMS Technology

Stage	Year	Event	Contribution
First stage	1954	Bell Labs found anisotropic etching behavior of silicon materials in alkaline solutions.	Theory
	1959	Physicist Richard Feynman delivered a speech at the annual meeting of the American Physical Society and proposed the concept of the micromechanical system.	Theory
	1962	Kulite Inc. developed a silicon micropressure sensor using a silicon membrane, a voltage-dependent resistor and bulk silicon-etching technology, which represented the starting point of MEMS sensors and MEMS bulk micromachining.	New technology
	1967	Harvey C.Nathanson from Westinghouse Research Laboratory developed a silicon-resonant gate transistor, which represented the starting point of MEMS actuators and MEMS surface micromachining technology.	New technology
	1968	Wallis from Mallory Company invented a silicon-glass electrostatic bonding technology, which became one of the main techniques of microsensor packaging.	New technology
	1974	The US National Semiconductor Corporation generated pressure sensors with large-scale production.	Industrialization
	1976	The University of Michigan developed a pressure sensor with integrated internal circuitry.	New devices
	1977	Stanford University developed a capacitive pressure sensor.	New devices
		IBM developed a MEMS inkjet printhead.	New devices
	1978	IBM's Robert A. Bassous invented the silicon micronozzle, which represented the starting point of the MEMS microstructure.	New devices
Second stage	1979	HP developed a MEMS inkjet printhead.	New devices
		Stanford University developed a capacitive acceleration sensor.	New devices
		Honeywell and Motorola co-produced pressure and acceleration sensors with large-scale production.	Industrialization
	1980	Varley Petersen from IBM developed a torsion micromirror, which represented the starting point of optical MEMS research.	New devices
	1982	Petersen from IBM published papers that outlined the mechanical properties of silicon and etching-related data and prompted the use of silicon as the mainstream material used in MEMS.	Theory

Stage	Year	Event	Contribution
Second Stage	1982	Honeywell developed a blood-pressure sensor.	New devices
	1983	Feynman delivered a speech detailing the development and future direction of MEMS and proposing the concept of NEMS for the first time.	Theory
	1985	German scientists invented LIGA technology, which was capable of producing a three-dimensional structure with a high aspect ratio (depth versus lateral dimension).	New technology
		Christopher Howe from the University of California-Berkeley developed an integrated circuit with an MOS polysilicon resonant beam, thus proving the compatibility of polysilicon structures with IC technology.	Theory
		University of California -Berkeley, MIT, and the University of Wisconsin improved sacrificial layer micromachining technology, andAlexander Barth from HP named it surface micromachining technology.	New technology
	1986	Abigail Shimbo invented silicon-silicon bonding technology.	New technology
		TaylorBinning from IBM developed an MEMS-based atomic force microscope, for which he was awarded the Nobel Prize.	New devices
	1987	IEEE hosted the first MEMS conference session.	Theory
	1988	MIT developed a microelectrostatic motor.	New devices
	1989	At a conference in Salt Lake City, Howe from the University of California Berkeley suggested the official use of MEMS for research.	Theory
	1991	Rockwell International Corporation and Hughes Aircraft Company released research results regarding the development of MEMS switches with support from the US Defense Advanced Research Projects Agency, popularizing MEMS communication devices.	New devices
	1992	Solgaard from Stanford University developed a MEMS diffraction grating device.	New devices
Third stage	1993	The Microelectronics Center of North Carolina provided multiuser MEMS processing technology (MUMP), which used surface micromachining technology to produce a three-layer polysilicon structure.	New technology

Stage	Year	Event	Contribution
Third stage	1993	ADI introduced micro-accelerometer ADXL50-based surface micromachining technology, which was widely used in the field of automotive electronics.	Industrialization
		Christopher Whitesides from Harvard University developed a soft lithography technique capable of producing polymer microfluidic devices.	New technology
	1994	US Sandia National Laboratory developed a surface micromachining technique, which could be used to produce a five-layer polysilicon structure, thus enabling the realization of a complex device structure.	New technology
		Germany's Bosch company developed a time-division multiplexing monocrystalline silicon using the deep dry-etching technique.	New technology
		The Japanese high-tech support corporation Hitachi developed a low-temperature silicon deep-etching technology.	New technology
		The University of Michigan developed micro-gyroscope integrated circuits.	New devices
Fourth stage	1996	Texas Instruments developed a DMD micro mirror.	industrialization
	1998	The University of Michigan developed an integrated chip-PCR analysis system, thus expanding the applications of MEMS to the fields of biochemistry and fluid mechanics.	New devices
Fifth stage	After 2000	Jewell Instruments developed dip angle sensors.	Large-scale industrialization
	2007	Apple developed the first smartphone, with an MEMS sensor.	

Source: China Center for Information Industry Development Consulting Report [CCIIDCR] (2014)

After the University of Michigan developed an integrated chip PCR analysis system and applied MEMS applications in the fields of biochemistry and fluid mechanics, the development of MEMS has experienced four major stages (Mounier, 2014), as shown in Table 3-1.

Stage 1: 1950s–1970s

The major accomplishment of that time was the development of microsystem manufacturing technology and the related theories. Bell Laboratories physicist Richard Feynman delivered a speech at the annual meeting of the American Physical Society proposing the micromechanical idea, thus laying a theoretical foundation for the development of MEMS technology. In 1963, Kulite Semiconductor Products, Inc. developed a silicon micro-pressure sensor that integrated technologies such as silicon film and bulk silicon etching, representing the starting point of the MEMS micro-sensor and bulk-micromachining era. During this stage, some representative commercial products became available, such as pressure sensors and acceleration sensors, which were prerequisites for the birth of a new industrial civilization.

Stage 2: 1970s–1980s

During this period, many countries began to conduct research on MEMS technology, with a gradual increase in corresponding investments. In particular, integrated sensors became the main object of relevant studies, and new practical MEMS technology frequently emerged. At academic conferences, the term MEMS was widely adopted and thus became a worldwide academic term. American companies such as Honeywell, NovaSensor, and Motorola started to produce a large quantity of pressure sensors for automotive and medical use. Meanwhile, MEMS sensors were first commercialized in the US.

Stage 3: 1991–1995

From 1991 to 1995, countries around the world invested a great deal of money in microsystem research, and the entire microsystem experienced rapid development, with intensive studies on MEMS-related theories, materials, processing, design, simulation, integration, measurement. In China, microsystem research started at the beginning of the 1990s at the Institute of Microelectronics at Tsinghua University, Fudan University, and Southeast University. Due to huge personal needs in the area of PCs and IT, along with a huge demand for sensors in the automotive industry, another round of microsystem commercialization began. Some products were representative of this era, such as DI developed by TI, inkjet printheads produced by HP and IBM, and acceleration sensors manufactured by ADI and Bosch.

Stage 4: 1996–2000

The fourth stage started in late 1996; at that time, microsystems had become popular and almost all fields were experiencing the miniaturization process. Additionally, microsystems had expanded into different branches, including nanodevices, biomedical applications, optics, energy, and mass data storage, and singular MEMS devices had evolved toward a systematic integration, which in turn promoted the relevant research on nanoscience, biochemical analysis, microfluidics theory. In terms of the industrialization of microsystems, the appearance of DMD, inkjet print heads, microgyroscopes, accelerometers, and microphones in the 1990s indicated that the microsystem market was robust. Moreover, RF and optical microsystems were produced on a large scale and applied to the communication field. Additionally, biological microsystems, chip laboratories, and other biochemical analysis and biomedical applications were ready to be developed (Duan, et al., 2012).

Stage 5: After 2000

MEMS technology has received increased attention worldwide and in recent decades some countries have even developed their own technology with the rapid development of MEMS research. There are three major types of MEMS technologies: silicon micro-processing technology based on integrated circuit processing technology in the US, LIGA technology in Germany, and precision machining technology in Japan.

3.2 Development of MEMS technology: patent data analysis

According to the WIPO, more than 90 percent of global technological innovation can be found in the patent literature (Huang & Li, 2010). We can use the patent data to show the development trend of MEMS technology.

3.2.1 Global patents related to MEMS technology

Globalization has led to the patent system becoming an important way for countries or companies to control either the technology chain or a high-end chain link to achieve huge profits. Since the late 1980s, MEMS technology has received increasingly widespread attention worldwide. To understand the current status of MEMS technology, we use Google’s Patent Search, Free Patents Online (Website), the Derwent Innovations Index, and several other tools to screen and select relevant and representative patents and then to provide a detailed analysis and summary of these patents (See Appendix 2).

According to the technical composition of Figure 3-2, different combinations of themes, such as “MEMS” or “accelerometer” or “gyroscope” or “magnetometer” or “pressure” or “microphone”, are used for search purposes. The time span is between 1982 and 2013 and the retrieval date is December 29, 2016. Because the lag time between patent application and authorization is more than 18 months, data from 2014 to 2016 were missing. Each record contains complete information, such as the title, the name of the patent applicant, the name of the patentee, the abstract, the Derwent classification, and the citing patent to reveal the development of MEMS technology. Figure 3-3 shows the changes in the number of global patent applications from 1982 to 2013.

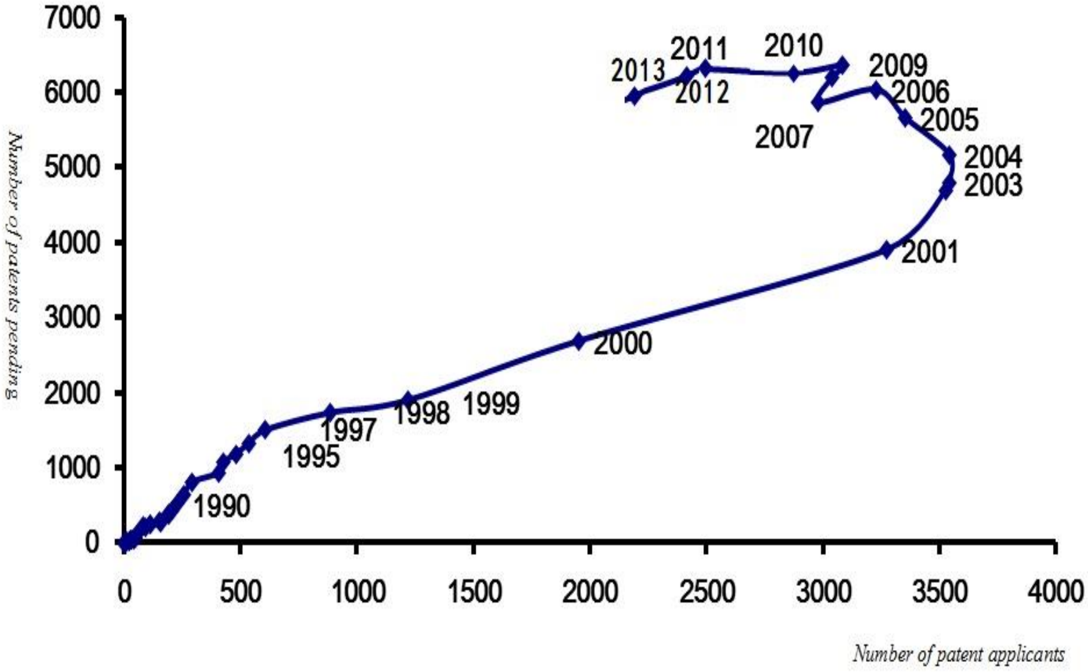

Figure 3-3 Global Patent Applications Related to MEMS Technology from 1982 to 2013

Source: The Derwent Innovations Index (2015)

Analyzing the number of patent applications related to MEMS technology can identify development and investment trends in MEMS. For some technical fields, the trend exhibits an “S” shape, indicating that the technology displays a different status during different periods (Martino, 2003). In 1987, the University of California at Berkeley invented the first micromotor based on sacrificial layers technology, which received a great deal of international attention. People saw the possibility of integrated fabricating with combined circuits and execution units, and many countries began to support such research. In the 1990s, many developed countries invested heavily in MEMS technology. Since then, the development of MEMS technology has accelerated and the number of patent applications continues to increase, especially with the emergence of deep etching technology. In 1993, American company ADI adopted this technology and successfully commercialized a miniature accelerometer. Because large quantities of these miniature accelerometers were used to make automotive air bags, this period also marked the beginning of the commercialization of MEMS technology. Due to this commercial success, more countries joined the competition to develop MEMS technology.

Later, between 2003 and 2005, Si microphones entered the mobile phone market and the application field for MEMS technology continued to expand. As a result, the number of relevant patent applications soared again. In 2006, MEMS microphones with digital output entered the laptop market. In 2007, companies started to apply motion sensors to portable consumer products. Beginning in 2004, because the industry had experienced several large-scale mergers and acquisitions and barriers to entry continued to increase, there was a sharp reduction in the number of patent applicants. In 2010, monolithic ink-jet printhead CMOS-MEMS with an integrated multidimensional data record became available, which was actually a combination of micromechanical and integrated multidimensional data in the head chip and could help record the entire circuit driven by a CMOS demultiplexer. In 2012, an inertial navigation-grade MEMS accelerometer became available. It completely released residual stress imposed on the internal structure and achieved a highly stable sensor unit by implementing technologies such as Si capacitive micromachine technology and mechanical decoupling technology (Falletti, 2011).

3.2.2 Patent distributions in countries

Countries or regions with high levels of published patent numbers often have great market potential for the application of patent technologies, and countries or regions with patent priority are usually the birthplace of technological innovation (Guan, 2005). A patent applicant usually first applies for patent protection in his/her homeland and then applies for patent protection in other countries using his/her existing patent priority. Therefore, when we address the question about the country to which a specific patent should belong, we must extract information about prior patent rights and obtain a country code to approximately represent the corresponding country (Sohn & Moon, 2003). The number of “priority” patent applications for a country could be counted as an important parameter because it reflects the country’s research and innovation capabilities. Here, we statistically analyzed the number of “priority” patent applications related to MEMS technology.

Figure 3-4 shows the changes in the number of MEMS patent application in main countries or regions from 1982–2013 (SK represents South Korea). From Figure 3-4, we may evaluate the research capability of MEMS technology across the world. Among these countries or regions, the US has the highest number of records in terms of patent priority

(27,943 patents recorded), followed by Japan, South Korea, China, and other countries. Overall, the US and Japan were the main research pioneers in the MEMS field, showing very strong and continuous innovative capabilities with high levels of R&D. For example, Japan has a huge number of patent applications, suggesting that Japan's patented technology occupies a dominant position in the international market. Indeed, China has accumulated patents over a relatively short period of time, with a total of 2176 patents after 20 years of development, ranking fourth in terms of the cumulative number of MEMS-related patents. Although China does not dominate the development of MEMS technology, it still has advantages in 3D, SiP-led, third-generation technology and R&D investment.

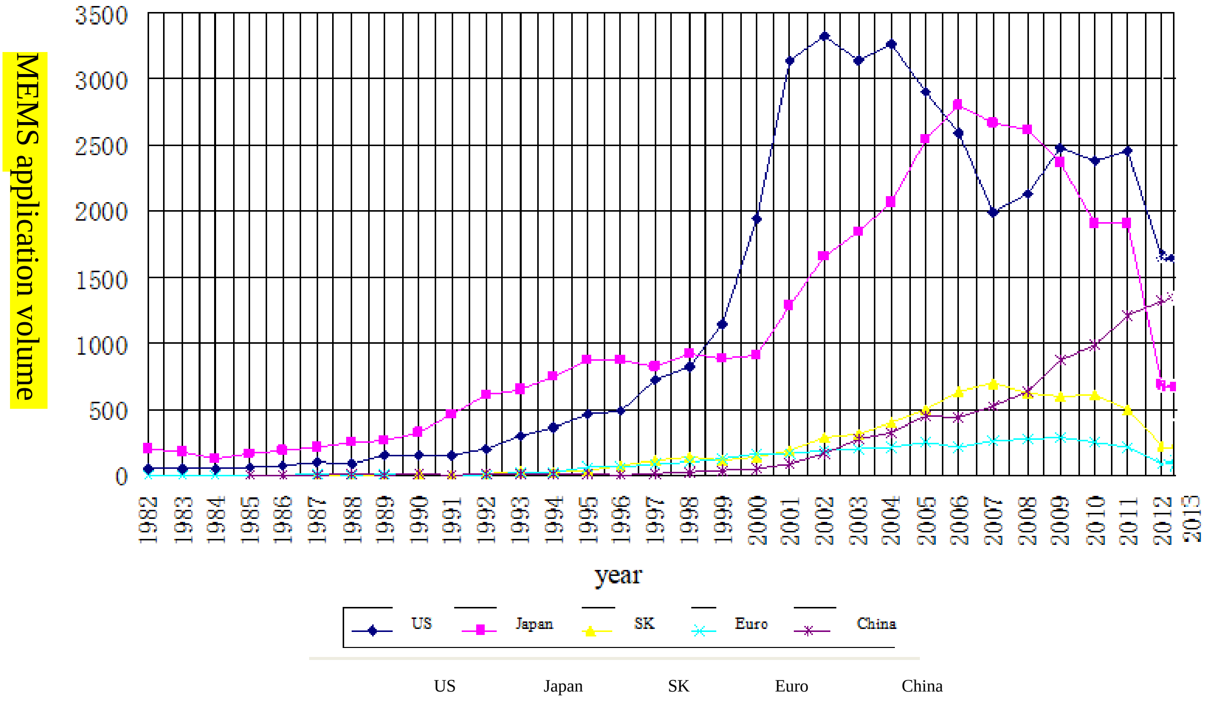

Figure 3-4 MEMS Patent Applications in Various Countries or Regions (1982 to 2013)

Source: The Derwent Innovations Index (2015)

Figure 3-5 shows the distributions of the main enterprises with MEMS technology all over the world. According to the distribution of relevant patents, those related to MEMS technology showed rapid growth from 2000 to 2005, during which time the US and Japan recorded the highest number of patent technologies. Of the top 10 MEMS sensor-technology companies worldwide, five are Japanese. Meanwhile, Seiko Epson Corporation (Japan) and Honeywell International Inc. (US) are companies with high numbers of MEMS patents. Therefore, it could be reasonably predicted that the US, Japan, Germany, and China have become the largest holders of patents in MEMS technology, and that they have occupied a central position in the MEMS industry.

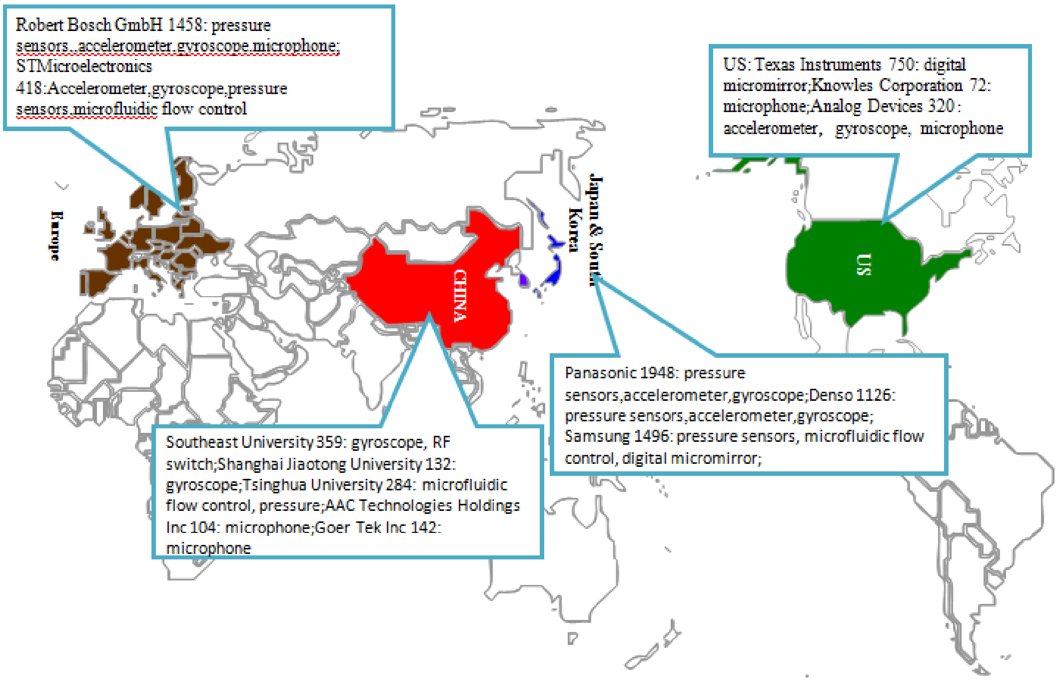

Figure 3-5 Distribution of Enterprises with MEMS Patents in the World

Source: The Derwent Innovations Index (2015)

3.2.3 Patents distributions in products

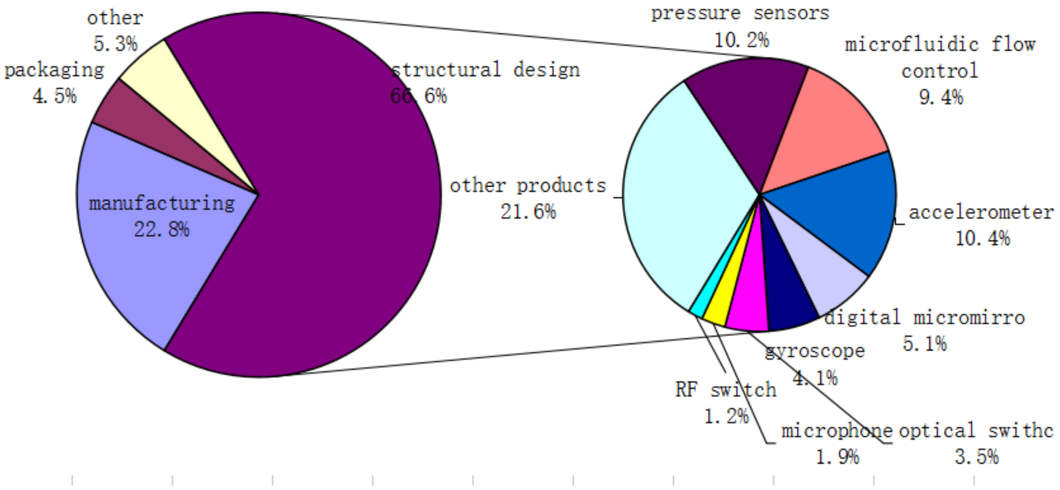

Figure 3-6 Distribution of MEMS Products in the Global Market (2013)

Source: The Derwent Innovations Index (2015)

To achieve the commercialization of MEMS technology, it is necessary to understand its applications; that is, the MEMS products. Based on 93,220 relevant patents, the developments and trends in MEMS technology during a specific period and the evolution processes of several research fronts can be identified.

As shown in Figure 3-6, from the MEMS technology components perspective, patents in structural design, manufacturing, and packaging processes account for 66.6 percent, 22.8 percent, and 4.5 percent of the total patents, respectively. Especially in structural design technology, the most important MEMS products are accelerometer, pressure-sensor, and microfluidic products, accounting for 10.4 percent, 10.2 percent and 9.4 percent of the total, respectively.

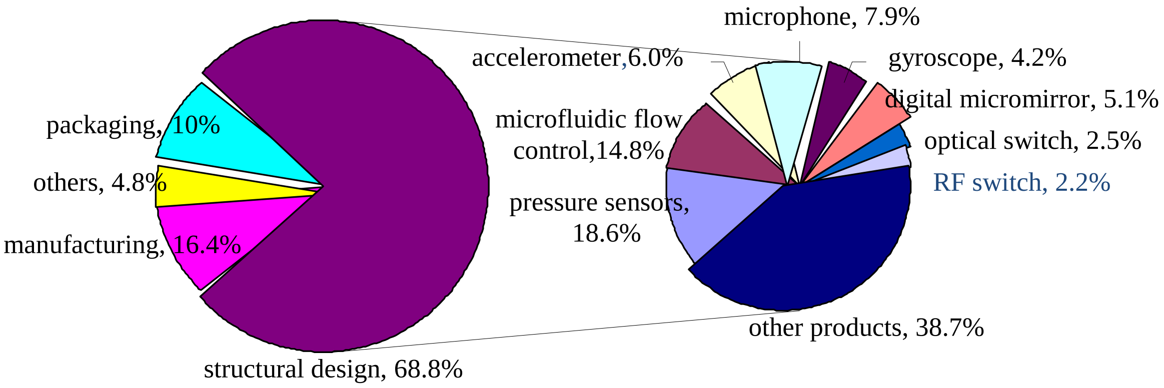

Figure 3-7 Distribution of MEMS Products in China

Source: The Derwent Innovations Index (2015)

Similarly, in China, as exhibited in Figure 3-7, structural design, manufacturing, and packaging processes are the top three types of MEMS technologies in terms of the highest number of patent applications, accounting for 68.8 percent, 16.4 percent and 10 percent of all MEMS patents, respectively. For structural design products specifically, the highest number of patents are from pressure-sensor products, followed by microfluidic and microphone products. Through the analysis of related patent applications, we may find that chip internal layers provide the base for stacking-based 3D packaging methods and relevant patents. Meanwhile, 3D integration technology is applied to facilitate inter- and intra-layer connections so that 3D stacked packages via die-to-die stacking or package-to-package manners are formed. Among all 3D packaging technologies, TSV could help achieve the shortest but most intense connections along the Z direction perpendicular to the package substrate (Hacker et al., 2012).

3.3 Developing trends of MEMS technology

In the future, MEMS devices will gradually evolve toward 3D architecture MEMS, high-performance single-chip MEMS and high integration-module MEMS, as well as low-power consumption, intelligence, networking, and exploratory devices and applications (Zhang, 2016). Meanwhile, mainstream global MEMS manufacturers have already investigated these areas with in-depth research and development, and some have successfully launched numerous prototype products (Zhang, 2016).

Trend 1: 3D-structural MEMS

Finnish company VTI was the first to launch 3D-structural MEMS, which integrated the base silicon layer with metal capacitor plates, the intermediate silicon layer with a motion-sensing structure, and the cover silicon layer to form an inertial MEMS capacitive accelerometer (Guan, 2005). VTI later designed inclination sensors, gyroscopes, and pressure sensors using similar technology. 3D-structural MEMS devices with miniaturization, low power consumption, and high-precision characteristics could detect motion activities along three orthogonal directions and help expand the design of the sensor chip to include a three-dimensional structure (Zhang, 2016). For the three-dimensional structure of MEMS devices, since usability has been greatly improved and relevant structural strength has been significantly enhanced, its application scope has been widely expanded (Zhai et al., 2015). In addition, power consumption has been reduced dramatically. The technological innovation in 3D-structural MEMS was acquired by Murata Manufacturing, a Japanese company. Currently, improvement of the 3D-structural MEMS concept and technology is ongoing. Even in the IC field, 3D technology has been invented during the process of chip designing and packaging. Because MEMS devices have special requirements for structural performance, the trend toward 3D-structural MEMS is inevitable (Wang & Su, 2016).

Trend 2: High-performance monolithic MEMS

Monolithic MEMS devices include accelerometers, gyroscopes, pressure sensors, and other single-function MEMS chips. Mainstream MEMS manufacturers are striving to develop an integrated module while improving the performance of monolithic MEMS devices with different brand names (Zhang, 2016). Examples include STMicroelectronics, which produced inertial devices, ADI, which introduced high-offset temperature sensitive accelerometers, and Freescale, which updated low-power physical tamper protection accelerometers. Additionally, the primary concern of subsequent improvements relates to aspects of cost control, size reduction, power consumption, accuracy improvement, reliability enhancement, user experience and compatibility boosting between product series, similar devices with different generation gaps, and different devices (Jiang, 2009). In fact, aspects of the modular process, structural design and platform development are in line with the ultimate goal of technology innovation, which is to improve the overall performance of MEMS devices, with the improvement of monolithic MEMS devices as the technology foundation of the modular integration platform. Currently, although the growth of monolithic chips has gradually slowed and almost gave way to a high-performance integrated module, monolithic chips remain important and have a wide range of applications for electronic products, the automobile industry. Therefore, continuous improvement in the performance of monolithic MEMS will remain the mainstream practice for the development of future MEMS technology (Zhu J., 2015).

Trend 3: Highly integrated module MEMS

The MEMS field has been developed in terms of a modular direction, and this is especially true for inertial MEMS devices. In contrast to the market for traditional accelerometers, the market for modules with integrated MEMS devices remains promising (Li & Chen, 2015). For example, ST and ADI have launched three-axis accelerometers, three-axis gyroscopes, high-accuracy digital altimeters, and ten-axis inertial module triaxial devices of pressure sensors with large-scale production. Based on the Windows 8 platform, Freescale launched a 12-axis sensor platform with well-integrated three-axis accelerometers, three-axis magnetometers, high-accuracy digital altimeters, and environmental optical sensors, offering a variety of gyroscopes for expansion purposes. Although the modulation process is necessary for the improvement and expansion of MEMS devices, the idea of integration is not limited to the application of sensors. Instead, the ultimate goal of integration is to achieve integrated and complete information-link connections based on MEMS and MCU. ST has introduced a new product with integrated MEMS and MCU. Additionally, the manufactured dual-core gyroscope instrument has a similar design. Indeed, the modular-integration trend is not limited to the development of relevant devices. The entire MEMS industry link is also working in this direction. For example, the world’s leading testing-machine manufacturer, Multitest Company, launched a nine-axis MEMS device-testing program in 2012 (Wang et al., 2015).

Trend 4: Low-power-consumption MEMS

Low power consumption has always been the basis of semiconductor products, and this is especially important for miniaturized MEMS devices. With the goal of optimizing the related structures and improving the standard platform, one of the major improvements in 3D-structural MEMS technology is reduced power consumption in MEMS devices (Yue, 2014). The purpose of this reduction is to lower power consumption and minimize heat transfer and to save energy. For example, ambient light sensors within a smartphone can help turn off the backlight automatically (Zhu J., 2015).

Trend 5: Intelligent MEMS

Intelligent MEMS devices are developed when MEMS performance is improved and multimode integration is achieved. Additionally, such devices represent important application ideas for MEMS technology. Through the development of multi-threaded processing management and integrated MCU, MEMS devices may automatically identify sensor information and process it intelligently. ST has launched a high-performance accelerometer and a six-axis MEMS device. The internal state machines and established mode selection functions of both devices allow them to determine the type of smart sensor information and to take intelligent actions in response (Zhang, 2016). Freescale’s products have also realized the intelligent function via MCU integration technology. Although an intelligence function is expected of MEMS devices and applications, STMicroelectronics has taken an important step in this regard by successfully developing intelligent devices within integrated modules (Mounier, 2014).

Trend 6: Networking MEMS

Device networking and wireless communication have always been important features and applications. MEMS technology is striving to achieve networking connections by integrating multipoint network devices and wireless communication modules, with the goal of ultimately realizing the development and applications of the Internet of Things (IOT) (Zhang, 2016).

Trend 7: Other exploratory MEMS devices

MEMS technology is experiencing rapid growth, with new types of devices and application modes being developed frequently. For example, Atmel has produced a very flexible, high-performance touch sensor called XSense, along with a combo chip that integrates MITSUMI distance and light-sensitive sensors. Similarly, Silicon Laboratories has launched a solar-powered wireless sensor. All of these products represent promising new MEMS technologies and programs (Wang & Su, 2016).

Overall, the demand for innovation has led to continuous improvements to MEMS devices. In the future, MEMS technology will have more applications, and MEMS technology with information-processing abilities and an intelligent feedback function will lead to its wider commercialization.

3.4 Commercialization of MEMS technology

3.4.1 Characteristics of developing MEMS products

3.4.1.1 Large investment

Since MEMS devices are highly complex in terms of their associated framework structure and its applications, their production standards are much higher than their design requirements. Thus, manufacturing and packaging technology is a key component of MEMS products (Lou, 2010; Zhang, 2016). The development and production of MEMS devices requires substantial outlays for equipment and large investments. During the production and processing stages, expensive scribing, lithography and etching machines, and other devices are needed. In the pilot production stage, a strict manufacturing environment is necessary (Zhao, 2004). For example, the primary processing area should meet ISO 5 (Class 100) cleanliness standards and each link is highly dependent on the supplied equipment. During the manufacturing process for MEMS devices, packaging-related expenses are extremely high, and chip-production failure is most likely to occur during this process. Additionally, MEMS technology requires a great deal of specialized equipment and significant financial investment (Wang, 2003). For instance, Suzhou began trial operations of its nano MEMS platform in May 2014, which involved a construction area of 33,000 square meters. The investment was more than 400 million RMB and the annual expenses for equipment maintenance and running costs were at least 10 million RMB (Wang, 2016).

3.4.1.2 Demand for high technological talents

MEMS technology is a multidisciplinary technology that requires multidisciplinary talents to work together. For example, in the design stage, the application of circuit design software and an integrated environment to a software platform should be combined to complete various tasks, including defining chip functions, designing a relevant framework, collocating involving modules, assembling the required pins, and carrying out all of the other commercial circuit design (Yue, 2014). Meanwhile, the simulation process requires that the chip templates be able to test the function of chips under an integrated simulation environment. Moreover, the followed steps, such as the flow sheet, additional testing, large-scale production, and packaging processes, all belong to late-stage work (Zhu J., 2015). The industrialization process for MEMS products is highly risky, both in terms of product development and market competition. Any mistake that occurs during the production-development stage could have a catastrophic impact on the entire produce. MEMS technology is a typical emerging technology that gradually entered the market after 2000 (Wei, 2006).

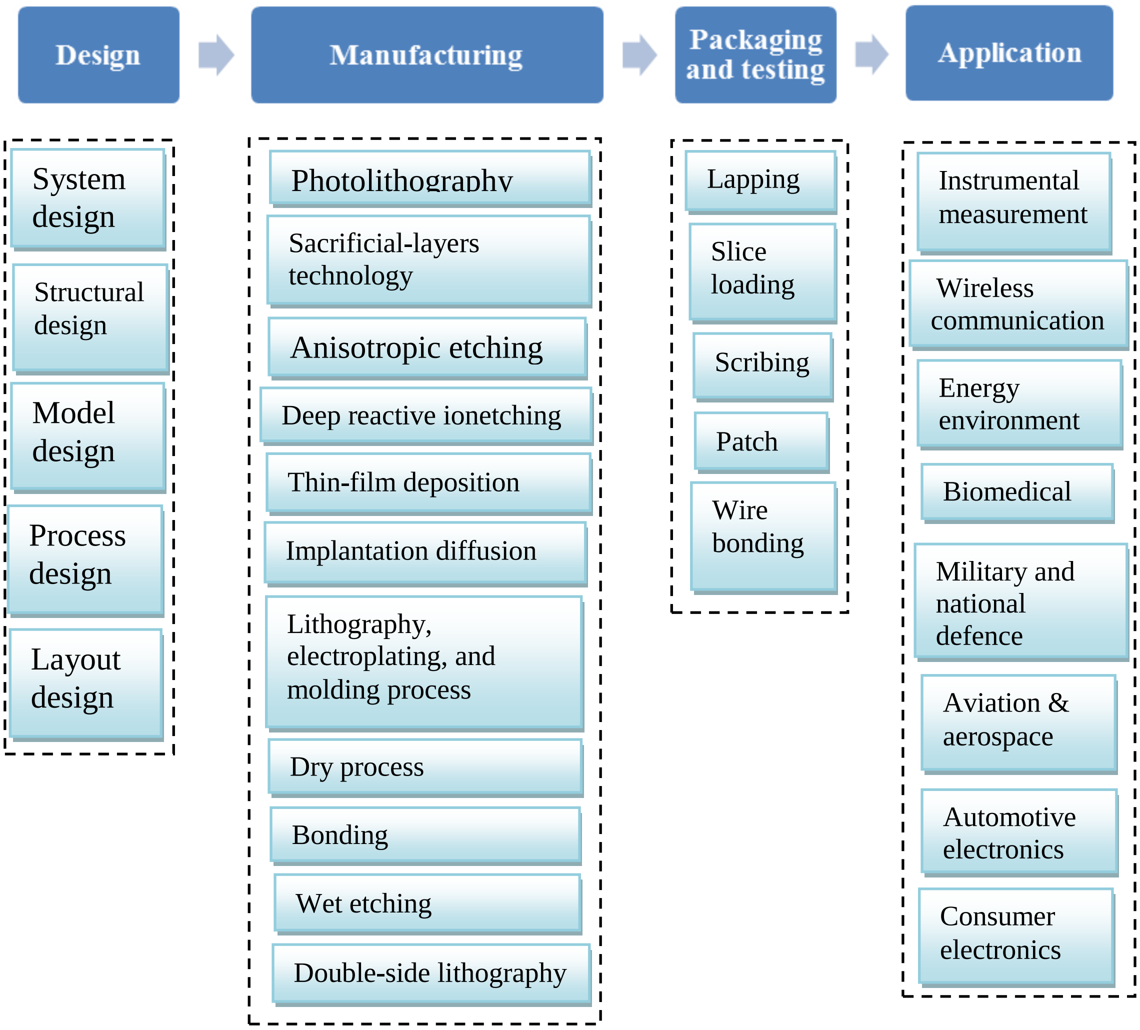

Figure 3-8 MEMS Industry Chain

Source: Jiang (2009) and Zhu (2015)

3.4.1.3 Inconsistent standards

At present, most MEMS devices are produced using the semiconductor-manufacturing technique, representing an extension of the integrated circuit industry in terms of both production methods and technical processes (Tian, 2009). MEMS design and manufacturing technology differs from the technology used in the semiconductor-manufacturing technique, mainly in that different types of MEMS chips could not be widely used to perform the same functions as IC chips on a compatible platform (Zhu J, Wen, T. D., Li-Ping, & X. U., 2015). This could imply that MEMS technology could experience long-term sustainable development in the future (Wang, 2003).

3.4.1.4 Long industry chain

As Figure 3-8 shows, the industry chain of MEMS technology can be divided into four stages – design, manufacturing, packaging and testing, and applications (Wang, 2011) – each of which is further divided into a number of sub-stages. For example, the design stage could be further divided into system design, structure design, model design, technique design, and layout design. Thus, MEMS technology is differentiated from traditional semiconductor technology since MEMS technology has a more complicated system with a very long industry chain. Consequently, MEMS technology is more difficult to develop and involves a longer development period (Jin, 2007).

3.4.2 MEMS market capacity

IOT provides a great opportunity to develop a variety of MEMS sensors. According to a MEMS consulting report, the MEMS market was worth US$8 billion in 2014 (CCIIDCR, 2014). Because the application of IOT requires a large quantity of low-cost MEMS devices, the relevant economies of scale are spectacular. Taking the sensor industry as an example, with the rapid development in automotive electronics, new digital consumer electronics, and medical industries, a variety of new demands for microsystem sensors and innovations-based microsystems continue to emerge. Marketing promotion programs and technological innovations from MEMS device manufacturers, among other things, mean that the MEMS industry is full of new opportunities. The development of the sensor industry has revealed three major global prospects (Sung & Dalal, 2010), as listed below.

(1) The world has witnessed the rapid expansion of its industrial scale since 2010. For example, global profits on sensors were approximately US$80 billion in 2015 and the rise of IOT has resulted in new opportunities for this industry (CCIIDCR, 2015).

(2) The entire development process is innovation-driven (Wang, 2003; Zhu et al., 2015). The use of sensors that have new materials, mechanisms, and structures, combined with the fact that companies are active in the R&D field that continuously improve the technology, has fulfilled the goals of reliability, adaptability, and sensitivity and helped the industry evolve toward a system with excellent integration, miniaturization, intelligence, and network connections (Zhu et al., 2015).

(3) The market for the sensor industry has become increasingly oligopolistic since 2012 (Shaeffer, 2013; Zhu et al., 2015). Siemens, Honeywell, ABB, and the rest of the world's most popular sensors and multinational enterprises have created a highly competitive market through globalization, mergers, and acquisitions, successfully occupying the high-value-added market and accelerating expansion into the low-value market (Huang & Zhang, 2015).

At the same time, an integrated terminal will eventually lead to a human digital evolution, and both intelligent terminals and smart healthcare services would continue to drive MEMS sensors' ROI. According to the relevant statistics, the average net profit margin could reach 17.6 percent, which is more than twice the net profit margin (8.1 percent) of the information industry (Wang & Tian, 2009). In general, an investment return is expected after a new MEMS product has been on the market for approximately three to four years (Tian, 2009). Additionally, the first entrants could seize on the opportunities to achieve rich profits. Because the development cycles involve a relatively long industry chain and very high the investment, latecomers may find it difficult to enter this industrial field. If the market's competitive conditions are relatively constant, the first entrants could enjoy stable and high returns (Wang & Tian, 2009).

With the development of semiconductor manufacturing technology, the application of MEMS technology in the field of consumer electronics also increases rapidly (Zhu et al., 2015). The integration of MEMS and CMOS technology via TSV has led to 3D IC technology which has received a great deal of attention (Zhu et al., 2015). Because 3D MEMS technology has heterogeneous integration characteristics, along with several obvious advantages such as low cost, small size, multifunction, and high performance, it is expected to bring about another technology revolution and provide greater opportunities for the development of CMOS/MEMS (Zhu et al., 2015).

MEMS has taken root in our daily lives because of its variety of applications. The main advantages of MEMS technology are its low cost and small size, which means that the final products are much smaller, lighter, and less expensive. However, there are still many barriers to the development of MEMS technology (Zhu et al., 2015). For instance, the diversity level of MEMS devices is often closely associated with the environment. The packaging process is also a significant challenge because of very high expenditures; to achieve more economical products, standardized (but cheaper) packaging techniques have become a major aspect of MEMS design. MEMS manufacturers have undertaken substantial research and development efforts to strengthen their positions during the packaging and manufacturing process and to develop new, special packaging devices (Wang & Su, 2016). In China, the development of the market economy has also contributed to the progress of the MEMS industry. From the above discussion we can see that the Chinese MEMS industry has experienced fast growth in the Asia-Pacific region (Zhu et al., 2015).

The Chinese sensor industry has passed through the technology introduction, imitation, and digestion stages and has now reached the exploration and innovation stage. Chinese enterprises have made a major breakthroughs in technologies such as high-precision pressure sensors, sensor transmitters, and 10-million-ton refinery core-control systems (Wang & Su, 2016). However, since the estimated value of sensors is less than 2 percent of the value of major technical equipment, coupled with the difficulties in developing relevant technologies, China’s MEMS industry still trails behind those of the US and Japan (Zhu et al., 2015). High-quality sensors for critical technical equipment are usually imported from other countries, making the need to promote the MEMS commercialization level in China quite urgent.

3.4.3 Formation of MEMS industry

As discussed above, since the beginning of the 21st century, MEMS technology has become one of the most rapidly emerging industries. MEMS technology is the product of cross-penetration and deep integration in the mechanical and microelectronics industry, supported by the breakthrough innovative technology of micro/nanotechnology fabrication. Its formation features can represent general features of new technology commercialization. Since 2010, consumer electronics products have undergone rapid development, thus promoting the development of MEMS technology (Mounier, 2014). From the DMD micro-mirror in 1996 to the $800 million revenues of MEMS products in 2014, MEMS technology has taken the leap from the technology-selection stage to the mass-production stage (Zhu et al., 2015).

By combining patent data and information from China Semiconductor Association (MEMS), the present study explores MEMS technology commercialization process from four stages: the technology-selection stage, the research and development stage, the pilot stage, and the mass-production stage (Day & Schoemaker, 2000; Duan, et al., 2012; Huang & Zhang, 2015). The formation of the MEMS industry involved both technology group development and commercialization. Formation consists of the anisotropic theory of etching silicon using an alkali metallic solution as a starting point, along with a breakthrough innovative technology (micro/nanotechnology fabrication technology) as the leader (together with other related technologies). Each period has its own characteristics. The technology-selection period is primarily based on scientific research activities related to MEMS technology (Duan, et al., 2012). Research and development activities were active during the research and development period, and countries provided various policies to support related R&D activities. However, some types of MEMS products are simple. During the pilot period, MEMS research and development activities were more active. Various branches of MEMS technology appeared with different products like pressure sensors, accelerometers, gyroscopes, microphones, and RF switches (Guan, 2005). Market demand increased gradually and the application of MEMS technology expanded. The government also provided policy support for the commercialization of MEMS technology and MEMS technology became the dominant position. Governments played a stimulating role in MEMS industry development during the mass-production stage, especially the initial period. In countries such as Japan and the US, preferential policies supporting MEMS industry included government investment, tax incentives, and other industrial policies (CCIIDCR, 2016).

3.4.4 Ways of MEMS technology commercialization

There are different ways to commercialize MEMS technology (Bi, 2015). In general, government plays an important role in this process. Demand in the military field has played a significant role in promoting the development and progress of MEMS technology and resulted in one of the earliest applications of MEMS technology (Fang et al., 2010). Since the appearance of MEMS technology, the world has attached great importance to its application in the area of military equipment and it has been considered as a key technology for future military equipment. MEMS represents an important strategy to enhance the military's combat effectiveness and maintain national security (Ding D., Li, Z. Hu, & M., 2013).

In China, the main state-owned enterprises that are promoting MEMS technology commercialization are the Aviation Industry Corporation of China, China Aerospace Science and Technology Corporation, China Electronics Technology Group Corporation, China North Industries Group Corporation, Norinco Group, and China National Machinery Industry Corporation (Wang, 2003). The Defense Advanced Research Projects Agency (DARPA) in the US has identified MEMS technology as an emerging technology in urgent need of development (Zhu et al., 2015). MEMS technology has been widely used in military electronic information systems, military micro-aircraft, military medical fields, and other fields that make weapons more sensitive, more accurate, and more lethal, so that the military can collect and address information more comprehensively, more rapidly, and more accurately (Zhu et al., 2015).

However, enterprises are still the main bodies for MEMS commercialization. Indeed, enterprise-driven MEMS commercialization has experienced three waves (Zhu et al., 2015). The first started at the end of the 1970s, when the pressure sensor was fabricated using a large silicon-etching structure and a back-etched diaphragm, and the pressure was converted into an electrical signal using the piezoelectric effect. The third wave occurred around the year 2000, when micro-optics devices, microfluidic systems, MEMS three-dimensional microstructures, IT sensing, and many other MEMS products entered the market (Zhu et al., 2015).

The MEMS industry has grown rapidly since 2013 due to the innovative development of video, audio, smart phones, and micromedical devices. In particular, smartphones and tablet computers have promoted the sustained and rapid development of MEMS devices (CCIIDCR, 2015). Recently, health care in high-value fields has represented the new wave of MEMS applications. Given the high current level of awareness of physical health, intelligent, portable medical devices have access to people's vision, and various devices for long-distance monitoring and high-precision treatments have been put into use. With current aging trends, the market for MEMS medical care will expand (Li & Chen, 2015).

Andrew and Sirkin (2004) concluded that there are three modes for technology commercialization: unified commercialization, integrated commercialization, and licensing authority. Unified commercialization refers to whole commercialization stages from technology selection to mass production, in which large enterprises develop new technology through internal R&D departments and commercialize independently. Integrated commercialization means that the commercialization primarily focuses on the commercial process; the upstream and downstream industry chain is also addressed, during which the owners of technical knowledge or products sell innovation achievements to other organizations using what is known as licensing authority. Licensing authority also allows organizations to manage other parts of the commercial process through authorization (Andrew & Sirkin, 2004). As shown in Table 3-2, each of these modes varies in terms of its investment characteristics, profit model, risk characteristics, technical requirements, and profit level.

Table 3-2 Three Modes of Technology Commercialization

	Unified commercialization	Integrated commercialization	Licensing authority commercialization
Advantages	Low risk, controlling all aspects of the commercial process	Use partners' assets and capacity	1. Require stock equity from enterprise 2. Lowest investment
Disadvantages	1. Takes the longest time 2. Highest amount of pre-investment	High risk, difficult to manage	Less profit, uncontrollable risk
Requirements for enterprises	Excellent manufacturing expertise, marketing skills and cross-functional areas of cooperation	1． Good at project management across the company 2． Good at developing partnerships 3． Know how to protect property rights	1. Need for knowledge and negotiation skills 2. Able to withstand the opposition of "ideas men"

Source: Andrew and Sirkin (2004)

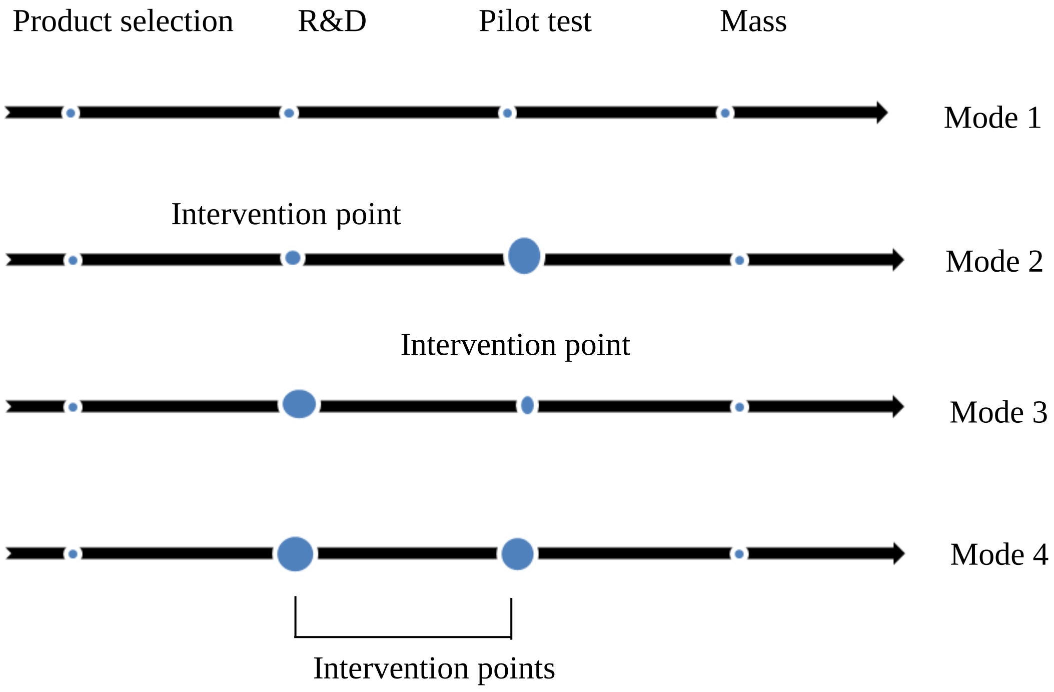

Figure 3-9 Modes for MEMS Technology Commercialization

Source: Zhao (2004).

According to Du (1999), the stage at which an enterprise enters into MEMS technology commercialization can be divided into the following four modes. Figure 3-9 illustrates these modes in the MEMS commercialization.

Mode 1: Unified commercialization means that enterprises, including universities and scientific research institutions, are simultaneously engaged in the entire product development process (Cooper, 1996). These organizations can complete research and development, pilots, and production independently. This form is common in large enterprises in some developed countries, such as the US and Japan. STMicroelectronics, and Bosch Sensortic are able to design and manufacture chips, package and test, and engage in mass production. They encompass all of the procedures of MEMS commercialization (Huang & Lu, 2009).

Mode 2: License-management mode means that technology owners (universities and research institutes) cooperate with enterprises at the stage of technical production. Universities or research institutes are not only research centers, but also incubation centers (Ding D., Li, Z. Hu, & M., 2013). Universities and research institutes complete product development and move directly to the pilot stage. Enterprises accept scientific research achievement directly from universities and research institutes after the pilot stage. For instance, the MEMS research center at the Institute of Microelectronics at Peking University and the National Key Laboratory of micro/nanotechnology machining technology were two of the earliest universities in China to study MEMS and provide MEMS OEM technology services (Huang & Wang, 2011). Their research areas include inertia sensors, microfluidic sensors, and biological MEMS. The results of their research include lithography, bonding, deep-groove etching, and other process technologies. They also own the intellectual property for these technologies. Some devices have entered the pilot stage, including the MEMS accelerometer, MEMS gyro, RF MEMS, and microfluidic MEMS (Huang & Zhang, 2015).

Mode 3: The third mode is for enterprises to intervene at the pilot stage of MEMS commercialization. This mode takes two forms (Zhu et al., 2015). One lets universities or scientific research institutes completely joint tests with enterprises. The other involves having universities and scientific research institutes complete joint tests at the pilot stage bases of the owning enterprise (Wang et al., 2015). For example, the Microelectronics Research Institute of Fudan University primarily studies passive, natural resources, ultra-low power integrated chips or technology of IOT, biomedical technology, ultra-low-power sensor electronic health systems, MEMS micro-processing and new nano-devices and integrated sensors, new material platform SIP/SOP three-dimensional systems integrated with multichip technology, micro/nanotechnology electronic devices, and advanced semiconductor technology (Huang & Yang, 2014).

Mode 4: The fourth method involves having universities or scientific research institutes develop their technical achievements and then transfer those achievements to the enterprise to cooperate and complete the pilot scale test (Li & Chen, 2015). This mode can make use of the advantages of all parties involved. The university or scientific research institutes obtain enterprise funds, the technical results are quickly transformed and applied in the enterprises, and the enterprises gradually achieve commercialization of those results. Wuxi BEWIS Sensing Technology LLC is a typical example. The company cooperates with MEMS university research institutions at Peking University, Zhejiang University and Xiamen University. It takes advantage of the research and talent offered by universities and research institutions to develop and manufacture inclinometers, tilt switches, digital compasses, inertial measurement units, navigation attitude references, and integrated navigation units. BEWIS has become China's leading high-tech enterprise in the design, manufacture, and sales integration of professional inertial attitude sensors.

The main bodies involved in development cooperation are MEMS enterprises, universities, and research institutes, which is a typical model of cooperation in industry-university cooperation (Zhu et al., 2015). Technology is the driving force for the cooperative relationship among industry, universities, and research institutions. The main body of operational cooperation is suppliers, MEMS companies, distribution channels, users, intermediaries, venture capital, public service platforms and incubators, which is a cooperative, market-driven relationship (Wang et al., 2015). Therefore, as shown in Figure 3-10, the technology-product stage and the product-market stage are two important linkages for technology commercialization. Development cooperation aims for technology-product transfer, while operation cooperation is a type of cooperation that emphasizes the product-market commercialization process.

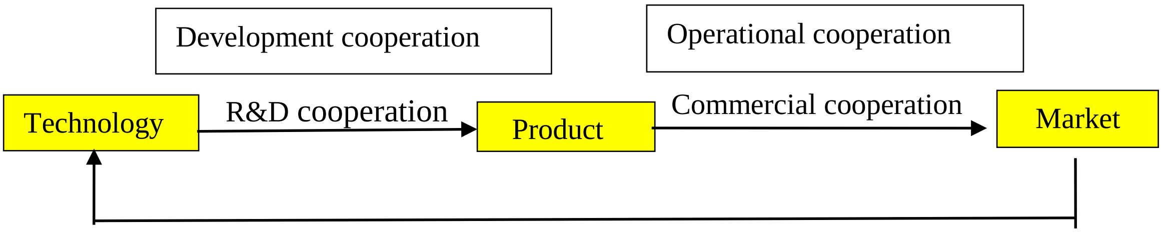

Figure 3-10: Two Types of Cooperation during MEMS Commercialization

Source: Li (2012)

3.5 Summary

This chapter has discussed the evolution process and applications of MEMS technology. We have also collected global MEMS-related patent data and analyzed its product and geographic distributions, which is important in order to understand the development of MEMS technology. We have proposed six MEMS technological trends: 3D-structural, high-performance monolithic, highly integrated module, low power consumption, intelligence, and networking. Finally, the formation of MEMS industry and the ways for MEMS technology commercialization were analyzed in detail. All of this laid a foundation for the later empirical study, in particular, the proposal of related hypotheses and the case study.

This page is deliberately left blank

Chapter 4: Empirical Study: Hypotheses and Research Design

The literature review on emerging technology in Chapter 2 and extensive analysis of MEMS technology in Chapter 3 shows that the commercialization of MEMS technology is a complex, systematic and high-risk process. Therefore, to increase the success rate and provide the practical guidance to MEMS enterprises, it is important to explore the determinants of MEMS commercialization, specifically in the Chinese economic context.

In this and the following chapters, we investigate which factors are determinants and to what extent those factors influence the commercialization of MEMS technology in China. While this chapter proposes the theoretical hypotheses and outlines the research design, Chapter 5 mainly reports the empirical results and discussion.

4.1 Hypotheses

The successful commercialization of an emerging technology cannot be guaranteed, even though there is sufficient capital and human resources (Andrew & Sirkin, 2004). Innovation economics indicates that the success of commercialization is dependent on factors such as policy, market acceptance, technology track and dominant design, and the state of the innovation system (Bright, 1970). Among these factors, due to the characteristics of different technology, some factors may be critical to the commercialization success of a specific one. Having reviewed the literature on the factors affecting the commercialization of emerging technologies and taking into account the characteristics of MEMS technology, this thesis suggests that the following six factors are the critical ones that determine the success or failure of MEMS technology commercialization: technology properties, enterprise capability, regional innovation network, market conditions, policy and regulation, and social environment.

4.1.1 Technology properties

As Howars and Guile (1992) pointed out, the commercial prospects of an emerging technology are closely related to the characteristics of the emerging technology, including the following four properties: (1) technology development status, such as technology developing space and speed; (2) technology quality, such as the level of technologies and the wide range of applications; (3) technology opportunity, which refers to whether emerging technologies can fill the gaps in the existing technology; and (4) technology difficulties, specifically whether the main obstacles to the process of developing emerging technologies are clear and resolvable. The maturity of a technology is the basis and the primary condition for emerging technology commercialization (Zhu et al., 2015; Zhou & Lv, 2010).

Not all emerging technologies can be commercialized (Huang & Zhang, 2015). First, emerging technologies should have innovativeness and be in a leading position both at home and abroad. These types of technology can enhance the competitiveness of a country or an enterprise. Moreover, emerging technologies should have reached a certain level of maturity. Maturity refers not only to the technology but also to the market (Wang et al., 2015). Finally, emerging technology should have operational and practical possibilities in the following three aspects: from concept to physical product, from business blueprint to production operation, and from raw material to product. Through the analysis on MEMS technology, we may find that it meets all the requirements for commercialization. In fact, MEMS is characterized by innovativeness, maturity and practicability as a comparatively high probability of achieving its commercialization (Li & Chen, 2015). Moreover, timing is also an important factor during this process. Participation that is either too early or too late will lead to failure. One reason for the failure of MEMS companies is that they put immature products into immature markets too early (Huang & Yang, 2014). Therefore, it is reasonable to propose the following hypothesis:

Hypothesis 1: There is a relationship between technology properties and the performance of MEMS technology commercialization.

4.1.2 Enterprise capability

MEMS technology relies heavily on professional equipment. Many MEMS enterprises have insufficient capital and resources to support the whole supply chain from the initiative R&D to the final production. There are other constraints as well, such as the non-standardized producing procedure and strong intellectual property protection, which hinder the commercialization of MEMS technology. To address these problems, the enterprise’s comprehensive management capabilities, including its managerial skills, financing, strategic management and even crisis management, are critical, among which innovation is a core competence, determining its technology level, competitive advantage, and future market position (Wang & Su, 2016). Since MEMS technology commercialization requires huge investment in a series of processes (Bi, 2015), financing ability is key for an enterprise to quickly obtain necessary capital with low cost. Strategic management is the ability to determine an enterprise's market orientation and development direction, which determines the enterprise's long-term development prospects (Zhai, et al., 2015). As with most products, marketing strategy is needed when a MEMS technology enters the market. In a dynamic context, decision makers should adapt to the new environment by continuously improving their responses to external environment changes according to the enterprise's own developing phase and resources. In addition, they should develop a more flexible organizational structure in order to adapt to the technological property and the market. Accordingly, we suggest the following hypothesis:

Hypothesis 2: There is a positive relationship between enterprise capacity and the commercialization performance of MEMS technology.

4.1.3 Regional innovation network

For many small and medium enterprises in MEMS sector, their limited resources and capabilities means they have to depend on the regional innovation network to acquire necessary knowledge and support (He & Bacchus, 2010). As Cooke (1998) suggested, a regional innovation network is a system that is established with the help of government, other enterprises, and research institutes. All the enterprises in the network can enjoy various benefits related to R&D, innovation and production. Furthermore, different networks may cooperate and coevolve with each other to provide rich resources for regional enterprises, especially the startups (He, Z., Rayman-Bacchus, L. & Wu, Y.M., 2011). For instance, the network formed by enterprises and intermediaries, banks, venture capitalists, and other institutions establishes a technical innovation service network. The supply of raw materials, product manufacturing, and sales networks established by the enterprise, the upstream suppliers and downstream customers form a market trade network (Ding & Li, 2013). Thus, the regional innovation network is a dynamic and open innovation network system that involves multiple participants and innovative resources. Among them, the four most important agents in the innovation network are universities and research institutions, enterprises, government, and intermediary organizations with innovative functions (He & Rayman-Bacchus, 2010). Any commercialization of technology cannot be separated from the industry's structure, labor productivity, and support, or from the influence of factors such as capital, technology and personnel (Bi, 2015).

As discussed before, MEMS is a complex technology with very long industrial chain, requiring a large number of enterprises and the public sector to provide relevant supplementary technologies, assets, or facilities (Huang & Zhang, 2015). The providers of these resources and their relationships constitute a supportive environment for MEMS commercialization (including supplementary facilities, supplementary technologies and related systems that support the development of emerging technology). As a type of radical innovation, MEMS technology commercialization is particularly influenced by production equipment, financial support, leading enterprises, and scientific research institutions. Accordingly, important factors in achieving MEMS commercialization include the structure of the industry and the resources, personnel, capital, and technology. However, it is difficult for an individual firm to obtain all of these factors, which makes the external supports critical to the commercialization (He et al., 2011). Therefore, we propose the following hypothesis:

Hypothesis 3: There is a positive relationship between regional innovation network and the commercialization performance of MEMS technology.

4.1.4 Market conditions

Market factors primarily include potential demands and competitive relationships. Emerging technology must be combined with market demand to complete the commercialization process (Li & Deng, 1999). As Yin and Wang (2010) declared, one of the greatest uncertainties for emerging technology commercialization is market demand. Although an emerging new technology will always fill the gap between the demand of a niche market and producers, it still faces many challenges during the product developing process (Zhang, 2016). Generally speaking, it is a long road for an emerging technology to achieve popularity. The success commercialization of MEMS technology relies on its acceptance of customers (Zhu et al., 2015). Only those technologies that can meet consumer demand can gain market share and obtain profit, realizing their commercial values. Therefore, the goal of MEMS commercialization is to let the market and consumers accept the related products. In other words, market factors play a decisive role in the commercialization of emerging technologies (Ding & Li, 2013; He & Rayman-Bacchus, 2010). Thus, we suggest the following hypothesis:

Hypothesis 4: There is a positive relationship between market conditions and the commercialization performance of MEMS technology.

4.1.5 Policy and regulation

Policy and regulatory factors can generally be divided into two parts: one involves the government policies that relates to an industry's technology and its development for an emerging technology; another includes relevant laws and regulations that restrict and protect the industry's development (He & Rayman-Bacchus, 2010; Wang & Su, 2016). Although MEMS commercialization has a huge impact on society and economy, it also requires significant initial investment, which may involve very high market risk. Therefore, the state and local government will play an important role in this commercialization process (He et al., 2011; Li & Chen, 2015). For example, government may provide some financial support for R&D and preferential tax to MEMS firms (Zhang, 2016). It is also necessary for local government to proactively establish regional innovation network (Wang & Su, 2016). In addition, to cultivate a fair and transparent marketing environment, related regulations should be established. Accordingly, this study puts forward the following hypothesis:

Hypothesis 5: There is a positive relationship between policy and regulation and the commercialization performance of MEMS technology.

4.1.6 Social environment

Social environment refers to an organization's social context, cultural traditions, values, religious beliefs, educational standards, and customs (He et al., 2011). To some extent, the social environment in which the enterprise is located may affect the economic environment (Zhang, 2016; Ding & Li, 2013). For example, the population will directly affect the market capacity of a country or region (Li & Chen, 2015); age structure plays a decisive role in the type of product offered and how it is promoted (Wang et al., 2015); education and living habits will impact the level of demand for the product (Li & Chen, 2015); the social values affect the business goals, business activities, and product recognition (Rayman-Bacchus & He, 2014). Therefore, in this study, we propose the following hypothesis:

Hypothesis 6: There is a relationship between social environment and the commercialization performance of MEMS technology.

4.2 Questionnaire design

To examine the six hypotheses proposed, We designed a questionnaire to empirically investigate the necessary data and information. In order to ensure the validity and reliability of measurement tools, the questionnaire was designed based on the existing literature including Wang et al. (2015), Wang and Su (2016), Yin and Wang (2010), and Ding D., Li, Z. Hu, &

M., (2013) (for details, please see Tables 4-2 to 4-8). Then, according to the background and purpose of this study, some items were added to form the first draft of the questionnaire. Then the draft of the questionnaire was tested by six senior managers from three MEMS firms and revised based on their various recommendations. We then invited eight experts, including three MEMS technology experts in the companies, two management professors, and three PhD candidates in the School of Management and Economics and School of Automation Engineering, University of Electronic Science and Technology of China, to further improve the questionnaire. Next, we invited two middle and senior managers from an MEMS enterprise to conduct semantic analysis and revision, and then invited a professor from the University of Electronic Science and Technology of China to further revise and review all the items in the questionnaire.

To eliminate the design flaws in the questionnaire before launching the large-scale survey, executives from five MEMS enterprises in Suzhou Nano Science and Technology Park were invited to perform the first pre-test. In-depth interviews and questionnaire were completed by the same person. All interviewees were asked to finish the questionnaire before the interview in order to check whether the questionnaire accurately reflected their thoughts. We carefully observed each respondent’s behavior, recording his or her questions and disagreements. We then had a short conversation with the respondent to ask for their opinions on the questionnaire content and format. Table 4-1 shows the eight MEMS enterprises that contribute to our questionnaire design.

Table 4-1 Enterprises Involved in the Questionnaire Design

MEMS company	Website
1. MEMSIC, Inc.	http://www.memsic.com/
2. Wuxi Sencoch, Inc.	http://sencoch.cn.china.cn/
3. Nano MEMS, Inc.	http://nmems2012.cn.china.cn/
4. NeoMEMS Technologies Inc., Wuxi China	http://www.neomems.com/en/index.asp
5. MEMSensing Co., Ltd	http://www.memsensing.com/index_en.php
6. MiraMEMS Sensing Technology Co., Ltd	http://www.miramems.com/en/
7. Suzhou Good-ark Electronics Co., Ltd.	http://www.goodark.com/
8. Wuxi Zhongke Microelectronics Co., Ltd	http://www.wxzkme.com/

This pre-test primarily examined the time required to complete the questionnaire, the clarity of the textual expression, and the reasonableness of the questions. With respect to specific questions, the pre-survey helped us identify the missing issues related to research content (for example, information on the technology inventor), questions that were prone to cause either misunderstanding or an incomplete understanding because of their complexity (for example, asking the respondents to describe changes in the value chain of the industry to which their enterprises belonged), and questions the respondents were unable or reluctant to answer (such as the definition of the innovativeness of the technology, the enterprise's ownership structure and shareholder information). Based on the feedback from the pre-survey, several open-ended questions were converted into multiple-choice questions (such as the professional background of the enterprise's general manager). The wording and content was clarified for approximately 25 percent of the questions, and 15 percent of the original questions were removed after the discussions, whereas some questions that were not initially included were added (for example, information about the technology inventor, intellectual property ownership, and financing).

After revising the questionnaire, we invited senior executives from seven enterprises at Wuxi Nanotechnology Park to conduct a second pre-survey. This pre-survey showed significant improvement in the clarity of the questions' narration and the respondents' ability to understand the questions. Finally, the formal questionnaire was completed. As shown in Appendix 1, the questionnaire consists of three parts:

Part 1: Basic information about the company. This part mainly collects some profile data on the enterprise regarding its ownership property, location, and human resources.

Part 2: Factors affecting the commercialization of MEMS technology. This part aims to investigate the six factors' impact on MEMS commercialization: technology property, enterprise capability, regional innovation network, market conditions, policy and regulatory factors, and social environment.

Part 3: Commercialization performance. This part collects the data on the performance of sampled MEMS firms.

For reasons related to the respondents' time and convenience, the structured questionnaire used in this study primarily consists of multi-choice questions and a small number of open-ended questions. There were a total of 63 questions and items. The questions were determined based on the following aspects: (1) the previous studies reviewed above (See Questions 10–15; items A1–A4, B1–B3, C1–C4, D1–D5, E1–E4, F2, G2–G4, I1–I4); (2) industry experts who had worked in the field of commercializing emerging technologies for many years; and (3) the author and research team's understanding of the commercialization of emerging technologies.

4.3 Variable measurement

4.3.1 Dependent variables and measurement

Based on the above theoretical analysis and data from the surveys and expert interviews, we found that there are various understandings for the successful commercialization of emerging technologies such as quality improvement, cost reduction, new product development, growth of an enterprise’s assets, personnel or sales. For some large companies, the financial indexes are suitable since they have established comprehensive producing system and explored their markets. However, for the small and medium enterprises, according to Lu (2008), there is a very high risk during any stage in the commercialization of emerging technologies, making risk control critical throughout the entire process. In contrast to the matured technology for which the financial indexes are suitable to measure the performance, we selected two variables – risk reduction and financial performance – as dependent variables to measure commercialization performance. While financial indexes mainly measure the present profitability of the commercialization, risk reduction is used to show a firm’s potential to make a profit in the future (Zhang, 2016).

Table 4-2 Dependent Variable: Risk Reduction and its Indicators (five-item scale)

Number	Indicator	Item		Reference
G1	Process risk	g1	Technology projects in the enterprise can effectively avert process risk	Huang and Zhang (2015)
G2	Team risk	g2	Technology projects in the enterprise can effectively avert team risk	Lu (2008)
G3	Organizational and environmental risk	g3	Technology projects in the enterprise can effectively avert organizational and environmental risk	Lu(2008)
G4	Market risk	g4	Technology projects in the enterprise can effectively avert market risk	Zhu (2015)
G5	Technology demand risk	g5	Technology projects in the enterprise can effectively avert technology demand risk	Zhu (2015)
G6	Technology complexity risk	g6	Technology projects in the enterprise can effectively avert technology complexity risk	Zhu (2015)

As shown in Table 4-2, risk reduction has six indicators: process risk, team risk, organizational and environmental risk, market risk, technology demand risk, and technology complexity risk. Process risk refers to the risk appearing during any stage of the commercialization and team risk mainly describes the risk coming from the team cooperation in a company (Lu, 2008). Organizational and environmental risk represents the risk from the internal organization management or external economy and society (Lu, 2008). Market risk refers to the risk of MEMS application products, and technology demand risk emphasizes the MEMS technological advancement and the possibility of being replaced by other technology (Zhu et al., 2015). Since MEMS is a complicated technology, technology complexity risk describes the uncertainty caused by this complexity.

Table 4-3 shows the four accounting indexes that measure financial performance: return on assets, main business revenue ratio, cash flow return on assets, and return on equity.

Table 4-3 Dependent Variable: Financial Performance and its Indicators (five-item scale)

Number	Indicator	Item	Reference
I1	Return on assets (ROA): $\frac{Net\ \mathrm{Pr}ofit}{Total\ Assets}\times 100\%$	i1 Current technology projects of the enterprise increase return on assets	Fang et al. (2010)
I2	Main business revenue ratio: $\frac{MEMS\ \mathrm{Re}venue}{Total\ \mathrm{Re}venue}\times 100\%$	i2 Current technology projects of the enterprise increase the main business revenue ratio	Zhu (2015)
I3	Cash flow return on assets: $\frac{Monetary\ Fund+Tradable\ Financial\ Assets}{Total\ Assets}\times 100\%$	i3 Current technology projects of the enterprise increase cash flow return on assets	Fang et al. (2010)
I4	Return on equity (ROE): $\frac{\mathrm{Re}tained\ \mathrm{Pr}ofits}{Average\ Net\ Assets}\times 100\%$	i4 Current technology projects of the enterprise increase return on equity	Zhu (2015)

4.3.2 Independent variables and measurement

According to the six hypotheses proposed in this chapter, there are a total of six independent variables: technology properties, enterprise capability, regional innovation network, market conditions, policy and regulation, and social environment. In this study, six variables are measured by the following indicators, as shown from Table 4-4 to Table 4-9.

1. Technology properties

Table 4-4 shows the independent variable technology property and its indicators, some of which require explanation.

(1) Technology innovativeness refers to how difficult it is for a competitor to imitate. Because of the inadequate protection of intellectual property rights in China and the

incompleteness of corresponding laws and regulations, it is very popular for competitors to rapidly imitate original MEMS products (Wang & Su, 2016). However, if the technology or related product is very innovative, making it hard for competitors to take the time to commercialize such technologies, the original innovator can maintain its profits with successful commercialization (Ding D., Li, Z. Hu, & M., 2013).

Table 4-4 Technology Properties and its Indicators

Number	Indicators	Item	Reference
A1	Technology innovativeness	a1 It is very difficult for competitors to imitate in a short time	Ding et al. (2013)
A2	Technology dependency	a2 Subsequent technology innovations can be accomplished independently by a company's R&D department	Zhu (2015)
A3	Entry of alternative technologies	a3 Alternative technologies develop rapidly	Fang et al. (2010)
A4	Technology superiority	a4 Since market introduction, this product has upheld its superiority	Fang et al. (2010)
A5	Technology applicability	a5 The applicable fields of the technology	Ding et al. (2013)
A6	Relationship between inventor and enterprise	a6 This technology has clearly defined intellectual property	Bi (2015)
A7	Technology alliances	a7 This technology can receive support from relevant parties	Bi (2015)
A8	Technology complexity	a8 Related technology is relatively complex	Yin and Wang (2010)

(2) Technology dependency. If technologies that are transferred from universities or research institutes to enterprises cannot be digested and absorbed, enterprises' technological improvement and product upgrades will be affected (Zhu et al., 2015).

(3) Entry of alternative technology. In the MEMS industry, the term "alternative technologies" primarily refers to technologies that use different operating principles to achieve the same functionality. When alternative technologies that are superior in reliability and cost are fully capable of achieving an identical function, there is an increased possibility that commercialization of the technology will fail (Zhu et al., 2015). It is worth noting that even if alternative technologies have not yet reached the commercialization stage, they may eventually replace technology that is currently being commercialized (Fang et al., 2010).

(4) Technological superiority. We primarily measure technological superiority from the point of view of technology advancement (Fang et al., 2010). The criteria for technology

advancement generally include determining a technology’s novelty by browsing the literature, patents, and reports (at home and abroad) related to similar technologies. Technological superiority can confer unique advantages on enterprises (Yin & Wang, 2010).

(5) Technology applicability. When a technology can be extensively applied, the pace of that technology’s commercialization will inevitably be accelerated (Ding D., Li, Z. Hu, & M., 2013).

2. Enterprise capability

During the commercialization process of MEMS technology, strong enterprise capability will enable the enterprise to formulate a suitable strategy and implement it efficiently. The relevant indicators of enterprise capability scale and their items are shown in Table 4-5.

Table 4-5 Enterprise Capability and its Indicators

Number	Indicators	Item		Reference
B1	Enterprise’s production capability	b1	The enterprise ensures the yield and quality of products within the specified time	Bi (2015)
B2	Enterprise’s marketing capability	b2	The enterprise has a competitive marketing team and marketing channels	Bi (2015)
B3	Enterprise’s service capability	b3	The enterprise has sophisticated pre- and after-sales services	Lu (2008)
B4	Enterprise’s resource-acquiring capability	b4	The enterprise can effectively integrate resources (human, financial, material)	Zhang (2016)
B5	Enterprise’s human resources management capability	b5	The enterprise’s human resource management can meet the needs of enterprise development	Yin and Wang (2010)
B6	Enterprise culture’s binding capability	b6	The corporate culture can effectively constrain employees’ behavior	Yin and Wang (2010)

(1) Enterprise’s production capability. After technological achievements pass the laboratory stage and enter large-scale production, producing process management will be critical to the final quality of MEMS products. Here, production capability refers to the ability of the enterprise to yield the quality of products within the specified time.

(2) Enterprise’s marketing capability. Since the enterprise will either enter an existing market to substitute a current product or enter a complete new market, the marketing strategy will be necessary according to the enterprise’s strength and the characteristics of MEMS products. Thus, producing and marketing capabilities are two important indicators with which to evaluate an enterprise’s capability as well as the potential of MEMS products (Bi, 2015).

(3) Enterprise’s service capability. Since MEMS products are sophisticated, after-sales service capability is important to the customer. Therefore, service ability is also important for locking in customers.

(4) Enterprise’s resource-acquiring capability. The complexity of MEMS products necessitates various resources, including materials and skills, making the ability to acquire resources important to the success of commercialization (Zhang, 2016).

(5) Enterprise’s human resources management capability. High-tech companies are quite different from traditional manufacturing ones, in which most of employees are knowledge workers, making it more difficult in human resource management (Yin & Wang, 2010).

(6) Enterprise culture’s binding capability. This refers to the impact of the culture on the firm’s management. As it is nearly impossible to monitor the behavior of all employees in a MEMS manufacture enterprise, good culture can encourage employees to abide by the requirements and regulations of the enterprise to guarantee the quality of the MEMS products (Yin & Wang, 2010).

3. Regional innovation network

The regional innovation network consists of governmental and other institutions that provide specialized training, education, information research, and technical support. It is a collection of enterprises and institutions that are interconnected in a particular field and geographically concentrated (Lu, 2008).

Table 4-6 Regional Innovation Network and its Measurement

Number	Indicator	Item		Reference
C1	Collaboration with research institutes	c1	Level of cooperation with research institutes at the R&D stage	He and Rayman-Bachuss (2010)
C2	Cooperation with financial institutions	c2	Obtaining external financial support in the commercialization process	Wang and Su, 2016
C3	Cooperation with technological mediators	c3	Obtaining support from technology mediator in the commercialization process	Wang et al. (2015)
C4	Gaining support from incubators	c4	Obtaining support from incubators in the commercialization process	He and Rayman-Bacchus (2010)
C5	Cooperation with leading enterprises	c5	Leading role of leading enterprises in this enterprise	Zhu (2015)
C6	Number of suppliers	c6	Scale of the supplier network	Lu (2008)

It includes numerous industries and other entities that are interrelated and play an important role in competition. It often extends downward to sales channels and customers and encompasses not only manufacturers of complementary products, but also industries or companies related to technologies, skills or investments (He & Rayman-Bacchus, 2010; Wang et al., 2015). Therefore, in the questionnaire we sought to include all important components in the network. Thus, the six indicators were chosen to measure the regional innovation network, as shown in Table 4-6.

(1) Collaboration with research institutes. Collaboration with research institutes is especially important at the R&D stage. This cooperation can make use of the advantage of university or other research institutes (He & Rayman-Bacchus, 2010).

(2) Cooperation with financial institutions. Considering the high risk during the commercialization process, it is critical to get external financial support (Wang & Su, 2016), as cooperating with financial institutions is an effective way to obtain the necessary investment (Wang & Su, 2016).

(3) Cooperation with technological mediators refers to whether the enterprise can obtain support from a technology mediator in the commercialization process (Wang et al., 2015).

(4) Gaining support from incubators. Since MEMS is an emerging technology and many companies are small and medium-sized, obtaining support from incubators in the commercialization process is often important at the beginning stage (He & Rayman-Bacchus, 2010).

(5) Cooperation with leading enterprises is especially important during the commercialization process because they may provide suggestions to the other companies. Therefore, cooperating with leading enterprises may increase the chances of survival for small companies.

(6) Number of suppliers. The number of suppliers measures the scale of the supplier network, which may be an important index to show the growth of MEMS industry.

4. Market conditions

As shown in Table 4-7, we selected 11 indicators to measure the market conditions. Those variables include but are not limited to the time required to make a profit in the new market, the degree of demand in the new market, and diversity of demand in the new market.

Table 4-7 Market Conditions and its Measurement

Number	Indicator	Item	Reference
D1	Time required to make a profit in the new market	d1 Either profit-generating time of the enterprise has been determined or the enterprise has been profitable	Yin and Wang (2010)
D2	Strong demand in the new market	d2 Currently, no products meet customers’ demand	Yin and Wang (2010)
D3	Diversity of demand in the new market	d3 Customers’ demand in the new market is simple, and products in R&D can meet that demand	Huang and Zhang (2015)
D4	Rapid growth of the new market	d4 A high-speed developmental stage will appear during the development of the new market	Huang and Zhang (2015)
D5	Competition in the new market	d5 Competition in the new market is not intense	Yin and Wang (2010)
D6	Number of potential customers in the new market	d6 The number of potential customers is huge and can support the continuous development of the enterprise	Zhou and Lv (2010)
D7	Expected profit rate of the new market	d7 The project’s expected profit rate is very high	Zhou and Lv (2010)
D8	Positioning of the user’s knowledge reserve	d8 The new market’s customers need to have a profound understanding of the technology	Yin and Wang (2010)
D9	Customer satisfaction	d9 The new market’s customers are satisfied with the enterprise’s product	Zhou and Lv (2010)
D10	Customer loyalty	d10 The new market’s customers will buy again	Zhou and Lv (2010)
D11	Price-bearing capacity of customers	d11 The new market’s customers can accept the price increasing	Huang and Zhang (2015)

Entrepreneurial enterprises should pay special attention to developing marketing channels, including the traditional and internet ones, and making a suitable strategy in the early stage of commercialization (Zhou & Lv, 2010). Good marketing channels can benefit the technology diffusion, letting more users recognize and accept a new product. Enterprises should actively explore new marketing channels. Moreover, in addition to selling their general products, enterprises should also actively participate in various public projects to promote their new products (Huang & Zhang, 2015). Thus, we considered market condition from the potential market size, customer structure and behavior, and competition situation perspective in order to comprehensively reflect the MEMS market. For example, the potential market size is measured by the indicators D1, D2, D3, D4, and D7; customer structure and behavior is measured by D6, D8, D9, D10, and D11; and competition situation is measured by D5.

Time required to make a profit in the new market refers to the time at which the enterprise can make profit (Yin & Wang, 2010). The most critical stage for the commercialization of emerging technologies is product sales, in which the new products from technology transformation are directly tested by consumers (Yin & Wang, 2010).

(1) Strong demand in the new market measures how strong the demand is in the new market (Yin & Wang, 2010).

(2) Diversity of demand in the new market considers the diversity of a new market. Sometimes the customers' demand in the new market is simple and products in R&D can meet that demand (Huang & Zhang, 2015).

(3) Rapid growth of the new market describes the growth rate of the new market. The high-speed developing trend may provide better survival opportunity to the MEMS enterprises (Huang & Zhang, 2015).

(4) Competition in the new market. The competition in the new market is critical for MEMS enterprises in terms of making a profit, which is related to the sustainable development of all the enterprises in this market (Yin & Wang, 2010).

(5) Number of potential customers in the new market. This predicts the future state of a niche market. If the number of potential customers is large enough to support the continuous development of the enterprise, then this market is a potential profitable market with low risk (Zhou & Lv, 2010).

(6) Expected profit rate of the new market. The expected profit rate of the project is very important for an enterprise to make decisions (Zhou & Lv, 2010).

(7) Positioning of the user's knowledge reserve measures the extent to which the new market's customers understand the technology (Yin & Wang, 2010).

(8) Customer satisfaction refers to the extent to which the new market's customers are satisfied with the enterprise's product (Zhou & Lv, 2010).

(9) Customer loyalty shows the extent to which customers have been locked into the market; for example, whether they will buy repeatedly (Zhou & Lv, 2010).

(10) Price-bearing capacity of customers refers to extent to which the customers in the new market can accept price increases (Huang & Zhang, 2015).

5. Policy and regulation

Table 4-8 Indicators for Policy and Regulation Variable

Number	Indicator	Item	Reference
E1	Government's preferential policies toward the industry	e1 Recently, the state's policies have become somewhat favorable to the industry	Wang and Su (2016)
E2	Technology can benefit from the preferential policy	e2 The technology project can enjoy policy-related preference	Ding et al. (2013)
E3	Financial support from the government	e3 The government provides financial support for this technology	Ding et al. (2013)
E4	Improvement of relevant laws and regulations	e4 Completion of the relevant laws and regulations has been achieved	Wang and Su (2016)

Table 4-8 shows the four indicators for measuring police and regulation, that is, government's preferential policies toward the industry, technology can benefit from the preferential policy, financial support from the government, and improvement of relevant laws and regulations.

(1) Government's preferential policies toward the industry. The government is an important booster to promote and maintain the social entrepreneurship networks by introducing a series of supportive policies, which is critical for enterprises' successful entrepreneurship as well as the sustainable growth of enterprises (Wang & Su, 2016).

(2) Technology can benefit from the preferential policy. For the MEMS industry, at the very early stage of emerging technologies, because commercialization projects require a large upfront capital investment with high market risk, it is necessary for the government to provide some support to control this uncertainty. There are many ways for the government to help the commercialization of emerging technologies to succeed. These include strengthening the construction of scientific and technological-innovation systems, improving infrastructure, establishing institutional systems for investment, or directly providing financing services for emerging technologies (Ding D., Li, Z. Hu, & M., 2013).

(3) Financial support from the government refers to government investment in basic R&D to reduce enterprises' risk (Ding D., Li, Z. Hu, & M., 2013).

(4) Improvement of relevant laws and regulations. The government should implement relevant laws and regulations to foster a favorable environment to the emerging industry (Wang & Su, 2016).

6. Social environment

Table 4-9 Social Environment and its Measurement

Number	Indicator	Item	Reference
F1	Social and cultural compatibility	f1 Whether the society and culture encourage entrepreneurship activities	Zhang (2016)
F2	Completeness of infrastructure	f2 The society already has infrastructure requirements required by the technology	Wang and Su (2016)
F3	Completeness of social services	f3 Whether a social service system has been well established	Bi (2015)

As shown in Table 4-9, we selected three indicators to measure the social environment including social and cultural compatibility, completeness of infrastructure, and completeness of social services.

(1) Social and cultural compatibility. In this study, social environment was treated as an independent factor: the more tolerance the entire society has for innovation and entrepreneurship, the more strongly it encourages people to engage in innovation and entrepreneurship. This type of tolerant environment increases the probability of success (Wang & Su, 2016). Thus, compatibility of society and culture was chosen as one of indicators with which to measure social environment.

(2) Completeness of infrastructure. Commercialization of emerging technologies requires a relatively sophisticated infrastructure that reduces logistics costs and improves work efficiency (Wang & Su, 2016).

(3) Completeness of social services. A good social environment is critical for enterprises with emerging technologies to retain talent, especially high-quality personnel needed for development, because such individuals are more inclined to require a favorable social environment (Zhang, 2016; Yin & Wang, 2010). Therefore, in the questionnaire, we chose completeness of infrastructure and social service to measure the social environment for MEMS technology commercialization.

4.4 Sample selection and data collection

4.4.1 Sample selection

The aim of this study is to investigate the determinants of MEMS technology commercialization in the Chinese environment. To find the sample of empirical study, the list of MEMS enterprises was obtained from the MEMS branch of the China Semiconductor

Industry Association and tried to contact their CEOs through telephones or emails. Eventually, 181 companies were willing to participate in the questionnaire survey and some executives even expressed a desire to offer in-depth interviews.

4.4.2 Data collection

The large-scale survey was conducted in 2015. We built a survey team and sent the questionnaires to 181 MEMS companies. We received 137 responses, of which 112 had fully completed the questionnaires, representing a 62.2 percent response rate. Fifteen questionnaires had missing data, which may be attributed to the companies' commercial confidentiality or other unknown reasons. All questionnaires were sent back through the following channels: (1) face-to-face answers, (2) email, or (3) the post. Thus, the sample size for this empirical study is 112. Appendix 2 shows the enterprise names and their website addresses. Since some of these enterprises are not the listed companies, their financial figures, such as capital and assets, are not published and cannot be collected.

The response rate to a questionnaire is usually related to its length, and written questionnaires typically have a rather low response rate. Our questionnaire had a broad topic and required a long time to complete. Therefore, we took the following measures to improve the response rate: (1) for face-to-face interviews, an appropriate time was chosen when the respondents were free, such as at meeting intermissions or during tea breaks; (2) for the online questionnaire, the respondents were followed up with and reminded via phone calls and emails. On average, two or three reminder emails or one or two reminder calls were needed to collect a questionnaire. The entire investigation lasted more than three months, from September to December, 2015.

4.5 Reliability and validity test

Before the analysis of empirical data, reliability and validity tests have to be done to examine the effectiveness of the questionnaire as well as data collected (Chen et al., 2017). We input the data of completed questionnaires into the Microsoft SQL relational database management system, in two independent databases, and then compared them through software to prevent from entry errors. We then also randomly checked the data to confirm the correctness of all information in the database. In this study, we used SPSS 19.0 to analyze the reliability and validity of all dependent and independent variables.

As exhibited in Table 4-10, the overall coefficient alpha reached 0.876 and the alpha value of each variable is also more than 0.7, indicating that the questionnaire has good internal consistency and the instrument has a certain degree of reliability (Nunnally, 1978).

Table 4-10 Reliability Test Results

Variable	**Coefficient α**	**Variable**	**Coefficient α**
Overall	0.876	Policy and regulation	0.726
Technology property	0.724	Social environment	0.721
Enterprise capability	0.734	Risk reduction	0.713
Regional innovation network	0.765	Financial performance	0.779
Market conditions	0.712		

Validity analysis aims to assess the structure validity of the questionnaire, determining whether the questionnaire needs to increase or decrease the factor, and examine whether each factor need to be adjusted. To test the validity of the questionnaire, “KMO and Bartlett’s Test” in SPSS was used. Generally speaking, the greater the value of KMO (Kaiser-Meyer-Olin) and the more common factors between variables mean that the data is more suitable for validity analysis. A KMO value less than 0.5 means it is not suitable for validity analysis (Li, 2004). When the card square value of Bartlett ball test reached a standard of significance, meaning that common factors exist between the correlation matrix representing the parent groups, this indicates that the data is suitable for validity analysis (Minglong, 2003).

As shown in Table 4-11, the KMO values of all of the variables in the questionnaire were more than 0.7 and their levels of significance were less than 0.01, meaning that the factor analysis results are ideal. These data correlate and are effective for further regression analysis.

Table 4-11 Validity of the Questionnaire

Variable	Technology property	Enterprise capability	Regional innovation network	Market conditions
KMO value	0.861	0.791	0.821	0.713
SIG.	0.000	0.000	0.000	0.000
Characteristic value	3.531	3.342	2.119	2.023
Variance ratio of interpretation	32.211%	11.623%	7.289%	5.489%
	Policy and regulation	Social environment	Risk reduction	Financial performance
KMO value	0.812	0.814	0.721	0.832
SIG.	0.000	0.000	0.000	0.000
Characteristic value	1.879	1.581	1.289	1.131
Variance ratio of interpretation	5.359%	4.851%	4.079%	3.829%

4.6 Summary

This chapter mainly discussed the theoretical hypotheses and research design in the empirical study on the determinants of MEMS technology commercialization. In this chapter, based on the previous literature and the discussion of the characteristics of MEMS technology, six determinants of MEMS commercialization were proposed: technology property, enterprise capability, market conditions, regional innovation network, policy and regulation, and social environment. Corresponding hypotheses were put forward. Then, a questionnaire was designed to obtain the data necessary to examine these hypotheses. Finally, 112 effective questionnaires were collected from Chinese MEMS firms. In addition, the chapter also tested the reliability and validity of the questionnaire data, making the analysis in the following chapter more trustworthy and explanatory.

Chapter 5: Results and Discussions

In Chapter 4, the related hypotheses on determinants of MEMS technology commercialization were proposed and the research design of empirical study was discussed (questionnaire design, sample selection, and data collection). The present chapter focuses on the data analysis and the empirical results will be reported to examine the proposed hypotheses. SPSS 19.0 was used to analyze the empirical data from 112 MEMS enterprises.

5.1 Descriptive statistics

5.1.1 Profile of sampled enterprises

Table 5-1 Profiles of Sampled Enterprises (*N=112*)

Variable		Number of firms	Percentage	Variable		Number of firms	Percentage
Firm's age (year)	>6	7	6.25%	Commercialization stage (may more than 2 stages)	Technology selection	5	4.46%
	5–6	4	5.06%		R&D	48	42.86%
	4–5	11	9.82%		Pilot test	45	40.18%
	3–4	16	14.29%		Mass production	51	45.53%
	2–3	30	26.79%	Technology field (may more than 2 fields)	Design	47	41.96%
	1–2	36	32.14%		Manufacturing	26	23.21%
	0–1	8	7.14%		Assembly and test	28	25%
Number of employees	<10	37	33.04%		Applications	58	51.79%
	10–20	28	25%	Technology source (may more than 2 sources)	Self-development	23	20.54%
	20–30	38	33.93%		Cooperative development	56	50%
	30–50	11	9.82%		Purchased license	21	18.75%
	50–100	5	4.46%		Other	32	28.57%
	>100	3	2.68%				
Assets (unit: 10,000 Yuan)	<100	35	31.25%				
	100–500	45	40.18%				
	500–1000	22	19.64%				
	1000–5000	8	7.14%				
	>5000	2	1.79%				

We analyzed the profiles of the 112 companies that provided valid questionnaires. As shown in Table 5-1, more than half of enterprises are startups with less than three years of existence and only 6.25 percent firms have been in business for more than six years; this shows that MEMS commercialization is still at the very beginning stage in China.

5.1.2 Descriptive statistics of variables

Table 5-2 shows the descriptive statistics of each variable. From Table 5-2, we may find that the average value of each factor and the performance of emerging technologies are greater than 3, except for policies and regulations. In the questionnaire, the value of 3 represents "agreement". Most respondents believe that technical factors, enterprise capabilities, the regional innovation network, the market factors, and the social environment can influence emerging technology commercialization.

Table 5-2 Descriptive Statistics for each Measurement Variable (*N=112*)

Variables	Min	Max	Mean	Standard deviation
Risk reduction	1.00	5.00	3.4998	.66543
Financial performance	1.00	5.00	3.3326	.76547
Technology property	1.00	5.00	3.6439	.63452
Enterprise capability	1.00	5.00	3.1534	.64567
Regional innovation network	1.00	5.00	3.6375	.67684
Market conditions	1.00	5.00	3.6752	.65435
Policies and regulations	1.00	5.00	2.5674	.68253
Social environment	1.00	5.00	3.0167	.55243

5.2 Correlation analysis

Correlation analysis can be used to examine whether there is an interaction among the variables. It does not reflect the causal relationship, but the possibility of interaction between the different variables. Through Pearson correlation analysis, we can preliminarily examine whether the model is established.

Table 5-3 Pearson Correlation Coefficients Among the Variables

Factor		1	2	3	4	5	6	7
1.Technology Properties	Pearson	1						
	Sig.	.000						
2.Enterprise Ability	Pearson	.430**	1					
	Sig.	.000	.000					
3.Regional innovation Network	Pearson	.385**	.672**	1				
	Sig.	.000	.000	.000				
4.Market Conditions	Pearson	.570**	.306**	.502**	1			
	Sig.	.000	.000	.000	.000			
5.Policies and regulations	Pearson	.470**	.232**	.418**	.379**	1		
	Sig.	.000	.000	.000	.000	.000		
6.Social environment	Pearson	.270**	.276**	.333**	.422**	.340**	1	
	Sig.	.000	.000	.000	.000	.000		
7.Risk reduction	Pearson	.479**	.406**	.393**	.491**	.282**	.250**	1
	Sig.	.000	.000	.000	.000	.000	.002	
8. Financial performance	Pearson	.451**	.386**	.533*	.522**	.240**	.139	.386**
	Sig.	.000	.000	.000	.000	.000	.054	.000

Note: ** Correlation is significant at the 0.01 level (2-tailed). * is significant at the 0.05 level (2-tailed)

According to the general standard, the “p” value is the test value, which is the correlation between the existence of the two variables in the sample and the same as the sample. The “r” value indicates the correlation coefficient among the variables in the sample, which indicates the size of the correlation. The results show that the correlation coefficient between the variables ranges from 0.139 to 0.672, meaning moderate and low correlation. From Table 5-3, we can find the following:

(1) Relationship between the technology properties and the commercial performance of emerging technologies

The Pearson correlation coefficient of the technology properties and risk reduction is $r=0.479$ ($p<0.01$), indicating that the technology properties and risk reduction are related. That is, complex technology, good compatibility between business and technology, a reduction in the cost of follow-up research and development, and clear technology knowledge of the property rights can reduce the commercial risks.

The Pearson correlation coefficient of the technology properties and financial performance is $r=0.4451$ ($p<0.01$), showing that the technology properties and corporate performance are related. That is, complex technology, good compatibility between business and technology, a reduction in the cost of follow-up research and development and clear technology knowledge of the property rights can improve corporate performance.

(2) Relationship between enterprise capability factors and performance of emerging technology commercialization

The Pearson correlation coefficient of enterprise capability and risk reduction is r=0.276 (p<0.01), which means that enterprise capability has a low correlation to risk reduction. Therefore, an improvement in enterprise production, marketing, services, access to resources, human resources management capabilities, and a strong cultural binding may help circumvent the risk of commercialization.

The Pearson correlation coefficient of enterprise capability and corporate performance is r=0.386 (p<0.01), which shows a low correlation between enterprise ability and corporate financial performance. Therefore, an improvement in enterprise production, marketing, services, access to resources, human resources management capabilities, and a strong cultural binding may help improve corporate financial performance.

(3) Relationship between the regional innovation network factors and the performance of new technology commercialization

The Pearson correlation coefficient of the regional innovation network factors and risk reduction is r=0.393 and (p<0.01), implying that there is a low correlation between the innovation network factors and risk reduction. That is, the improvement in the ability of the regional innovation network in risk management, decision making, innovation, and coordinated learning may help avoid the risk of commercialization.

The Pearson correlation coefficient of the regional innovation network factors and corporate financial performance is r=0.533 (p<0.01), indicating a correlation between the innovation network factors and corporate financial performance.

(4) Relationship between the market factors and the performance of emerging technology commercialization

The Pearson correlation coefficient of the market factors and risk reduction is r=0.491 (p<0.01), which indicates a correlation between the market factors and risk reduction. Therefore, the market profit time, demand and supply, and user orientation have a large influence on avoiding commercial risk.

The Pearson correlation coefficient of market factors and corporate financial performance is r=0.522 (p<0.01), indicating a correlation between the market factors and corporate financial performance. Market profit time, demand and supply, and user orientation may help improve corporate financial performance.

(5) Analysis of the correlation between policies and regulations and the commercial performance of emerging technologies

The Pearson correlation coefficient of policies and regulations and risk reduction is r=0.282 (p<0.01), which shows a low correlation between policies and regulations and risk reduction. The policy, the enterprise’s enjoyment of preferential treatment with regard to capital or taxes, and the relevant laws and regulations may not have a statistical influence on reducing the risk of commercialization.

The Pearson correlation coefficient of policies and regulations and corporate financial performance is r=0.240 (p<0.01), implying a low correlation between policies and regulations and corporate financial performance. That is, the policy, the enterprise’s enjoyment of preferential treatment with regard to capital or taxes, and the relevant laws and regulations provide little help in improving corporate financial performance.

(6) Analysis of the relationship between the social factors and the performance of emerging technology commercialization

The Pearson correlation coefficient of the social environment and risk reduction is r=0.250 (p<0.01), which shows a correlation between the social environment and risk reduction. That is, the improvement of the social environment may have a certain effect on the risk reduction of commercialization.

The Pearson correlation coefficient of the social environment and financial performance is r=0.139 (p<0.01), implying that the social environment and corporate financial performance are not related. That is, social factors do not play a significant role in improving corporate financial performance.

5.3 Confirmatory factor analysis

Confirmatory factor analysis aims to examine whether the various items can measure a variable sufficiently. Here, factor analysis was used for each variable to check its measurement.

(1) Risk reduction and company financial performance

The risk reduction and company performance factor analysis results are shown in Table 5-4. Risk reduction and the KMO value of the company's performance scale are 0.721 (0.721>0.7), and the chi square value of Bartlett's test of Sphericity is 198.895 (55 degrees of freedom). The level of significance is 0.000, showing that this scale is suitable for factor analysis.

From the perspective of factor extraction, there are two factors of the characteristic value that are greater than 1 – namely, 3.567 and 2.548 – and the explained variances of the factors are 35.668 percent and 25.480 percent, and the cumulative variance is 61.148 percent. The factors extracted from analysis correspond to risk reduction and company performance, respectively.

Table 5-4 Risk Reduction and Company Performance-factor Matrix after Rrotation

Survey item	Factor 1	Factor 2
g1	0.591	
g2	0.629	
g3	0.568	
g4	0.758	
g5	0.589	
g6	0.761	
h1		0.727
h2		0.674
h3		0.684
h4		0.656
Characteristic value	3.567	2.548
Variance ratio of interpretation	35.668%	25.480%

(2) Technology property

Table 5-5 Technology Property- factor Matrix after Rotation

Survey item	Factor 1	Factor 2
a1	0.761	
a2	0.702	
a3	0.798	
a4	0.680	
a5	0.502	
a6	0.647	
a7		0.625
a8		0.612
Characteristic value	4.832	1.084
Variance ratio of interpretation	60.4%	13.55%

The factor analysis of the scale of technology property is shown in Table 5-5. The KMO value of the technical factor scale is 0.861 (0.861>0.7). The chi square value of Bartlett's test of Sphericity is 104.742 (36 degrees of freedom). The level of significance is 0.000, indicating that the scale is suitable for factor analysis. From the perspective of factor extraction, the characteristic values of the two factors are more than 1 (4.832 and 1.084), and the explained variances of the factors are 60.4 percent and 13.55 percent, respectively. The results of the factor analysis extract two factors. From the analysis of factor 1, we know that factor 1 corresponds to the related problems of technological development. From the item analysis of factor 2, we know that factor 2 reflects the technology problems in the related field, which falls outside the scope of this research.

(3) Enterprise capability

The validity analysis results of enterprise ability are shown in Table 5-6. The KMO value of the enterprise capability scale is 0.791 (0.791>0.5). The chi square value of Bartlett's test of Sphericity is 152.469 (66 degrees of freedom). The level of significance is 0.000, which indicates that the scale is suitable for the factor analysis. In terms of factor extraction, the characteristic value of the factor 4.854 is greater than 1. The explained variance of the factor is 40.45 percent, and the cumulative variance is 58.55 percent, which is greater than 50 percent, indicating that the questionnaire has good validity.

Table 5-6 Enterprise Capability Factor Matrix after Rotation

Survey item	Factor
b1	0.732
b2	0.687
b3	0.641
b4	0.546
b5	0.589
b6	0.762
Characteristic value	4.854
Variance ratio of interpretation	40.45%

(4) Regional innovation network

The validity of the regional innovation network scale is shown in Table 5-7. The KMO value of the regional innovation network scale is 0.821(0.821>0.5). The chi square value of Bartlett's test of Sphericity is 152.469 (66 degrees of freedom). The level of significance is 0.000, which indicates that the scale is suitable for factor analysis. In terms of factor extraction, the characteristic value of the factor is 2.172, which is greater than 1. The explained variance of the factor is 18.1 percent, and the cumulative variance is 57.56 percent, which is greater than 50 percent, indicating that the questionnaire has good validity.

Table 5-7 Regional Innovation Network Factor-factor Matrix after Rrotation

Survey item	Factor
c1	0.735
c2	0.642
c3	0.558
c4	0.633
c5	0.622
c6	0.635
Characteristic value	2.172
Variance ratio of interpretation	18.10%

(5) Market conditions

The factor analysis of the market factor scale is shown in Table 5-8. The KMO value of the market factor scale is 0.713 (0.713>0.5). The chi square value of Bartlett’s test of sphericity is 207.644 (36 degrees of freedom). The level of significance is 0.000, indicating that the scale is suitable for factor analysis. In terms of factor extraction, the characteristic value of the factor is 7.456, which is more than 1. The explained variance of the factor is 67.782 percent, corresponding to the market factor.

Table 5-8 Market Condition-factor Matrix after Rotation

Survey item	Factor
d1	0.661
d2	0.602
d3	0.698
d4	0.660
d5	0.502
d6	0.647
d7	0.563
d8	0.678
d9	0.632
d10	0.675
d11	0.665
Characteristic value	7.456
Variance ratio of interpretation	67.782%

(6) Policy and regulations and social environment

The analysis results of the policies and regulations and the social environment scale are shown in Table 5-9. The KMO value of the policy and social environment scale is 0.812 (0.812>0.5). The chi square value of Bartlett’s test of Sphericity is 184.400 (36 degrees of freedom). The level of significance is 0.000, which indicates that the scale is suitable for factor analysis. From the perspective of factor extraction, the characteristic values of the two factors are 3.206 and 1.411, both of which are more than 1, and the explained variances of the factors are 45.803 percent and 20.157 percent, respectively. The cumulative variance is 65.960 percent, which is greater than 50 percent, indicating that the questionnaire has good validity. The results of the factor analysis extract two factors that correspond to the policies and regulations and social environment factors.

Table 5-9 Policy and Regulations and Social Environment-factor Matrix after Rotation

Survey item	Factor 1	Factor 2
e1	0.712	
e2	0.673	
e3	0.722	
e4	0.656	
f1		0.633
f2		0.743
f3		0.714
Characteristic value	3.206	1.411
Variance ratio of interpretation	45.803%	20.157%

Table 5-10 Final items – the Rotation Factor Matrix

Survey item	Component							
	1	2	3	4	5	6	7	8
a1	0.782							
a2	0.731							
a3	0.813							
a4	0.691							
a5	0.611							
a6	0.632							
b1		0.732						
b2		0.687						
b3		0.641						
b4		0.546						
b5		0.589						
b6		0.762						
c1			0.735					
c2			0.642					
c3			0.558					
c4			0.633					
c5			0.622					
c6			0.635					
d1				0.661				
d2				0.602				
d3				0.689				
d4				0.660				
d5				0.502				
d6				0.647				
d7				0.563				
d8				0.678				
d9				0.632				

Survey item	Component							
d10				0.675				
d11				0.665				
e1					0.712			
e2					0.673			
e3					0.722			
e4					0.656			
f1						0.633		
f2						0.743		
f3						0.714		
g1							0.591	
g2							0.629	
g3							0.568	
g4							0.758	
g5							0.589	
g6							0.761	
h1								0.727
h2								0.674
h3								0.684
h4								0.656

After preliminary analysis on some items and eliminate some item, we further analysis the reliability of each variable. From the validity analysis of the technology of variable factors, it is easy to find that the variable has higher reliability after eliminating items A7 and A8, so we eliminated those items in this study. After dealing with the item of variables, we concluded the final scale; the consistency reliability test results are shown in Table 5-10.

5.4 Multiple regression analysis

5.4.1 Multicollinearity examination

In the process of multiple regression, if the correlation among the independent variables is very high, then the least squares method will fail, which means the parameters in the regression equation cannot be accurately determined and the estimated parameters cannot be obtained. In the relevant theory of statistics, this phenomenon is called multicollinearity. Multicollinearity can weaken the independent effect of the independent variables on the dependent variable and influence the explanatory variable coefficient, making accurate calculation difficult. If multicollinearity is very serious, it is possible to affect a theoretical model or a variable selection problem. Thus, before conducting the regression analysis, we need to correct for multicollinearity.

From the variables correlation analysis, we found that many variables were not independent, but that there was a certain degree of correlation. Thus, it is necessary to perform a multicollinearity diagnostics test to evaluate whether there is a serious multicollinearity problem among the independent variables that needs correction.

We adopted “commercial performance” as the response variable and other variables as the explanatory variables to perform a total linear diagnosis of the sample data. We chose tolerance, the variance inflation factor, and the condition index as the three indicators, as shown in Table 5-11.

Table 5-11 Multicollinearity Diagnosis

Explanatory variable	Tolerance	Variance inflation factor (VIF)	Condition index
Technology property	.513	1.949	14.313
Enterprise capability	.478	2.092	16.348
Regional innovation network	.586	1.706	12.411
Market conditions	.520	1.923	10.571
Policies and regulations	.561	1.783	13.573
Social environment	.547	1.828	15.868

Tolerance: The decision coefficient is reduced by 1. The smaller the value is, the more accurate the prediction of the independent variables and the more serious the total linear phenomenon. If the tolerance of a variable is less than 1, then there may be multicollinearity.

Variance inflation factor (VIF) is the reciprocal of tolerance. If VIF>10, then there is multicollinearity.

Condition Index (CI): When 0<CI<15, multicollinearity is not obvious; when 15<CI<30, there is a moderate intensity of multicollinearity; and when CI>30, there is serious multicollinearity.

According to the above standards, there is a moderate intensity of multicollinearity between enterprise capacity and the social environment. Meanwhile, from the correlation analysis, we find that social environment is not related to corporate financial performance. Therefore, in the following regression analysis, we deleted social environment variable to control the multicollinearity problem.

5.4.2 Multiple regression analysis

Regression analysis is a statistical analysis method for determining a quantitative relationship between the dependent and independent variables or multiple independent variables. According to the number of independent variables, it is divided into monadic regression and multiple regression analysis. If regression analysis includes an independent variable and a dependent variable, the relationship of the two factors can be expressed by a straight line; it is then called a monadic linear regression analysis. If the regression analysis includes two or more independent variables, and the relationship between the dependent variable and independent variables is linear, it is called a multiple linear regression analysis.

Table 5-12 Regression Analysis Rresults (Dependent Variable: Risk Reduction)

Factor	Non-standard coefficient		Standardized Regression Coefficient	t value	Sig.
	B	Standard Error			
Technology property	0.335	0.332	0.390	2.760	0.000
Enterprise capability	0.086	0.126	0.099	0.922	0.869
Regional innovation network	0.112	0.213	0.319	1.123	0.023
Market conditions	0.347	0.235	0.375	2.758	0.012
Policies and regulations	0.138	0.126	0.142	1.325	0.679
Constant term	3.578	1.234		4.831	0.000

Table 5-13 Regression Analysis Results (Dependent Variable: Financial Performance)

Factor	Non-standard coefficient		Standardized Regression Coefficient	t value	Sig.
	B	Beta			
Technology property	0.333	0.346	0.352	2.394	0.032
Enterprise ability	0.125	0.368	0.333	3.234	0.011
Regional innovation network	0.118	0.236	0.327	1.535	0.042
Market conditions	0.327	0.098	0.335	1.979	0.036
Policies and regulations	0.089	0.086	0.097	0.083	0.965
Constant term	3.475	2.354		5.212	0.000

We used multiple regression analysis in this study. As the results of correlation analysis show, all five independents variables are related to risk reduction and financial performance. We then used regression analysis to further examine the extent to which these variables affect the performance of MEMS technology commercialization. Tables 5-12 and 5-13 report the corresponding regression results.

From the results of regression analyses in Tables 5-12 and 5-13, we can examine the proposed hypotheses in Chapter 4.

(1) Technology property and commercialization performance

The standard regression coefficients of technical factors on risk reduction and commercial performance are 0.389 and 0.333, respectively, with SIG. values of 0.000 and 0.032, respectively, which means that technology property has a significant impact on the risk reduction and financial performance. Thus, H1 is supported; that is, there is a significant relationship between technology property and the performance of MEMS technology commercialization.

(2) Enterprise's capability and commercialization performance

The standard regression coefficients of enterprise competence on risk reduction and financial performance are 0.099 and 0.011, respectively, with SIG. values of 0.869 and 0.012, respectively, which shows that only the influences of enterprise capability on financial performance is significant. Thus, H2 is not partly supported by our empirical data; that is, there is a significant relationship between enterprise capacity and the financial performance of MEMS technology.

(3) Regional innovation network and commercial performance

The standard regression coefficients of regional innovation network on risk reduction and commercial performance are 0.319 and 0.327, respectively, with SIG. values of 0.023 and 0.042, respectively, which shows that regional innovation network has a significant effect on risk reduction and commercial performance. Thus, H3 is supported; that is, there is a significantly positive relationship between the completeness of the regional innovation network and the commercialization performance of MEMS technology. MEMS enterprises in the regional innovation network can improve business performance.

(4) Market conditions and commercial performance

The standard regression coefficients of market on risk reduction and commercial performance are 0.375 and 0.335, respectively, and SIG. values are 0.002 and 0.036, respectively, which shows that the market factor has a significant effect on risk reduction and commercial performance. Therefore, H4 is supported; that is, there is a significantly positive relationship between market conditions and the commercialization performance of MEMS technology.

(5) Policies and regulations and commercial performance

The standard regression coefficients of policies and regulations on risk reduction and the commercial performance are 0.089 and 0.097, respectively, and SIG. values are 0.679 and 0.965, respectively; that fact that both are more than 0.05 suggests that the influence of policies and regulations on risk reduction and of commercial performance is not significant. Thus, hypothesis H5 is not supported.

5.5 Discussion of empirical results

According to the empirical data, H1, H3, and H4 are supported, while H5 and H6 were not supported, with H2 partly supported. Table 5-14 summarizes our empirical results.

(1) Technology property and market conditions all have significantly positive impacts on the commercialization performance of emerging technology. Therefore, to enhance the commercialization performance of emerging technologies, MEMS businesses should understand the MEMS technology thoroughly, including the technological developing status, technology quality, technology opportunity and technological obstacles. The enterprises should continuously strengthen their technological innovation efforts and maintain a high level of technological superiority while keeping a close eye on the market changes, such as competitors' dynamics, customer demand, and customer satisfaction. It is important that effective measurement should be developed to observe changes in customer demand, especially potential demand, so as to increase the successful commercialization performance. Our findings also highlight the characteristics of emerging technology including the high market uncertainty and technological development roadmap, making it difficult to predict the prospects of a specific product.

(2) Enterprise capability has a certain degree of influence on the commercialization performance of emerging technologies, although it is weaker than the influences of technology property and market conditions. Our findings suggest that there is a significant positive relationship between enterprise capability and corporate financial performance of emerging technology while there is not a significant impact on risk reduction, showing that most risks of MEMS technology are difficult to control or even identify. Once an enterprise's capabilities related to R&D, production, and marketing reached a certain level, it may help the

enterprise quickly complete the early stage of commercialization. However, at later stages, the enhancement of the enterprise's basic capabilities did not guarantee that innovation activities with a low success rate averted risks or enhance performance. Due to the complexity and uncertainty of market demand, it is difficult to make a marketing strategy. Meanwhile, many unpredicted factors, such as overseas competitors and government regulation, may also influence the acceptance of emerging technology products. Faced with an immature market, an individual company may sometimes have to rely on other complementary enterprises in the supply chain to explore the market.

Table 5-14 Test Results of the Hypotheses

Hypothesis	Independent variable	Dependent variable	Empirical results	Conclusion
H1	Technology property	Risk reduction	significant	Supported
		Financial performance	significant	
H2	Enterprise capability	Risk reduction	Not significant	Partly supported
		Financial performance	Significant	
H3	Regional innovation network	Risk reduction	significant	Supported
		Financial performance	significant	
H4	Market conditions	Risk reduction	significant	Supported
		Financial performance	significant	
H5	Policy and regulation	Risk reduction	Not significant	Not supported
		Financial performance	Not significant	
H6	Social environment	Risk reduction	Not significant	Not supported
		Financial performance	Not significant	

(3) Regional innovation network has a significant influence on the commercialization performance of emerging technologies. Developing new products of emerging technology is a very complex process, with increasingly high risk, especially at the final stage. In particular, MEMS technological products require multi-disciplinary crossover and the integration of knowledge from various fields. It is very difficult for individual enterprises to achieve synchronous development in all complementary technologies. In this sense, the traditional linear innovation model is no longer applicable. Therefore, the technological innovation networks from the cooperation among various parties, such as venture capitalists, government, universities, research institutes, and enterprises have particular roles in the commercialization process. One of the distinct advantages for this innovation network is that, in the face of an

ever-changing external environment, it can reallocate resources within the network to decrease the uncertainty in the commercialization of emerging technologies, thus increasing the probability of successful commercialization. As a result of the coordination mechanisms within the network, MEMS companies can obtain the information, knowledge, and funds necessary to engage in innovation activities and achieve resource complementation, benefit-sharing, and risk-sharing among the parties. Through the interviews, we also found that successful MEMS companies such as Wuxi Meixin, Wuxi BEWIS, and Shenzhen Ruishen are in the MEMS regional innovation network. In the regional innovation network, the operating costs of enterprises are reduced, and the probability of success of commercialization is enhanced through the division of labor and cooperation, knowledge spillover, and transfer.

(4) Policy and regulation and the social environment have no significant impacts on the commercialization performance of emerging technologies. In terms of policy and regulation, the development pace and changes in market structure of emerging technologies have made it difficult for governments to make effective industrial policies to enhance the commercialization performance of emerging technologies. At the same time, the complexity of MEMS technology makes it hard for governments to provide detailed regulations to control the risks that enterprises faced. Thus, they were unable to begin to have a significant influence on risk reduction and performance improvement in commercialization performance. In addition, in this study, most of questionnaire answers returned from overseas and have been working in science parks designed by the government. Their homogenous background may lead to the insignificant effect of social environmental factors on the commercialization performance of emerging technologies. More importantly, since nearly all the MEMS products are intermediate ones, it is difficult for the respondents to know whether the demographic factors, like age structure and living standard, have any influence on the commercialization of MEMS technology.

5.6 Summary

This chapter has reported the empirical study results. It has also provided some descriptive statistical data from the field survey and used the Pearson correlation to examine the correlation between six independent and two dependent variables. We then employed multiple regression analysis to measure the extent of each factors impact on MEMS commercialization performance. Empirical results show that the proposed hypotheses H1, H3, and H4 were supported, with H2 partly supported, whereas H5 and H6 were not supported. Therefore, according to this study, we may conclude that technology property, market conditions, regional innovation network, enterprise capability are the main determinants that have significant impacts on the commercialization performance, while policy and regulation, and social environment have no significant effects.

This page is deliberately left blank

Chapter 6：Case Study of MEMS Commercialization: Wuxi BEWIS Sensing Technology Company

In Chapter 5, we conducted an empirical study to investigate the determinants of MEMS commercialization in China. Our findings suggest that technology property, market conditions, regional innovation network, and enterprise capability are the determinants for emerging technology commercialization. However, this empirical study examines the extent to which these determinants affect MEMS commercialization. In this chapter, a case study is employed to further explore how the determinants influence the commercialization process at the different stages. As discussed previously, studies on the commercialization of emerging technologies are still in their infancy, especially in China. Therefore, this chapter takes Wuxi BEWIS Sensing Technology Company as a case to analyze the roles of various determinants on MEMS product development.

6.1 Objective and method of case study

The overall design of a case study includes the following four aspects: (1) clarifying the objectives of the case study, (2) research methods, (3) sample selection, and (4) research process (Bassey, 1999). In this section, to the first step of case study, the objective and corresponding method are discussed.

6.1.1 Objective of the case study

Enterprises in the MEMS industry vary in the different commercializing stages; some are startups or in the R&D phases, while others may finish pilot testing and move to the mass production stage. To better guide their product development process, thereby increasing their success rate, it is important to explore the roles of these determinants on the four different commercialization stages. Therefore, the purpose of this case study is to explain how the determinants proposed by the empirical study in Chapter 5 influence the entire MEMS commercialization process, in detail, including:

(1) how the determinants including technology property, market conditions, regional innovation network, and enterprise capability affect the product selection stage during emerging technology commercialization;

(2) How these determinants affect the R&D stage during emerging technology commercialization;

(3) How these determinants affect the pilot test stage during emerging technology commercialization; and

(4) How these determinants affect the mass production stage during emerging technology commercialization.

6.1.2 Research method

Among the most popular case study methods are the exploratory case study method, the descriptive case study method, and the explanatory case study method (Bassey & Case, 1999).

Table 6-1 Comparison of Three Types of Case Study Methods

Type	Exploratory case study	Descriptive case study	Explanatory case study
Application	Proposing hypotheses	Describing a case	Explaining the reality
Objective	Finding a new theory	Storytelling, painting the picture	Verifying a theory

Source: Bassey (1999)

As Table 6-1 shows, the objective of an exploratory case study is to form a preliminary understanding of an issue that will serve future studies. Exploratory case studies often bypass existing theoretical systems and use perspectives, hypotheses, ideas, and methods to resolve management phenomena. Descriptive case studies generally start with the “description” of a theory, and the “described theory” can cover the case under study in depth and generate a set of causal hypotheses and propositions. Explanatory case studies focus on applying existing theoretical hypotheses to understand and explain organizational activities in reality (Bassey, 1999).

The research methods can be divided into single-case and multi-case research methods. Single-case studies are mainly applied to falsify a particular theoretical hypothesis and to verify a particular theory with a relatively narrow scope, making it possible to analyze the management concepts and problems hidden in the case in detail and depth. However, the narrow scope of single-case studies makes them unsuitable for constructing and testing the theoretical framework for new technology commercialization. Multi-case studies usually rely on a single theme or theoretical framework to conduct an in-depth analysis of several separate cases and draw theoretical conclusions and empirical results. The advantages of multi-case studies are reflected in their ability to rely on the same study theme and to systemically and comprehensively demonstrate cases with diverse backgrounds based on analyses of interdependent within-cases. Their primary disadvantage of this method is that the complexity of cross-case analysis in multi-case studies is much higher, and rigorous design and coding are needed to ensure its effectiveness (Bassey, 1999).

In the present study, since the case study is complementary to the empirical study, explaining how the determinants affect the technology commercialization rather than developing a novel theory or model, an explanatory single-case is used to achieve the above-mentioned goal. The empirical study described in Chapter 5 shows that four factors – technology property, regional innovation network, market conditions, and enterprise capability – have significant relationships to the performance of MEMS technology commercialization. To further explain how they worked in reality, a typical case will be chosen to explain their real impacts.

6.2 Case selection and background

6.2.1 Case selection

The quality of a case study depends on the selected cases and analysis techniques. Only when the sample selection follows the principle of “typicality” can it comprehensively clarify the issues under study with the limited number of cases. A typical case can clearly reveal the management mode hidden behind real-life behavior (Eisenhardt, 1989). In this study, we chose Wuxi BEWI Sensing Technology Ltd. (BEWIS) as the case for the following reasons:

(1) BEWIS is one of the largest and most technologically advanced companies and has experienced the whole MEMS commercialization process. This study focuses on the commercialization of emerging technologies, requiring the selected enterprise to complete the entire process, from MEMS technology choice to mass production, independently. BEWIS has relied on its ability to conduct R&D and commercialize new technologies and accomplish start-up, growing and thriving in the process of commercializing emerging technologies. Furthermore, new products launched by BEWIS have the potential to substantially impact on the industry. During this process, BEWIS has gradually established a comprehensive management system and it is also embedded in an innovation cluster, all of which are typical in the Chinese context, representing the developing trajectory for nearly all Chinese emerging firms.

(2) The convenience of data collection. As the founder of BEWIS, the author is familiar with the enterprise's history, products, and business strategies and can collect all necessary data easily and accurately, making this case study real and highly reliable.

6.2.2 Data collection and analysis

6.2.2.1 Approach for data collection

To obtain complete and adequate data, the data collection step is critical and provides the basis for the case study's reliability and validity. In general, the data are collected through various methods such as interviews, documents, archives, direct observations, participant observations, and physical evidence (Yin, 1984). The most commonly used methods are the following:

(1) Observation: Observations are made through participation in relevant company activities and meetings and informal communication with the employees by the research staff; investigators deepen their understanding of the issues through personal contact. In this study, the observation method was applied through formal participation in management activities within the enterprise; attendance at important meetings involving corporate decision making; and browsing company archives, meeting minutes, financial data in various development stages. By collating the enterprise's internal data, the investigators obtained a more profound understanding of the entire commercialization process of BEWIS. These observations and experiences provided more opportunities for the investigators to further address the pattern of the commercialization of emerging technologies.

(2) Documentation: As an important supplement to interviews and observations, the documentation method is achieved by collecting relevant internal documents, annual reports, project documentations, and specialized information databases from the enterprise; it is a simple method in terms of implementation. However, faced with a vast amount of data and information, investigators must subsequently fulfill a high data-analysis requirement. Case studies on the commercialization of new technologies in entrepreneurial companies combine the observation and documentation methods to collect the data, through which the investigators can comprehensively examine issues and improve the validity of the test on theories by gathering an array of data from various sources.

In this case study, the documentation method was primarily applied by collecting BEWIS reports and information in specialized databases and online. Successful commercialization of new technologies by entrepreneurial companies is the result of the entrepreneurs' unique professional background, management philosophy, and adventurous spirit. Therefore, documents relevant to BEWIS internal management and external collaboration, along with interviews, news reports, and information related to entrepreneurs in various fields were rigorously collected to understand the entrepreneurs' mindset – from their unique perspective – in the face of various uncertainties in the process of the commercialization of emerging technologies. That mindset enabled the entrepreneurs to lead their teams to break through "bottlenecks" and realized leaps in progress.

6.2.2.3 Data analysis

Data analysis is the process of confirming and testing data and information processes that are related to typical cases. Yu (2004) stated that the data analysis process includes three steps. First, by gathering and separating information, the acquired data are comprehensively registered and further classified based on the analysis strategy. Second, a detailed description of major issues is presented in which the issues are appropriately portrayed and explained based on a particular method. Third, sufficient evidence and necessary data are provided. It is through this data analysis method that the present case study's primary theoretical models were confirmed.

Data analysis is the most critical and the most difficult part of a case study. The effectiveness of data analysis is directly determined by the investigators' research experience and ability to think logically, as well as the selected analysis method. Data analysis and data collection processes are often implemented simultaneously, and recursive data collection and analysis allow some hypotheses to be gradually validated with data and also to support the next round of data collection. Commonly used methods of data analysis include longitudinal analysis and critical-event technique. In the present study, we combined longitudinal analysis and critical-event technique to improve the case study's rationality, effectiveness, and feasibility.

In a longitudinal analysis, the contents of historical activities that are related to the selected case are coherently organized and analyzed in chronological order, and its development trajectories are exhibited through the time dimension, activity tracking, and analysis of changes. The critical-event technique embodies the belief that identifying and describing critical events that are of strategic importance or represent a turning point in the selected case development processes reflects the major events experienced by the select case in management activities. In the present study, the analysis of the commercialization of new technologies of entrepreneurial enterprises was based on the entrepreneurial processes of

BEWIS and the refinement of the critical events in the commercialization processes, which effectively summarized the key research topics and milestones of the study’s core issues. Thus, the data analysis of BEWIS employed in this study was well suited to the comprehensive applications of longitudinal and critical-event techniques, which also requires the investigators to complete the data acquisition on the start-ups’ entrepreneurial stage and critical moments in the data-collection phase so that the analysis is complete and adequate.

6.3 Background of Wuxi BEWIS Sensing Technology Ltd. (BEWIS)

BEWIS, located in Wuxi, in the Jiangsu Province in eastern China, is a high-tech enterprise specializing in the MEMS design and manufacture of inertial posture sensors with products such as an angle sensor, tilt switch, and electronic compass. Founded in 2010 by a senior engineer and a professor at Peking University after seven years of development, BEWIS has completed both technological R&D and the promotion of MEMS new products and is now in the initial stage of mass production.

Currently one of the largest MEMS companies in China, with branches in Hong Kong, Dalian, Shaoxing, Ningbo and Xiamen, the company’s core business areas cover integrated inclinometer sensors system, digital compasses, accelerometer, navigation altitude system, fiber-optic gyroscopes, and inertial navigation systems. Their MEMS products have wide applications in high-precision laser equipment levels, engineering machinery and equipment leveling, rangefinders, measurement pitch angle of directional satellite communications antennas, ship sailing posture measurement, shield pipe jacking applications, dam detection, geological equipment tilt monitoring, artillery barrel early-launch angle measurement, radar detection of vehicle platforms, satellite communications, vehicle posture detection, which relates to the construction, automation, aerospace, medical, academic, system surveillance, and agriculture industries.

BEWIS has been a critical enterprise in the MEMS industry, in which its ultra-precision angle sensor is a world-leading product. In 2014, BEWIS was awarded the Innovation Fund for SMEs from the Chinese Ministry of Science and has been one of the fastest growing MEMS companies in recent years. To be one of the most technologically advanced companies that specializes in MEMS technology, BEWIS currently also provides technical and sales services in many countries, including Germany, United Kingdom, Spain, Japan, South Korea, and the United States. The international staff from the United States, Hong Kong, Japan account for 10 percent of all employees, while over half of employees hold Master's and/or doctoral degrees. BEWIS also employs several IEEE fellows, Chinese Academy of Sciences Fellows, "Hundred Talents" selected candidates, 973 chief scientists, and two candidates from "Thousand Talent Plan in China" experts. BEWIS has been in charge of many national projects, including the Science and Technology Innovation Fund Support Program, Jiangsu Province Science and Technology Support Program, National Scientific and Technological Projects, China's high-tech Research and Development Program (863 Program), the Hong Kong Innovation Technology Fund Support Program, Semiconductor Particles (National Plan) Support Program, and the National Natural Science Foundation Support Program.

6.4 Stages of MEMS commercialization in BEWIS

In August 2009, the State Council approved the establishment of the National Sensor Network Innovation and Demonstration Zone and the National Sensing Information Center in Wuxi. In 2010, China issued its "Twelfth Five-Year Plan", which officially listed IOT as a next-generation strategic emerging industry. Thus, the application and development of IOT has been further promoted. As a representative of a new generation of IT, IOT indicates the direction of future development. Many companies have already started to develop and invest in IOT industry to obtain first-mover advantages in this rapidly expanding market. On August 18, 2010, Engineer Wang Chunbo and Professor Shi Guangyi decided to establish a company focusing on MEMS technology (BEWIS) with initial registered capital of 500,000 RMB, with each having a nearly 50 percent share. After seven years of development, BEWIS has initiated its own MEMS commercialization system and business model. It has built strategic partnerships with many external parties through extensive collaboration. In addition to being a designated supplier to large companies such as Siemens, China Ordnance Group, and Aerospace Science and Technology, it has also become a pioneer and market leader in China's inertial attitude measurement market. Through the critical-even analysis, we can divide the whole commercialization process into the four stages shows in Figure 6-1: technology (product) selection, R&D, pilot test, and mass production. According to Li (2012), the business model of BEWIS is development cooperation, in which the enterprise collaborated with Peking University at the early R&D phase.

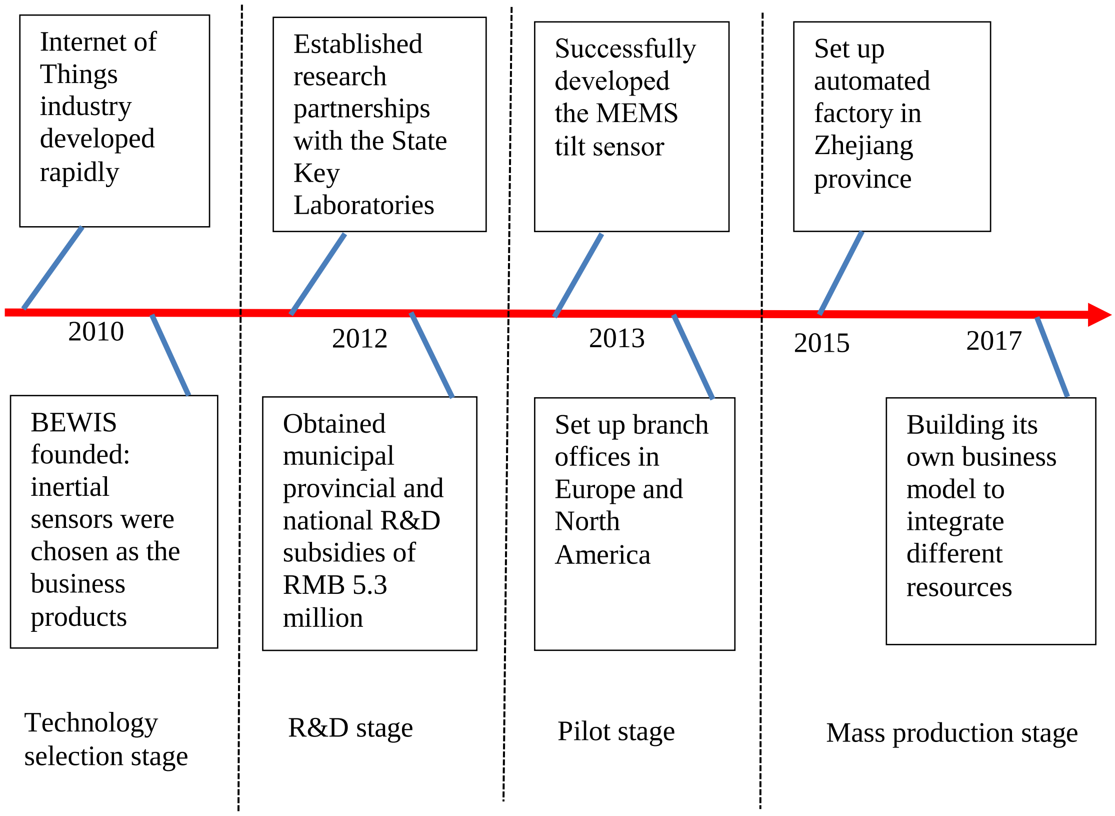

Figure 6-1 Stages of MEMS Commercialization in BEWIS

6.4.1 Technology (product) selection stage (2010–2011)

After BEWIS was established, the first task was to select a product from numerous MEMS applications. Through an extensive survey, the two founders, Mr. Wang and Mr. Shi, found that the rapid development of IOT industry had generated strong demand for sensors. At that time, however nearly all the high-level sensors were imported from foreign developed countries. Wang and Shi then decided to position the business on MEMS tilt sensors, electronic compasses, and attitude heading reference systems. The company’s income would mainly depend on selling the sensor module to national defense and military entities, manufacturers of construction machinery-related equipment, research institutes, manufacturers, of medical equipment.

As discussed regarding the characteristics of MEMS commercialization, the development of the MEMS products in BEWIS quickly faced a bottleneck. The R&D of products was heavily dependent on specialized equipment because of the production and test processes, demanding a large capital investment. Because BEWIS was a start-up, it was impossible to buy all of the necessary equipment on its own and it was imperative to find a suitable business location. After the investigation, BEWIS eventually found a suitable location in Wuxi, where there was some industrial basis and a variety of public service platforms along with well-established supporting policies.

BEWIS is a high-tech private enterprise that was supported and promoted by government funds. It received 400,000 RMB in support from the Wuxi local government for start-up capital and the free use of a 100-square-meter R&D space for three years. As Prof. Shi said in his interview, the strong support from local government was critical for BEWIS's initial survival. Since 2005, the local government has viewed the introduction of overseas talent as an important way to implement the strategy of “Growing the City with Talents” and has launched “Program 530” to take advantage of the benefits of overseas talent. Moreover, the local government has made a plan to attract introduction of entrepreneurial leadership talent to overseas Chinese returnees. The industry chain, the talent environment and the government's support of various aspects were all key to the early development of BEWIS.

6.4.2 R&D stage (2011–2013)

The inertial sensors developed by BEWIS were forward-looking MEMS intelligent systems, which required close interaction and cooperation with all parties related to the industry chain so that dispersed resources could be gathered and concentrated to achieve large-scale innovation. In 2011, BEWIS collaborated with the State Key Laboratory of Nanometer and Micron Encapsulation Technology and the Research Center for the Development of IOT in Jiangsu Province. The company made full use of its device platforms, which were worth $100 million. With respect to product development, BEWIS took advantage of innovative products and was awarded numerous government financial supports, including two Wuxi Municipal Science and Technology Innovation Fund awards totaling 160,000 RMB, one Jiangsu Province Science and Technology Industrial Support Fund of 1.3 million RMB, two National Innovation Funds and matching funds of 1.92 million RMB, a special IOT award for 320,000 RMB, and several million RMB from various types of talent-related funds. BEWIS closely followed the government's development programs and achieved rapid growth in financing by relying on governmental investment.

In the R&D process for the MEMS inertial sensors, BEWIS achieved effective synergies with sensor-chip companies, the government, universities, research institutions, and users. In the upstream industry chain, sensor-chip companies had mature hardware and algorithm solutions, which enabled BEWIS to integrate and produce sensor modules. In the downstream industry chain, military and civilian markets had different market demand characteristics, requiring BEWIS to develop suitable sensor products based on the needs of the company. In terms of industry support, the government, universities, and research institutions were able to provide adequate financial, policy, and intellectual support to help BEWIS overcome difficulties with R&D and pilot production. Because of the rapid development of networking technology, the loosely coupled relationships between BEWIS and external collaboration parties enabled BEWIS to maintain innovation and resource integration.

6.4.3 Pilot test stage (2012–2015)

Since R&D and pilot tests are often intersecting activities with reciprocal feedbacks and interactive effects, it is difficult to separate them completely. In October 2012, BEWIS initiated R&D for tilt sensors. Like most start-up companies with emerging technologies, BEWIS relied on the supply of accelerometers, the core chip in tilt sensors, from upstream companies. Combining these chips with its own capabilities in digital circuit design and interface driver software design, it took only six months for BEWIS to complete its R&D. Because BEWIS already had experience in design, its first R&D attempt proved a success. After less than two months of testing and correction, volume sales were initiated in mid-2013.

In January 2013, BEWIS collaborated with Professor Wu from the City University of Hong Kong to set up another joint-venture company (Company S), which specializes in the R&D of next-generation sensors with carbon nanotube materials. Because Company S was foreign-funded, it was conducive to international business. Therefore, BEWIS split its export business with Company S. Because the tilt sensors were launched relatively early and BEWIS adopted a unique temperature-compensation algorithm, the performance of the products was superior, and their sales led the market with nearly 10,000 sets of products by the end of 2014.

6.4.4 Mass production stage (2015–present)

In June, 2015, BEWIS launched its dynamic angle sensor series, electronic compass series, and attitude heading reference system series in dozens of models in four major series. Its customers include several international corporations, such as SIEMENS. Currently, its market is showing rapid growth and the biggest challenge for BEWIS is quality control in mass production. BEWIS’s product line-up is far superior to those of its competitors. In the first half of 2015, BEWIS became China’s top brand in the tilt sensors sector. More importantly, from the feedback of customers, BEWIS largely extended the market and finally found its accurate position in the MEMS industry.

Faced with various competitors, BEWIS has established long-term several cooperation relationships to conduct MEMS continuous innovation and cultivated talents with Peking University, Beijing; University of Arkansas, USA; City University of Hong Kong; and Zhejiang University and Xiamen University in China.

BEWIS has built its own business model. It is headquartered in Wuxi and takes advantage of the public-service platforms of the Chinese R&D Center for IOT to conduct the tests, while the manufacturing and PCB plate and surface mounting are outsourced to nearby contract companies. The products are sold to the world through the company's own marketing channels, which not only reduces the costs of production inputs but also makes it possible to take control of key technologies, avoiding the patent infringement issues that plague R&D companies. In addition, operating costs are lowered by the separation into four industrial sections. This has proven to be a great advantage for BEWIS and the most critical factors in the success against the competition.

6.5 Determinants of MEMS commercialization in BEWIS

6.5.1 Technology pproperty and market conditions

From the case analysis of BEWIS, we can see that the market conditions technology property were the most important determinants for the first product selection stage. In this case, the huge demand resulting from the emergence of IOT industry provided very good opportunities for BEWIS. Unlike mature technology that is widespread, an emerging technology often involves the coexistence of multiple branches, plans, or designs. Additionally, the most important feature of emerging technologies is the uncertainty of their market outlook. On one hand, any one of a variety of competing technologies has the potential to either alter the existing market or create a new market. Therefore, to avoid missing market opportunities, it is better to invest in various products simultaneously under the condition of sufficient resources. On the other hand, an emerging technology may be unacceptable to the market. Thus, commercialization process, it is important to find a niche market and continue to check and extend this niche market. In the BEWIS case, even at the initial product selection stage, the founders had a very clear marketing strategy, focusing on national defense and military entities, manufacturers of construction machinery-related equipment, research institutes, and manufactures of medical equipment. They eventually extended the niche market to wider customers. Of course, to identify this demand at the beginning and make a correct decision depended largely on the entrepreneurs' characters, insights, experience, and knowledge.

The case of BEWIS also shows that, for emerging technology such as MEMS, the technological characteristics can affect the marketing strategy as well as the production process. For BEWIS, most of the products are customization, making small-scale flexibility production popular, which largely increased the product cost and the difficulty of quality management. Meanwhile, since emerging technology develops quickly and always has a comparatively short life-cycle, the enterprises must continue innovating in order to meet the changing speed and maintain its advantages. From this perspective, the emerging technology and its market often coevolve to promote the development of each other.

6.5.2 Regional innovation network

Based on BEWIS, it is easy to find that regional innovation network played a key role in R&D and pilot test stages of MEMS commercialization. In countries that have a developed integrated circuit (IC) industry, the cluster-innovation network is an important feature when promoting the IC industry (Zhu et al., 2015; Wang & Su, 2016). The cluster innovation network usually consists of research institutes, public service platforms, competitive and non-competitive enterprises, leading enterprises, government public-service platforms, financial institutions, and service agencies; dynamic innovative networks are formed among the components.

In BEWIS, at the technology-selection stage, the role of the cluster-innovation network in promoting commercialization was to create knowledge spillover within the relationships among enterprises and research institutes. In the R&D and pilot stages, the role of the cluster-innovation network was to reduce the costs of constructing specialized pilot platforms in the commercialization process. It is usually impossible for enterprises to complete the technical processes from R&D to pilot production to mass production and value creation without the support of MEMS engineering platforms providing small-scale, personalized services. Specialized pilot platforms provided specialized MEMS R&D and OEM for start-up companies, including MEMS R&D, prototyping, manufacturing, intellectual property (IP) authorization, technical consultation, and testing and packaging services. Companies could also execute centralized management and integrated operations based on patents and gradually form a value-added patent portfolio, thereby solving software problems at the commercialization stage. During the mass product stage, regional innovation networks may help form a producing network.

This case study also shows that, in nurturing emerging technologies and developing new industries, effective, government-built development platforms are the key to promoting MEMS commercialization in terms of cultivating talent and teams. The recruitment of leading talent and research teams is another advantage of an industrial cluster. A public R&D platform supports the aggregation of R&D factors; participants can use such a platform to share laboratories' resources and establish contact with partners and sources of innovation. As an important platform for MEMS industries, the Chinese R&D Center for IOT in Wuxi has constructed various refinement platforms – including an R&D platform, a technology transformation platform, a project platform, a financing platform, and a public service platform – to serve MEMS industries at different development stages. These platforms provide services to MEMS researchers or enterprises in different phases. In particular, the external incubation and development conditions, and the construction of public service platforms can provide startup enterprises with much-needed public services such as financing, intellectual property protection, project reporting, talent recruiting, finance, and management.

6.5.3 Enterprise capability

During the development of BEWIS, enterprise capability is one of the most important determinants. Regardless of what stage it is in, the entrepreneurs always had clear strategies and could implement them within the highly uncertain environment. At the initial product selection stage, this capability is reflected in the ability to find a niche market. Later, in the R&D and pilot test stages, BEWIS could make full use of all external resources and conditions to finish the product development. BEWIS enhanced its management by improving its operations and effective incentives. It had formed effective external collaborations and increased its commercialization capabilities. Supporting industries shore up relevant technologies, human resources, markets, industries, and products from both upstream and downstream segments that are associated with an enterprise's production, management, and sales in the region. Well-developed supporting industries enable enterprises in the region to generate external economic benefits through specialization and close-range cooperation. BEWIS took advantage of the facilities of supporting industries to provide raw materials and other resources to leading enterprises and pillar enterprises in the region. The company's goals were to engage in the commercialization of emerging technologies and also to occupy a high position on the industry chain at the very beginning of the start-up.

During the mass production stage, BEWIS has established an efficient production line. Its vision is to be the world-leading high-quality equipment and process solution provider in SENSOR. BEWIS has built comprehensive quality and reliability assurance and control systems into all its processes and services, from technology development to production. In addition, BEWIS has various labs and analytical tools to perform chemical and material analysis, product failure analysis, and yield enhancement, reliability qualification and monitoring, as well as tool calibration.

BEWIS has passed the ISO9001, CE, and ROHS certifications. Product and service quality and market competitiveness have been promoted according to the consistent improvement of these systems. To ensure a consistent level of quality and flexibility for our customers, BEWIS uses an “On Line Test” concept whereby all equipment and process recipes are tuned to achieve the same calibration accuracy for same type of sensors. To achieve high-quality delivery services, BEWIS integrates quality standards and procedures through the entire operations chain, including:

(1) Built-in reliability in technology development and production processes

(2) Process reliability monitoring during manufacturing

(3) Strict quality control of incoming raw materials and outgoing materials

(4) Stringent monitoring of in-line processes

(5) A built-in reliability database (Built-in Reliability Diagnosis System, or BIRDS) that tracks soldering, package, and product level reliability through the development, qualification, and production stages.

(6) Implementing statistical process control (SPC) and module reliability control in mass production for fast feedback and continuous improvement.

The pursuit of quality is a continuous effort at BEWIS. To maintain a high level of quality in the work and processes, BEWIS emphasizes clear and concise process definitions, standardized procedures, well-defined responsibilities, detailed document of customer requirements, module performance and production analysis, and a high level of customer transparency. As part of the quality management system, BEWIS is working hard to ensure:

(1) Customer requirements and internal quality standards are fully communicated, understood, and adhered to;

(2) On-time delivery of high-quality services;

(3) Improvement in service and product quality and reliability through the implementation of PDCA (plan, do, check, act) steps, together with internal and external customer feedback.

To protect the organization’s core business and improve competitiveness, BEWIS maintains a comprehensive information security management system, including three basic components: employee management, information technology application, and establishment of rules and policies. As part of its Information Security Management System, BEWIS continuously works to ensure that it:

(1) Always prioritizes the security of customer information;

(2) Properly protects all information assets;

(3) Conducts risk management to ensure business continuity and minimize losses if the information system is affected.

Except for the four determinants discussed above, we can see from the BEWIS case that government plays a critical role in the commercialization of emerging technology – even though this has not been statistically proven by the empirical study in Chapter 5 – particularly at the early stages, including product selection, R&D and pilot test. From macro emerging IOT industry to various financial supporting projects, both of BEWIS’s founders admitted that without the financial support of local governments, BEWIS could not have passed through the startup stage. Meanwhile government has played an important role in planning and guiding supporting industries to effectively balance the relationships among pillar industries, leading industries and emerging industries in the region. It has also consciously introduced MEMS industry chain-related enterprises so that start-up companies involved in MEMS technology commercialization can continue to seize various opportunities and achieve sustainable business development.

6.6 Implication of the case study

In the previous section, we discussed the roles of various determinants on MEMS technology commercialization. Table 6-2 summarizes how these factors impacted the product development process in BEWIS.

(1) The necessary resources and conditions are quite different at the different stages. Even the same factors also exert different impacts on technology commercialization. Thus, it is necessary to analyze the market and formulate strategy according to the external context and internal capability. The external environment is particularly important in order to discover new market demand. The emergence of IOT industry indicates the future direction of emerging technologies and the field of social needs. In particular, after the launch of the revitalized manufacturing plan “Made in China 2025”, a new generation of information technology has been developed. BEWIS has become the leader in the high-quality sensor industry in this new wave of technology. Therefore, how to discover and grasp the opportunity from outside is key to emerging technology commercialization.

Table 6-2 Main roles of Determinants on MEMS Commercialization in BEWIS

Determinants	Stage 1: Product selection	Stage 2: R&D	Stage 3: Pilot test	Stage 4: Mass production
Market conditions	Provide demand for MEMS technology	Provide customer demand and competitor information	Provide feedback from the customer and promote continuous improvement	To examine the acceptance of products and to provide some new markets
Technology properties	Affect the choice due to its high uncertainty	Affect the difficulty and risk of R&D	Affect the difficulty and risk of product	Client customized, high cost, rapidly changing
Regional innovation network	Provide the knowledge spillover	Provide necessary hardware and knowledge supports	Provide necessary hardware and knowledge supports	Provide comprehensive supply chain, talent, and skilled workers
Enterprise capability	Find niche market	Make use of all resources and conditions	Integrated all resources	Flexible production, quality management, continuous innovation
Policy and regulation (not supported by empirical study)	Financial support	Financial and preferential policies	Financial and preferential policies	Administrative management as general firms

From the case study, some experiences and lessons may be learned from BEWIS’s evolution.

(2) In the commercialization process of emerging technologies, because most of the core chips used by enterprises were not created independently by those enterprises, the innovation process of BEWIS-type companies was more inclined to provide novel user-targeted solutions that enabled the technical architecture to be adjusted to user needs. Therefore, the main value was reflected in external collaborations; that is, the rear end of the value chain. For these types of enterprises, differentiated marketing approaches had to be developed for use by targeted downstream users, and different profit models had to be adopted for different users, which required a strong ability to integrate resources. The strength of government support, the density of social capital, and the sophistication of supporting industries in a company's region are important indicators of the impact of technology commercialization. Therefore, this type of outstanding MEMS companies generally clusters in areas with concentrated industries, such as Wuxi or Suzhou. BEWIS's location fully reflects the external collaboration features of the commercialization of emerging technologies in light of the great importance that the Wuxi City government attached to IOT and IC technology. Additionally, several hundred upstream and downstream supporting firms in the Wuxi and Suzhou areas exerted an important influence. Therefore, when start-ups choose a location for commercializing emerging technologies, they should consider multiple aspects. Instead of blindly "crowding" into mega-cities such as Beijing, Shanghai, Guangzhou, and Shenzhen, start-ups should conduct a comprehensive investigation and thoughtfully consider how to fully integrate their enterprises' advantages, their products' features, and their regional innovation networks.

(3) From the perspective of R&D, new technology is more complex and difficult, with high uncertainty in R&D process. In the development process, a new technology may die because of various technical difficulties. Therefore, the simultaneous development of multiple technological projects that serve the same application helps ensure the ultimate success of a product in the R&D stage. In addition, because of the characteristics of the rapid upgrade of emerging technologies, new technical solutions and standards continue to emerge, while the market demand and acceptance of technologies at various levels remain unknown. Therefore, it is very difficult for enterprises to accurately tap the market. Accordingly, to adopt, several solutions or standards in multi-generational technologies are needed so that when market demand gradually becomes obvious or a technological upgrade stabilizes, one solution or standard representing a particular generation of technology can stand out. Based on this case study and the survey of China's MEMS companies, 56 percent of companies have adopted this strategy for the R&D of emerging technologies. From airbag sensors in automotive

electronics products to consumer products such as mobile phones, entertainment, television remote controls, industrial systems and joysticks for equipment and digital games – these products all use the same core proprietary technology, which has been used in different products to fulfill the diverse needs of customers.

(4) Developers of emerging technologies often confront uncertain competitors. Several companies are likely to compete strongly against time in the R&D and commercialization of a particular emerging technology, and it is difficult to predict who will be the first to launch. At the market-introduction stage, which is characterized by immature consumer behavior, the product that is the first to be launched can often attract customers and thus prevail; this type of “path dependence” is continuously strengthened and becomes the dominant design. Once a rival is the first to launch, other companies are placed in a compromised position. Therefore, when one does not know the capacity and strategy of one’s rivals, it is necessary to develop a variety of technologies while striving for a leading position in a particular aspect of the technology.

6.7 Summary

This chapter has used Wuxi BEWIS Sensing Technology Ltd. as a case with which to explore how the four determinants in Chapter 5 affected the MEMS commercialization. Divided the entire commercialization process into four stages, this chapter explain how the roles of technology property, market conditions, regional innovation network, and enterprise capability affects the development of each stage. In addition, the case study also provides some novel findings inconsistent with empirical results. We found that policy and regulation also played an important role on the product development through supporting the survival of startup.

Chapter 7：Conclusions and Recommendation

7.1 Conclusions

In this thesis, we have explored the determinants of commercialization of emerging technology in China. Using 112 enterprises as a sample, we empirically examined which of the proposed factors affect MEMS technology commercialization, and to what extent. In addition, taking Wuxi BEWIS as a case, we further discussed how these determinants influenced the product developing process. The main results are as follows.

(1) Based on the theoretical analysis, in this study, six factors (technology property, market conditions, regional innovation network, enterprise capability, policy and regulation, and social environment) were proposed to be critical to emerging MEMS commercialization. Through the multi-regression analyses, our empirical study shows that the first four factors have significant relationships with the commercialization performance of MEMS technology. Among them, technology property, market conditions, and regional innovation network were supported, while enterprise capability was partly supported by empirical data in this study. Thus, these four factors are the main determinants of emerging technology commercialization, while the other two factors – policy and regulation and social environment – are not determinants of MEMS commercialization.

(2) The case study on BEWIS further analyzed how the four determinants affect the different stages during the whole product developing process. The four determinants have various effects on the commercialization in different stages. At the product selection stage, the most important task is to find potential customer demand and identify the niche market, in which market conditions are a key factor. In the R&D and pilot test stages, the biggest challenge is to integrate the necessary resources to do R&D and then finish the pilot test for new products efficiently and economically, in which regional innovation network play an irreplaceable supporting role and technology property determines the R&D difficulty. Finally, during the mass production stage the flexible production and quality control are important to the final products, in which enterprise capability is critical to success.

(3) Although government policy and regulation have no significant relationship with the commercialization performance of MEMS technology through the empirical analysis, the

BEWIS case study still shows its key role on product development. Various financial supporting projects by local government are critical to the startup's survival at various stages, including the product selection, R&D, and pilot test phases.

(4) Through collecting the patent data of MEMS-related technology, this study also explored the MEMS product category as well as geographic distributions around the world. According to these results, this thesis suggests that TSV technology would be a future direction for three-dimensional MEMS packaging technology. In addition, we analyzed six trends of MEMS technology: 3D-structural, high-performance monolithic, highly integrated module, low power consumption, intelligence, and networking.

7.2 Recommendations

The results of the empirical and case studies on the determinants of emerging technology commercialization may provide some valuable recommendations, both for enterprises and for governments.

7.2.1 Recommendation to governments

(1) There have been relatively high barriers to entering the MEMS industry. Some companies only received limited types of investment and financing. China's financial market has been particularly underdeveloped; 60 percent of the MEMS companies investigated in this study adopted equity financing, whereas bank financing accounted for a very low proportion. It has been particularly difficult for start-up MEMS companies to obtain credit financing from banks. Although, in recent years, the government has strongly advocated the establishment of the appropriate financial institutions to offer small loans specifically to SMEs, these countermeasures have failed to have the desired effect. Therefore, it has remained difficult for a large number of MEMS companies to obtain credit financing from banks. Under current market conditions, support funds from the government and venture capital are important funding sources for the early development of MEMS enterprises.

(2) During the technology-selection stage, the government could formulate policies to guide the direction of technological development. During the technological development stage, the government could help to support the development of emerging technologies by increasing R&D expenditures. In the pilot stage, the government could help increase the success probability of relevant trials by constructing a common technology and public service

platform, introducing strategic investors and using financial capital as guidance. During the mass-production stage, the government could support emerging technologies commercialization by stimulating demand, regulating markets, assembling complementary assets, and promulgating financial, taxation, and economic policies

(3) Local government should emphasize the autonomy of enterprises and allow them to independently determine their innovation object, innovation method, and innovation achievement. Moreover, government can support public technology platforms to provide technical support and personnel training. Meanwhile, government may use market mechanisms and interests to innovate cooperation approaches and achieve a comprehensive union of capital and technology, risk sharing and “win-win” development.

7.2.2 Recommendation to enterprise

(1) The collection of a large amount of demand information that was originally scattered can help enterprises scan market opportunities and observe development trends. Although it has been proven (Day & Schoemaker, 2000) that technical innovation needs to reflect user needs and market trends, market information is often somehow vague and incomplete. Since emerging technologies have an expanding knowledge base and are undergoing innovation in the applications in existing markets or with developing or forming new markets, they experience a particularly prominent form of market uncertainty. In such cases, the enterprises should consider related questions carefully. For example, what types of features are presented by market demand? What types of requirements do users have for product features, price, and quality? It is impossible for enterprises to have a firm grasp of such information before initiating R&D on emerging technologies. Getting ahead of users’ needs requires entrepreneurs to maintain alertness toward new product users when working with complex products and services at the forefront of market demand. These customers strive to ameliorate inadequacies in existing products and services and are adventurous in terms of trying new technologies that have proven more capable than ordinary technologies of providing richer and more accurate information about future market demand. By paying close attention to the needs and feedback of customers, companies can obtain high-quality information about the market demand of emerging technologies to control the negative effects of market uncertainty and recognize market opportunities

(2) Engaging iterative development and achieving progressive entrepreneurship. Compared to the traditional model, progressive entrepreneurship can help companies to

launch products that customers need more quickly and cheaply; progressive entrepreneurship can also reduce such companies' commercialization risk (Blank, 2013). The two most fundamental points of progressive entrepreneurship are to meet the customer demand and to provide solutions. Listening to customer feedback instead of trusting one's own instincts; adopting iterative design instead of using the traditional development method of creating a detailed design in advance; and providing prototypes and concepts of new products are all conducive to saving time and costs. Therefore, progressive entrepreneurship should produce simplified and achievable products quickly so that customer feedback can be immediately available and products can be improved based on customer feedback. By continuously repeating this cycle, enterprises either test their designed products and make further adjustments or transform their products to eliminate unworkable designs or functions. Through iterative, progressive process, enterprises can proactively avoid inconsequential activities, making full use of all their resources. Emerging technologies may generate substantial commercial value by having a far-reaching impact on the industry. It is critical to seize market opportunities. Therefore, every enterprise should try its best to shorten the R&D cycle so that it is better prepared to launch its product at the right time. Moreover, emerging technologies are often founded on basic research, resulting in higher R&D costs and challenging enterprises' financial capacity. An iterative development and progressive approach can effectively address the issue of a lack of funds at the early stages of a start-up.

Indeed, while being committed to understanding and addressing users' needs, the method of getting ahead of users has often resulted in the development of prototypes of commercially valuable products and services. Pioneering development activities intended to get ahead of users are directly integrated into an enterprise's development process of products and concepts. The product development team benefits from prototypes provided for innovative users, which greatly reduces the workload of product development engineers, accelerates the process of concept development, saves R&D costs, controls the uncertainties of R&D, and reduces risk.

(3) The Internet provides platforms with which to showcase emerging technologies and products and is conducive to commercial promotion. Emerging technologies often confront a completely new industry or field, and their products may be unprecedented in the market. Therefore, it could be difficult for the product to be quickly accepted by consumers. This is the primary uncertainty in the commercialization of emerging technologies. Advanced users are more prone than other users to propose specific requirements and have a more profound

understanding of emerging technologies, more mature needs, a more stable user environment and greater aptitude in terms of their applications. Therefore, the Internet has become a platform for showcasing emerging technologies and products and connecting to users, not only because they are beneficial to promotion and publicity but also because they can guide and accelerate market development.

(4) Establishing social networks and strengthening internal and external cooperation. The commercialization of emerging technology is often accomplished through continuous interaction and exchange between an enterprise’s internal and external factors. It requires an enterprise to form a loosely coupled innovation system in which factors within and without the system continue to flow, interchange, and continuously strengthen their integration. This process requires the enterprise to implement corresponding measures based on its own characteristics and rational coordination of resources to ensure its innovation system’s efficient operation and sustainable development. An enterprise’s strategies include its technology, marketing, and financing strategies. Start-ups at this early stage may actively seek financial support from local government or even achieving broader cooperation with the government.

(5) Building jointly human resource training programs with universities. Enterprises can use the advantages of a university to cultivate or find talents and skilled workers. With good teaching environments and learning conditions, teachers and academic resources provide the basic conditions for personnel training. On the other hand, with the involvement of enterprises, employee training will be more in line with market needs. This customized training program can provide a good channel for the human resource of enterprise.

7.3 Limitation and further research

Although this study combines empirical study and case study methods to explore the determinants of emerging technology commercialization, it has certain limitations that need to be acknowledged and perhaps addressed in future research.

(1) Due to the limited time, this study only takes MEMS technology as a typical example to investigate the determinants of commercialization. Although emerging technologies have some similarities, there are many specific features that affect the developing trajectory of a technology as well as its commercialization. Therefore, in the future, it will be necessary to further explore the commercialization determinants of other

emerging technologies, which can not only examine the results of this study but also provide the more valuable references to various technology development.

(2) In the present study, the policy and regulation factor showed inconsistent results in the empirical study and case study. This may result in the sample size as well as the cross-section method in the empirical study, which were primarily acquired through questionnaire surveys and field investigations from members of the MEMS branch of China’s Semiconductor Industry Association and enterprises in science parks in Wuxi, Suzhou. Future studies should include more enterprises in order to further explore the roles of government in emerging technology commercialization. Meanwhile, longitudinal empirical study may be more suitable for studying the commercialization of emerging technology, even though the data collection is much more difficult. To address this problem, in the future, big data techniques may be used to collect more data for empirical study.

Bibliography

Adomavicius, G., Bockstedt, J. C., Gupta, A., & Kauffman, R.J. (2007). Technology roles and paths of influence in an ecosystem model of technology evolution. *Information Technology & Management*, 8(2), 185–202.

Andrew, J. P. & Sirkin, H. L. (2004). From innovation to revenue generation. *Harvard Business Review*, 47(2), 65–67.

Bassey, M. (1999). Case Study Research in Educational Settings. *Doing Qualitative Research in Educational Settings*, 100, 78.

Barney, J. (1991). Firm resources and sustained competitive advantage. *Advances in Strategic Management*, 17(1), 3–10.

Bi, C. (2015). Coevolution mechanism of emerging technology, emerging market and emerging industry. *Science & Technology Progress and Policy*, 32(11): 45–49.

Blank, S. (2013). What lean start-ups do differently. *Harvard Business Review* 34(5), 65.

Bower, J. L. & Christensen, C.M. (1995), Disruptive technologies: Catching the wave. *Harvard Business Review*, 73(1), 43–53.

Bright, J. R. (1970). *Practical Technology Forecasting*. Austin: Technology Futures, Inc.

Cao, D. M. (2012). “Combination-Creation-Evolution” technology – an attempt to open the ‘black box technology’. *Studies in Dialectics of Nature,* 28(3), 44–49.

Chen, G. H. & Wang, X. Z. (1995). The new technology innovation, technology diffusion and technology progress relationship. *Studies in Science of Science*, 4, 33–34.

Chen, X. (2005). Technology Innovation Diffusion in Industry Cluster, *Chinese Journal of Management*, 2(3), 333–336 .

Chen, X. H., Zhou, Y., David, P., and Su, J. (2017), Managing knowledge sharing in distributed innovation from the perspective of developers: Empirical study of open source software projects in China. *Technology Analysis & Strategic Management*, 29(1), 1–22/9.

Chen, Y. S. (1997). High technology: definition, management and system. *Science Research Management*, 6, 67.

Cooke, P. (1998). Regional systems of innovation: An evolutionary perspective. *Environment and Planning*, 30, 1563–1584.

Cooper, R. G. (1996), *Winning at New Products*. Wesley: Wesley Publishing Co.

Cooper, R. G. & Kleinschmidt, E. J. (1995). Benchmarking the firm’s critical success factors in new product development. *Journal of Product Innovation Management*, 12(5), 374–391.

Crawford, M. & Benedetto, D. A. (2006). *New products management*. New York: McGraw-Hill.

Day, G. S. & Schoemaker, P. J. H. (2000). *Wharton on Managing Emerging Technologies*. Hoboken: John Wiley & Sons, Inc.

Dillon, D. (1998). The next big thing. *Fast Company*, 97–110.

Ding, D., Li, Z. & Hu, M. (2013). Potential risks in the Development of Emerging Technologies and the Problems of Technology Governance. *Chinese Soft Science,* 6, 62–70 .

Dreje, A. & Kofoed L. B. (2000). *Management of Technology, Center for Technology Management.* In Janszen, F., *The Age of Innovation,* London: Pearson Professional Limited.

Duan, L. M., Du, Y. P. & Meng, L. (2012). Empirical study of factors affecting the commercialization performance of Emerging Technologies. *Studies in Science of Science,* 30(9), 1354–1362.

Doering, T. L. (2000). How Does Cryptococcus Get Its Coat. *Trends in Microbiology,* 8 (12), 547–553.

Eisenhardt, K. (1989). Building theories from case study research. *Academy of Management Review,* 14 (4), 532–550.

Falletti, E. (2011). *Satellite and Terrestrial Radio Positioning Techniques*. Oxford: Elsevier Ltd.

Fan, X. R. & Li, W. B. (2002). Evaluation of risk in investment projects. *Journal of Central South University of Technology,* 8, 43–47.

Fang, R. G., Yin, L. & Wang, M. X. (2010). Analysis on government policy in evolution process from Emerging Technologies to strategic emerging industry. *Technology Economics,* 29, 12.

Fu, J. Y., & Tong, Y. H. (1996). *The Technology of Industrial Economics (Third Edition),* Beijing: Tsinghua University Press.

Geels, F. W. (2006). Co-evolution of technology and society: the transition in water supply and personal hygiene in the Netherlands (1850–1930): a case study in multi-level perspective. *Technology in Society,* 24, 363–397.

Geels, F. W. (2002). Technologies transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, 31, 1257–1274.

Glynn, J. M. & Paulson, A. (1996). Marketing and discontinuities innovation: The probe and learn process. *California Management Review,* 38(3), 8–37.

Gould, S. & Eldredge, N. (1977). Punctuated equilibria: the tempo and mode of evolution reconsidered. *Paleobiology,* 3, 115–151.

Gu, C. L. & Zhao, L. X. (1998). *Chinese High-tech Industry and Industrial Park*. Beijing: CITIC Publishing House.

Guan, R. F. (2005). *The Design, Packaging Technology and Application Research of MEMS Devices*. PhD Thesis, Wuhan: Huazhong University of Science & Technology.

Hacker, J., Hillman, C., Papavasiliou, A., Chong, G. K., Abbaspour-Tamijani, A., & Kim, C. Y. (2012). A 16-element transmit/receive Q-band electronically steerable subarray tile. *Microwave Symposium Digest*, 1–3.

Hatch, J. & G. Mckay (1996). Assessing technology-driven firms. *Canadian Banker,* 14–20.

He, Z. & Rayman-Bacchus, L. (2010). Cluster network and innovation under transitional economies: An empirical study of the Shaxi garment cluster. *Chinese Management Studies*, 4(4), 360–384.

He, Z., Rayman-Bacchus, L. & Wu, Y. M. (2011). Self-organization of industrial clustering in a transition economy: a proposed framework and case study evidence from China. *Research Policy*, 40, 1280–1294.

SIPO of P.R.China (2014). *China and Global Patent Examination Information Inquiry* Retrieved August 10, 2014, from Http://cpquery.sipo.gov.cn/ State Intellectual Property Office Intechno Consulting(2010). *Process Plant Markets.* Retrieved October 11, 2012, from Http://www.intechnoconsulting.com/ic/reports/detail/process-plant-market-2010.php.

Hu, J. T. (2012). *Report of Eighteenth National Congress of the Communist Party of China*.Retrieved October 11, 2012, from http://politics.people.com.cn/n/2012/0.html.

Huang, L. C. & Li, Y. (2010). Evaluation system of technology trend based on patent analysis. *Journal of Management & Systems*, 19 (4), 383–388 .

Huang, H. & Zhang, Z. (2015), Commercialization Process Research of Emerging Technology Products Based on Disruptive Innovation: Example of Apple Inc. *Chinese Science and Technology Forum*, 2, 37–42 .

Huang, N. & Yang, X. (2014). Coevolution mechanism between emerging technology and emerging industry. *Science & Technology Progress and Policy*, 31(3), 72–78 .

Huang, L. C. & Lu, W. G. (2009), Study on the identification of Emerging Technologies by an attribute synthetic measure model. *Science Research Management*, 30(4), 190–194.

Huang, L. C., Wang, J. W. & Lu, W. G. (2007). Research on the industrialization potential evaluation of new technology based on ANP. *Science of Science and Management*, (4), 122–1251.

Huang, L. C. and Wang, J. (2011), Empirical research on the environment effect factors of new technology commercialization, *Science & Technology Progress and Policy*, 1, 1–5.

Huang, L. C. & Yang, X. J. (2014). An analysis of the evolutionary relationship between emerging technologies and new industry. *Science & Technology Progress and Policy*, 31(3), 72.

Hou, H. Y. & Wang, H. C. (2003). Research on the assessment of HT venture's sustainability. *Systems Engineering – Theory & Practice*, 8, 11–15.

Jiang, R. L. (2009). *Research and Design on MEMS Capacitive Sensor Signal Processing ASIC*. Master Thesis, University of Science and Technology of China.

Jin, R. T. (2005). Theoretical explanation of Emerging Technologies, *Management Science Forum – Management of Emerging Technologies Academic Conference Proceedings*, Chengdu.

Jin, R. T., Liu, P. & Fu, C. L. (2006). Explanation of organization theory detected by newly Emerging Technologies. *R&D Management*, 18(5), 82–88 .

Jin, T. (2007). *The design and optimization of MEMS devices*. Master’s Thesis, Nankai University.

Jolly, V. K. (2001). *Commercialization of New Technology – From the Idea to the Market*, Beijing: Tsinghua University Press.

Kalaitzandonakes, N. G. (1997). *Commercialization of research and technology.* Doctoral dissertation. Columbia: Department of Agricultural, Economics University of Missouri.

Koberg, C. S., Detienne, D. R. & Heppard, K. A. (2003). An empirical test of environmental, organizational, and process factors affecting incremental and radical innovation. *Journal of High Technology Management Research*, 14(1), 21–45.

Kostoff, R. N., Boylan, R. & Simons, G.R. (2004). Disruptive technology roadmaps. *Technological Forecasting & Social Change*, 71(1–2), 141–159.

Li, H. Z. (2004). *Research Methodology*. Xi'an Jiaotong University Press .

Linton, J. D. (2004). Determining demand, supply, and pricing for emerging markets based on disruptive process technologies. *Technological Forecasting & Social Change* 71, 105–120.

Li, Y. (2012). *Research on New Technology Commercialization of Entrepreneurial Enterprises*. PhD Thesis, Graduate School, Chinese Academy of Social Sciences .

Li B. & Chen, X. (2015). Comparative analysis of core and emerging technologies between Mainland China and Taiwan based on patent citation network. *Science Research Management*, 36(2), 96–106.

Li, P. & Chen, X. (2015). Nano technology identification based on patent citation coupling cluster. *Journal of Intelligence*, 34(5), 35–40.

Li, S. M., Li, P. & Xiao, L. (2005). The change of Emerging Technologies and the viewpoint of strategic resource. *Chinese Journal of Management*, 5(3), 304–306.

Li, S. M., Xiao, L. & Xiao, Y. G. (2007). Review of emerging technologies management. *Journal of Management Sciences in China*, 10, 6–10.

Li, Y. & Deng, S. L. (1999). A research method for competitive advantage analysis and strategy formulation: an example in a transitional economy. *European Journal of Operational Research*, 118(2), 259–270.

Liu, C. Y., Duan, J. & Wu, F. Y. (1996). Venture capital evaluation decision process. *Foreign Science and Technology Policy and Management*, 12, 64–74.

Liu, J. L. & Y. J. Li (2005). Emerging technologies, technological uncertainty and its implications for businesses. *Theory and Reform,* 5, 159–160 .

Lou, L. F. (2010). *MEMS and the Design*. Beijing: Electronic Industry Press.

Lu, W. G. (2008). *Potentiality Evaluation and Growth of emerging technology industrialization*. Doctoral Dissertation, Beijing University of Technology .

Masters, B. & Thiel, P. (2014). *Zero to One: Notes on Startups, or How to Build the Future*. United States: Crown Publishing Group.

Mao, J. Q. & Liu, N. (2010). Research on co-evolutionary mechanism based on ecological technology. *Studies in Dialectics of Nature*, 26(11), 26–30.

Martino, J. P. (2003). A review of selected recent advances in technological forecasting. *Technological Forecasting& Social Change*, 70, 719–733.

Minglong, W. (2003). Empirical Analysis of SPSS: Questionnaire Survey and Practical Analysis. Beijing: Science Press.

Mounier, E. (2014). Challenged by newcomers proposing low-cost solutions, established MEMS companies must develop new strategies, *Sensors*. July, 1–6.

Munir, K. A. & Phillips, N. (2002). The concept of industry and the case of radical technological change. *Journal of High Technology Management Research*, 13, 279–297.

National Bureau of Statistics of China. (2017). *China Statistical Yearbook 2016,* Beijing: China Statistics Press .

Nie, Z. R (2002). University transformation model. *Changjiang Securities,* 11, 3 .

Nunn ally, J. C. (1978). *An Overview of Psychological Measurement: Clinical Diagnosis of Mental Disorders.* New York: Springer.

Olayan, H. B. (1999). Technology transfer in developing nations. *Research-Technology Management*, 42(3), 43–48.

Pelikan, P. (2003). Bringing institutions into evolutionary economics: another view with links to changes in physical and social technologies. *Journal of Evolutionary Economics,* 13, 237–258.

Rayman-Bacchus, L. & He, Z. (2014), Assessing clustered SME practice towards environmental and social impact: a Bourdieusian approach. *International Journal of Innovation and Sustainable Development,* 8(2), 167–189.

Rinne, M. (2004). Technology roadmaps: Infrastructure for innovation. *Technological Forecasting & Social Change*, 71, 67–80.

Pustan, M., Dudescu, C., & Birleanu, C. (2016). Static response and stiction analysis of mems micromembranes for optical applications. *Physica Status Solidi,* 12(12), 1322–1327.

Schumpeter J. A. (1911). *The Theory of Economic Development*. Boston: Harvard University Press.

Shaeffer, D. K. (2013). MEMS Inertial Sensors: A Tutorial Overview. *IEEE Communications Magazine,* 4, 100–109.

Smith, C. S. (1954). Piezoresistance effect in germanium and silicon. *Physical Review,* 94(1), 42–49.

Sohn, S. Y. & Moon, T. H. (2003). Structural equation model for predicting technology commercialization success index. *Technological Forecasting & Social Change,* 70(9), 885–899.

Spinelli, K. D. (2002). Commercializing emerging technologies: interpreting and acting on information under conditions of high uncertainty. *Babson Entrepreneuria*l *Review,* 10, 47–57.

Song, F. M. & Chen, T. T. (1999), Research on the evaluation index system of high-tech investment projects, *China Soft Science,* 1, 90–93.

Sui, Z. N. & Wang, Z. P. (1998), *Evaluation of Scientific Research Achievements*. Shanghai: Shanghai University of Finance and Economics Press.

Sung, W. K. & Dalal, M. (2010). A3MHz spoke gyrospope with wide bandwidth and large dynamic range. *Proceedings of the IEEE International Conference on Micro Electro Me-chanical Systems*. Hong Kong, China, 104–107.

Tan, Y. & Huang, Y. L. (2007). Research on the planning of Emerging Technologies and the section of relevant models. *Science and Technology Management Research,* 8, 5–9.

Tian, W. C. (2009). *The Principle, Design and Analysis of MEMS*. Xi'an: Xidian University Press.

The World Bank. (2016). World development indicators, http://data.worldbank.org/country/china.

Watkins, W. M. (1990). *Business Aspects of Technology Review*. Germany: Noyes Publication.

Webster (1986). *Webster's Third New International Dictionary*. Chicago: Encyclopedia Britannica.

Wang, C. B. (2011). *Research on Development Strategy of BW Company*. Master Thesis, University of Electronic Science and Technology of China .

Wang, J., Ling, F. & Tang, J. (2015). Evaluation of emerging technology impact on future industry based on patents. *Journal of Intelligence*, 33(5), 44–48.

Wang, J. W., Huang, L. C. & Lu, W. G. (2008). A discussion on meaning and evaluation method of commercial potential of Emerging Technologies. *Science of Science and Management of S&T,* 4, 32–35 .

Wang, L. & Tian, H. J. (2009). Development prospects of inertial MEMS devices. *Journal of Henan Science and Technology,* 46(1), 24–26 .

Wang, X. L. (2004). *The Use of Evaluation Model for Assessing Commercialization of Emerging Technologies by Stages*. Master's Thesis, Tsinghua University .

Wang, Z. Y. (2003). Advanced manufacturing technology IC & MEMS manufacturing technology and its development trend. *Equipment for Electronic Products Manufacturing,* 10(1), 16–21.

Wang, C. & Su, Q. (2016). Analysis of the effects of policy measures on emerging technology evolution: a case study of 3D printing technology. *Science & Technology Progress and Policy*, 33(6), 110–116.

Wei, G. P. (2006). *Emerging Technologies Management Strategy – Classification Analysis Based on the Characteristics of Emerging Technologies*. Master's Thesis, Hangzhou: Zhejiang University.

World Intellectual Property Organization. (1977). *Customs Handbook for Developing Countries*, 38.

Wu, G. S. (2000). *Management of Innovative Technologies*. Beijing: Tsinghua University Press .

Wu, G. S. & Xie, W. (1999). Review on the research of Chinese and foreign technology management, *Science Research Management*, 2, 8–13.

Yang, R. F. & Tong, Y. H. (2004). A survey of new technology commercialization and its evaluation, *Studies in Science of Science,* 12(22), 82–83.

Yin, R. K. (1994). *Case Study Research: Design and Methods*. Newbury Park: Sage Publications.

Yin, L. & Shi, Z. G. (2005). Emerging Technologies: concept and new management. *Modern Management Science,* (4), 5–7.

Yin, L. & Wang, M. (2010), *Introduction of the Management of Emerging Technologies*. Beijing: Science Press.

Yin, L. (2005). New thinking on management of Emerging Technologies. *Chinese Journal of Management*, 2(3), 277–280 .

Yue, Z. G. (2014). Research on collaborative development of technical chain and industrial chain of strategic emerging industries. *Science of Science and Management of S&T,* 35(2), 155.

Yoffie, D. B (1996). Competing in the age of digital convergence. *California Management Review,* 38(4), 31–53.

Yu, J. (2004). Case study and case study method. *Economic Management,* 10, 24–29.

Zehner, W. B. (2000). The management of technology degree: A Bridge between technology and strategic management. *Technology Analysis & Strategic Management,* 12(2), 21–23.

Zhai, D, Xia, J. Zhang, J., Li, Q. & Feng, X. (2015), Method of Weak signal identification based on emerging technology patents, *Journal of Intelligence,* 34(8): 31–36 .

Zhang, Z. Y. (2005). The impact on corporate governance structure on technological innovations. *Management Science Forum – Management of Emerging Technologies Academic Conference Proceedings,* Chengdu, 232–237.

Zhang Y. (2016). *The Competitive Technical Intelligence Methodology for Emerging Technology*. Doctoral Dissertation, Management and Economics, Beijing Institute of Technology.

Zhao, X. (2004). *About Key Factors Affecting the Commercialization of Emerging Technologies*. Master’s Thesis, Beijing: Tsinghua University.

Zhao, Z. Y., Yin, L. & Cheng, H. (2004). Challenges of emerging technologies against the traditional managerial mode and a policy for a special market exploitation. *China Soft Science,* 7, 72–77.

Zhou, D. S. (2008). *Research on Factors Affecting Bio-pharmaceutical Industry and Associated Mechanisms*, PhD Thesis, Dalian: Dalian University of Technology.

Zhou, J. Y. & Lv, Y. J. (2010). Commercial Potential Evaluation of Emerging Technologies-Based on Grey Clustering Model of AHP. *Science and Technology Management Research,* 24, 48–51.

Zhu J. (2015). *Micro mechanical gyro Design and Research based on mesoscopic piezoresistive effect.* PhD dissertation, Shanxi: Zhongbei University.

Zhu J, Wen, T. D., &Li-Ping, X. U. (2015). Research of MEMS gyroscope based on mesoscopic calender effect. *Transducer & Microsystem Technologies,* 3, 34–39.

Appendix 1: Questionnaire

Dear Sir/Madam:

We are a research group at UESTC-ISCTE conducting research about “Influencing factors in the success of MEMS technology commercialization”. Thank you for taking the time to help complete this questionnaire. We hope to provide a scientific evaluation criterion, a system, and a process for MEMS technology commercialization. We also hope that this study will provide information about and suggestions for enterprises related to decision making and valuation.

The survey primarily addresses scientific and technological enterprises involved in commercializing MEMS technology. Please read the questions carefully and answer them. There is no single correct answer, although multiple-choice questions require a single response, unless labeled otherwise. It would be preferable for the survey to be completed by the company’s key management personnel (general managers).

Solemn declaration: Your information is completely confidential. It will only be used for this research. To ensure the veracity and integrity of the survey data, please answer truthfully and in the terms prescribed. Please return the questionnaire to the issuer or send an email to your contact.

Do not hesitate to ask any questions, either to the questionnaire issuer or Jack Wang. We will send you the research findings, so please provide your email address. Thank you again for your support!

Contacts:
Address: Building 30, NO. 58, Xiuxi Road, Binhu District, Wuxi Jiansu China
Post code: 214001
Email: jack.wang@foxmail.com
Telephone: 0510-85737158   Cell phone:

Please provide your e-mail only if you want to fill out an anonymous form. We will contact you if an answer is unclear or incomplete.

Name: ________________ Job: ______________Telephone: _________________
Email: ____

Address: ____

Post code: ________________________________

Part I: Basic information about the company

1. Company information:

Company name: _______________________________

Website: ________________________

Address: ____

Postcode: _____________

Telephone: ____________________

Fax: __________________________

Date of establishment: __________________

Industry involved: ___________________

Registered capital: ____________ (10 thousand￥)

Total assets: _____________ (10 thousand￥)

2. Shareholders of the company

A. State-owned enterprise B. Private enterprise C. Foreign-owned enterprise

D. Other (please specify) ______________________

3. Personnel Structure

		Educational background (%)				
	Number of people	Doctoral degree	Master's degree	Bachelor's degree	Junior	Other
Senior manager						
Technician						
Production personnel						
Marketing personnel						
Head count						

4. Your company's core technology or leading product relies on the following technology (please indicate the most important technology):

____

5. The technique falls into which of the following categories:

A. Design technique B. Manufacturing technology C. Packaging and testing technology D. Application technique E. Other fields_______________

6. At which stage is the technology currently?

A. Technology-selection stage B. R&D stage C. Pilot stage

D. Mass production stage

7. ***This technology is an***

A. Original innovation B. Introduction of foreign technology

C. Imitation D. Other (please describe) ________

8. How did you access this technology?

A. Self-developed B. Cooperative development C. Purchasing a technical license

D. Other (please describe) ____________

9. The intellectual property for this technology belongs to:

A. The company B. The technical director or technical inventor

C. A university or scientific research institution

D. Other (please specify) ______________

10. Background of the inventor (principal):

A. Professor B. Researcher at a scientific research institution

C. R&D personnel of the company D. Other (please specify) _______________

11. The director or inventor of this technology :

A. Owner

B. Is the senior manager in the company

C. Is the company’s technology director

D. Offers technical support to the company

E. Is one of the founders of the company

F. Other (please describe) ___________

12. The manner in which the company protects this technology:

A. Utility model patent B. Invention patent C. Design patent

D. Technical solutions or technical expertise

E. A stable and excellent technical team F. Other (please describe) ________

13. The primary advantage of this technology is:

A. Progressiveness B. Uniqueness C. Irreplaceability

D. Difficulty in imitating E. Economic F. Other ________

14. Is there a technique to implement the same function in different ways?

A. More than two B. One or two C. There is no such technology

D. Not sure

15. Time to market for (available or potential) technology that substitutes for this technology:

A. Shorter than current product technology

B. The same as current product technology

C. Longer than current product technology

D. Not sure

16. Future development trend of this technology focuses on:

A. Adding current product function B. Developing new applications

C. Improving technical parameters and technical performance

17. This technology is (multiple choices):

A. Widely known by experts domestic and overseas B. Known by clients

C. Known by competitors D. Known by hardly anybody E. Not sure

Part II: Independent variables

18. Technology properties

	Technology properties	Strongly Disagree ⟵		| Not sure |		⟶ Strongly Agree
a1	It is very difficult for competitors to develop products that would replace your company’s products in a short period of time.	1	2	3	4	5
a2	R&D technical problems can be independently solved by the R&D department of your company.	1	2	3	4	5
a3	The product upgrades very quickly.	1	2	3	4	5
a4	The R&D cost of the product has been reduced.	1	2	3	4	5
a5	Your company can digest and absorb the technology in a relatively short period of time.	1	2	3	4	5
a6	The product has clear intellectual property rights.	1	2	3	4	5

19. Enterprise capability

	Enterprise capability	Strongly Disagree		| Not sure |		Strongly Agree
b1	Your company guarantees the yield and quality of the product within the specified time.	1	2	3	4	5
b2	Your company has a competitive marketing team and marketing channels.	1	2	3	4	5
b3	Your company has sophisticated after-sales service.	1	2	3	4	5
b4	Your company can effectively integrate internal and external resources.	1	2	3	4	5
b5	Human resources management can meet the needs of enterprise development.	1	2	3	4	5
b6	The corporate culture can effectively constrain the behavior of employees.	1	2	3	4	5

20. Regional innovation network

	Regional innovation network	Strongly Disagree		| Not sure |		Strongly Agree
c1	At the R&D stage, your company has cooperated with research institutions.	1	2	3	4	5
c2	In the commercialization process of the technology, your company has cooperated with financial institutions.	1	2	3	4	5
c3	In the commercialization process of the technology, your company has cooperated with technological agencies.	1	2	3	4	5
c4	In the start-up stage, your company has obtained support from incubators.	1	2	3	4	5
c5	Your company has cooperated with leading companies.	1	2	3	4	5
c6	There are numerous upstream suppliers that your company can choose from.	1	2	3	4	5

21. Market conditions

	Market conditions	Strongly Disagree		| Not sure |		Strongly Agree
d1	The timeline of corporate profits has been determined, or the company has already been profitable.	1	2	3	4	5
d2	The features of the product demanded by the emerging market are clear.	1	2	3	4	5

	Market conditions	Strongly Disagree		| Not sure |		Strongly Agree
d3	The demands of users in the emerging market are simple, and the developed product meets current demand.	1	2	3	4	5
d4	A rapid development stage will emerge in the development of the emerging market.	1	2	3	4	5
d5	Currently, the competition in the emerging market is not intense.	1	2	3	4	5
d6	The emerging market has already had a number of potential buying groups.	1	2	3	4	5
d7	The expected profitability of the project is high.	1	2	3	4	5
d8	Customers in the emerging market need to have a deep understanding of the technology.	1	2	3	4	5
d9	Customers in the emerging market are satisfied with the product of the company.	1	2	3	4	5
d10	Customers in the emerging market will buy the product again.	1	2	3	4	5
d11	Customers in the emerging market can accept price increases.	1	2	3	4	5

22. Policy and Regulation

	Policy and Regulation	Strongly Disagree		| Not sure |		Strongly Agree
e1	In the near future, the national policy will have a certain preference with regard to this industry.	1	2	3	4	5
e2	The current technology projects can enjoy the related preferential policies.	1	2	3	4	5
e3	The government offers financial support for this technology.	1	2	3	4	5
e4	Technology-related laws and regulations have already been sophisticated.	1	2	3	4	5

23. Social environment

	Social environment	Strongly Disagree		| Not sure |		Strongly Agree
f1	The social culture of the surrounding holds an encouraging attitude toward the technology of your company.	1	2	3	4	5
f2	Society already has the infrastructure that is needed by the technology.	1	2	3	4	5
f3	The social service system in the cluster has already been established.	1	2	3	4	5

Part III: Dependent variables

24. Risk reduction

	Risk reduction	Strongly Disagree ⟵		| Not sure |		Strongly Agree ⟶
g1	The technology projects in your company can effectively reduce process risk.	1	2	3	4	5
g2	The technology projects in your company can effectively reduce team risk.	1	2	3	4	5
g3	The technology projects in your company can effectively reduce organizational and environmental risk.	1	2	3	4	5
g4	The technology projects in your company can effectively reduce market risk.	1	2	3	4	5
g5	The technology projects in your company can effectively reduce the risk of technology needs.	1	2	3	4	5
g6	The technology projects in your company can effectively reduce the risk of technical complexity.	1	2	3	4	5

25. Corporate financial performance

	Corporate financial performance	Strongly Disagree ⟵		| Not sure |		Strongly Agree ⟶
e1	The current technology projects of your company have improved the return on assets.	1	2	3	4	5
e2	The current technology projects of your company have improved the proportion of main business income.	1	2	3	4	5
e3	The current technology projects of your company have improved the cash flow return on assets.	1	2	3	4	5
e4	The current technology projects of your company have increased the return on equity.	1	2	3	4	5

The End

Thank you for your cooperation!

Appendix 2: MEMS Patent Data from 1982 to 2013

Year	Pressure sensors	Accelero-meter	Microph-one	Gyroscope	RF switch	Microfluidic flow control	Digital micromirror	Optical switch	Other products
1982	99	20	1	4	1	0	2	12	88
1983	124	17	2	1	0	1	1	9	103
1984	139	23	1	3	1	0	0	13	121
1985	173	27	1	5	1	0	9	14	143
1986	167	42	2	10	1	1	4	23	157
1987	197	55	2	10	1	3	4	20	160
1988	201	71	1	9	2	1	2	27	184
1989	206	101	1	6	1	0	9	19	198
1990	228	119	4	11	1	0	1	33	201
1991	221	163	2	22	3	1	4	31	222
1992	248	175	3	38	3	1	11	39	237
1993	223	235	3	46	8	7	16	33	250
1994	220	268	2	53	5	11	53	53	271
1995	269	279	6	65	6	12	82	27	243
1996	341	266	6	98	4	44	100	61	304
1997	322	291	8	138	12	68	120	80	331
1998	358	246	14	103	22	85	190	54	306
1999	336	203	16	100	36	143	180	85	369
2000	253	210	32	130	36	247	194	275	359
2001	330	263	26	159	74	446	319	391	393
2002	308	285	35	124	111	501	301	453	403
2003	320	260	38	166	95	522	398	269	656
2004	488	277	53	186	80	572	353	184	865
2005	554	364	109	228	90	591	338	161	1189
2006	602	389	183	187	70	593	283	191	1510
2007	563	401	142	204	67	559	258	173	1540
2008	623	412	188	299	65	691	302	185	1845
2009	786	462	231	328	77	783	525	231	2004
2010	635	401	215	272	61	788	489	198	1923
2011	687	821	214	320	96	629	502	216	1780
2012	643	760	138	309	107	569	472	220	1531
2013	631	644	118	254	74	582	316	216	1337

Source: The Derwent Innovations Index (2015)

Appendix 3: List of Sampled MEMS Companies (112)

List of sampled MEMS companies (112)		
Province	**Company**	**Website**
Jiangsu (36)	1. MEMSIC, Inc.	http://www.memsic.com/
	2. Wuxi Sencoch, Inc.	http://sencoch.cn.china.cn/
	3. Nano MEMS, Inc.	http://nmems2012.cn.china.cn/
	4. NeoMEMS Technologies Inc., Wuxi China	http://www.neomems.com/en/index.asp
	5. Wuxi Sencoch Semiconductor Co., Ltd.	http://sencoch.cn.china.cn
	6. Wuxi Maizhe Technology Co., Ltd.	
	7. Wuxi HOPE Microelectronics Co., Ltd.	http://www.hpsaw.com/en/eindex.asp
	8. Wuxi Weiao Technology Co., Ltd.	http://www.wiotek.com/
	9. Wuxi Zixing Technology Co., Ltd.	
	10. Wuxi Qihe Technology Co., Ltd.	
	11. Wuxi Micronano Industry Development Co., Ltd.	http://www.memspark.cn/
	12. Wuxi Zhongke Microelectronics Co., Ltd.	http://www.wxzkme.com/
	13. Wuxi Ubisensing Technologies Inc.	http://www.ubisensing.com/
	14. MEMSensing Co., Ltd.	http://www.memsensing.com/index_en.php
	15. MiraMEMS Sensing Technology Co., Ltd.	http://www.miramems.com/en/
	16. Suzhou Good-ark Electronics Co., Ltd.	http://www.goodark.com/
	17. China Wafer Level CSP Co., Ltd.	http://www.wlcsp.com/EN/index.html
	18. Nanjing Gaohua Technology Co., Ltd	http://www.govasensor.com/
	19. Nanjing Wotian Technology Co., Ltd	http://www.wtsensor.net/
	20. Kunshan Bridging Sensor Control Technology Co., Ltd.	http://www.sqsensor.com/en/
	21. Nantong Fujitsu Microelectronics Co., Ltd.	http://www.fujitsu-nt.com/en/
	22. MultiDimension Technology CO., Ltd.	http://www.dowaytech.com/en/
	23. Jiangsu Intellisense Technology Co., Ltd.	http://en.intellisense.com.cn/index.html
	24. Macrocloud Corporation	http://www.macrocloud.cn/
	25. Jiangsu Changjiang Electronics Technology Co., Ltd.	http://www.cj-elec.com/en/
	26.Wuxi Aleader Co., Ltd.	http://www.aleader.com.cn/
	27.Suzhou Idmsensor Sensing Technology Co., Ltd.	http://www.idmsensor.com/

Province	Company	Website
	28. Suzhou Leanstar Electronic Technology Co., Ltd.	http://www.leanstar-tech.com/
	29.Wenhao Co., Ltd.	http://www.whchip.com/
	30. Suzhou st Noel Sensor Technology Co., Ltd.	http://www.ssn-sensor.com.cn/
	31. Suzhou Simems Micro-nano Systems Co., Ltd.	http://www.simems.net/
	32. Lertech Co., Ltd.	http://www.lertech.com/
	33.Consensic Co., Ltd.	http://www.consensic.com/
	34.Wuxi Jdsensing Co., Ltd.	http://www.jdsensing.com/
	35. Beetech Co., Ltd.	http://www.beetech.cn/
	36. Wuxi WoPu Photoelectric Sensing Technology co., Ltd.	http://www.wopuopto.com/
	37.Tongding Interconnection Information Co., Ltd.	http://www.tdgd.com.cn/
	38.SZDK Sensor Co., Ltd.	http://www.szdksensor.com/
	39. AB Electronic Sensor (suzhou) co., Ltd.	http://www.abelektronik.de/home.html
Beijing (18)	1. First Mems Co., Ltd.	http://www.mems.com.cn/English/ind.htm
	2. TUMEMS Technologies (Beijing) Co., Ltd.	http://www.tumems.com/english/
	3. Beijing Aerospace Times Photoelectric Technology Co., Ltd.	http://www.nti.org/learn/facilities/64/
	4. Beijing Xinnuojin Sensing Technology Co., Ltd.	http://xinnuojin.n-g.com.cn
	5. North GuangWei Technology, Inc.	http://www.gwic.com.cn/en_index.html
	6. Beijing Acuti Microsystems	http://www.acuti.com
	7. Beijing SVS Technology Co., Ltd.	http://www.svs-tech.com/
	8. Beijing NMC Co., Ltd.	http://en.bj-nmc.cn/index.html
	9. Beijing StarNeto Technology Development Co., Ltd.	http://www.starneto.com/
	10. MXTronics Corporation	http://www.mxtronics.com/
	11. Beijing Jinshengweina Technology Co., Ltd.	http://www.jswnkj.com/
	12. Beijing Chuangshi Micronano Technology Co., Ltd.	http://www.weinaworld.com.cn
	13. DOFSIM Technologies Co., Ltd.	http://www.dofsim.com
	14. Beijing Sunground Technology Co., Ltd.	http://www.sunground.net/
	15. Beijing Boao Biotechnology Co., Ltd.	http://www.capitalbio.bioon.com.cn/
	16. Beijing Guohao Sensor Technology Research Institute	http:// www.sensor.com.cn
	17. Beijing North Branch of Analytic Instrument Limited Company	http://www.bxequ.com/
	18. Legend Holdings, Ltd.	http://www.legendholdings.com.cn/en/Index.aspx

Province	Company	Website
Shanghai (15)	1. Senodia Technologies (Shanghai) Co., Ltd.	http://www.senodia.com/
	2. FineMEMS, Inc.	http://www.finemems.com/en/
	3. Shanghai Integrated Micro-systems Technology Co., Ltd.	http://www.simst.com.cn/English/
	4. Lexvu Opto Microelectronics Technology (Shanghai), Ltd.	http://www.lexvu.com/p_45.html
	5. Silicon Wisdom Technology, Inc.	http://www.siwi-tech.com/
	6. Shanghai Dingyao Technology Co., Ltd.	
	7. Shanghai Micro Electronics Equipment Co., Ltd.	http://www.smee.com.cn/
	8. Shanghai Belling Co., Ltd.	http://www.belling.com.cn/
	9.MicroLink SensTech Co., Ltd.	http://www.mlsenstec
	10.Shanghai Mingkong Sensing Technology Co., Ltd.	http://www.shmind.cn/
	11. Shanghai Wenxiang Automobile Sensor Co., Ltd.	http://shwxqccgq.china.herostart.com/
	12. TE Microsystems Co., Ltd.	http://www.timelitemems.com/
	13. Magnity Electronics Co., Ltd.	http://www.magnity.com.cn/
	14. Welltech Co., Ltd.	http://www.welltech.com.cn/
	15. Shanghai Welltech Co., Ltd.	http://www.welltech.com.cn/
Shanxi (8)	1. Xi’an Chinastar M&C Limited	http://www.websensor.com/index.php?lang=en
	2. Shanxi Spaceflight the Great Wall M&C Co., Ltd.	http://www.tuoluoyi.com/
	3. Xi’an Winnersensor Co., Ltd.	http://www.winnersensor.com/
	4. Xi’an LeadMEMS Sci&Tech Co., Ltd.	http://www.leadmems.com/
	5. Qingming Sensor Co., Ltd.	http://qinmingsensor.cn.china.cn
	6. Micro Sensor Co., Ltd.	http://www.microsensor.cn/
	7. Baoji Hengtong Electronics Co., Ltd.	http://www.cn-htdz.com/eindex.html
	8.Avic Zhonghang Electronic Measuring Instruments Co., Ltd.	http://www.zemic.com.cn/
Shandong (7)	1. Goer Tek, Inc.	http://www.goertek.com/en/
	2. Shandong Gettop Acoustic Co., Ltd.	http://www.gettopacoustic.com/en/
	3. SHR Automation Technology Co., Ltd.	http://www.hrsensor.cn/
	4. Shandong Qixin MEMS Co., Ltd.	http://www.qxmems.com/
	5. Shandong Sunfull Geophysical Equipment Co., Ltd.	http://www.sunfull.com
	6. Weifang Geer Optical Technology Co., Ltd.	http://www.goerxon.com/
	7. Goertek Inc.	http://www.goertek.com/
Guangdong (7)	1. Shenzhen Rion Technology Co., Ltd.	http://en.rion-tech.net/
	2. AAC Technologies Holdings Inc.	http://www.aactechnologies.com/
	3. Micropoint Bioscience Inc.	http://www.micropointbio.cn/index.html
	4. Optiviva Inc.	http://www.optivivainc.com/
	5. Shenzhen Xinli Technology Co., Ltd.	http://www.itbsxl.com/
	6. Guangzhou Sick Sensor Co., Ltd..	https://www.sick.com/cn/zh

Province	Company	Website
	7. Tecsis(Shenzheng)Sensor Co., Ltd.	https://www.tecsis.cn/
Tianjin (3)	1. Tianjin North Micro System Co., Ltd.	
	2. Tianjin MNCHIP Technologies Co., Ltd.	http://www.mnchip.com/index_e.html
	3. Turk (Tianjin) Sensor Co., Ltd.	http://www.turck.com.cn/cn/
Zhejiang (6)	1.Ningbo MEMS Electronic Technology Co., Ltd.	http://www.mems.cc
	2. Raynisen Technology Co., Ltd.	http://rnsdz.chinapyp.com/
	3. Silan Microelectronics	http://www.silan.com.cn/english/all/default.aspx
	4. Dali Technology Inc.	http://www.dali-tech.com/
	5. Aerospace Southocean (Zhejiang) Science and Technology Co., Ltd.	http://www.china-cells.com/
	6. Hangzhou Silan microelectronics Co., Ltd.	http://www.silan.com.cn/
Hunan (2)	1. Hunan Huaxingyu Sensing Technology Co., Ltd.	http://hua.e-eway.com/
	2. Firstrate Co., Ltd.	http://www.firstsensor.cn/
Hebei (3)	1.MT Microsystems Co., Ltd.	http://www.cetcmems.com/
	2.Winson Co., Ltd.	http://www.winsensor.com/
	3. Unigroup Guoxin Co., Ltd.	http://www.jingyuan.com/
Liaoning (2)	1.Liaoning Hanking Microelectronics Co., Ltd.	http://hankingwdz.cn.gongchang.com
	2.SSCL Co., Ltd.	http://www.industry.siemens.com.cn/topics/cn/zh/oc/SSCL/Pages/SSCL.aspx
Chongqing (1)	Chongqing Jinshan Science & Technology (Group) Co., Ltd.	http://english.jinshangroup.com/
Sichuan (1)	Chengdu GoldTel Electronical Technology Co., Ltd.	http://www.guoteng.com.cn/en/en/
Hubei (3)	1.Universal Sensors Inc.	http://www.usisensor.com/
	2.China Aerospace Times Electronics Co., Ltd.	http://www.catec-ltd.cn/
	3.Wuhan Guide Infrared Co., Ltd.	http://gaodehw.company.lookchem.cn/
Shanxi (1)	1.Shanxi Kotelmems Co., Ltd.	http://www.kotelmems.com/
Anhui (1)	1. Hefei Xinfoo Sensor Technology Co., Ltd.	http://www.xinfoo-ic.com/index.html