FACULTY INVENTION DISCLOSURE AND PATENT ASSIGNMENT IN UNIVERSITY-INDUSTRY TECHNOLOGY TRANSFER IN CHINA: A MIXED METHODS STUDY

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Faculty Invention Disclosure and Patent Assignment in University–Industry Technology Transfer in China: A Mixed Methods Study

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Certificate of Originality

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ABSTRACT

In the past few decades, universities have established a close relationship with industry, thus placing university–industry technology transfer at the forefront of academia, industry practice and policymaking. Discussions in this regard are based primarily on the assumption that university faculty voluntarily disclose details on inventions to the universities with which they are affiliated. Evidence from the US and European countries illustrate, however, that a sizeable number of faculty inventions are not assigned solely to universities. Many studies also point out that the invention disclosure process is affected by moral hazard and adverse selection. Although existing research has demonstrated the negative influence of invention disclosure on university technology transfer, few studies have been devoted to faculty invention disclosure in the context of Chinese universities. This scarcity is attributed to considerable difficulty in data collection. To fill the aforementioned research gaps, this thesis investigates the reality that surrounds the patent assignment practices of university faculty in mainland China. To this end, theoretical game models that simulate stakeholder strategies are developed.

First, I create a special dataset that comprises 18,435 faculty/patent pairs. The investigation indicates that from 2002 to 2012 13.16% of pairs are not solely assigned to universities in 35 top patent application Chinese universities. The empirical study conducted at the individual faculty level correlates types of patent assignment with the characteristics of inventions, the intellectual eminence of universities and policies for licensing. The study emphasises the following insights: patent assignment changes depending on research field; university assignment is positively related to patent claims but negatively related to the number of co-inventors; and university royalty and equality policies play different roles in the patent assignment practices of university faculty. The empirical research carried out at the organisational level is intended to analyse the influence of university characteristics, R&D input/output and external environment. The results reveal that university faculty tend to attribute low-quality inventions to the universities with which they are connected.

Second, I scrutinise the influence of patent checking on faculty invention disclosure and university licensing strategies, after which I develop a static game model specifically for examining such influence. I found that patent evaluation is negatively related to invention disclosure but that it influences high-value inventions to a lesser extent. I propose that the requirement for universities to match checking policies, licensing strategies and checking rates are negatively related to inventor share rates. This study also explores the process of technology transfer from faculty inventors to industrial firms. The theoretical results uncover a series of conditions necessary for invention disclosure and commercial model selection. They also serve as bases for formulating an optimal revenue distribution scheme and patent licensing contract. The empirical results confirm the validity of the theoretical conclusions and provide valuable practical implications. Moreover, this research introduces the concept of a university technology transfer chain and generates a game model that enables the investigation of a double moral hazard problem. I found that the licence contract commonly adhered to in Chinese universities cannot reduce such hazard. The portfolio contract with royalties and revenue sharing successfully works only under specific circumstances, but the side-payment self-enforcing contract can effectively coordinate all stakeholder behaviours.

Finally, on the basis of the empirical and theoretical insights derived in this work, the influence of university policies and government-related measures is qualitatively analysed. The policies and measures reviewed include regulations on the ownership of university inventions, patent checking, government funding and teachers' key performance indicators. This research provides new insights for faculty who are interested in patent application and presents implications for university administration and policymaking.

Keywords: University technology transfer; Faculty invention disclosure; Patent evaluation; Licence revenue management; Licence contract coordination

PUBLICATIONS

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5. Zhan, Z.H., **Chang, X.H.**, Fong, P.S.W. Liang, T. (2014). Project-based online collaborative knowledge sharing model: Based on game theory. *Open Education Research*, 20(5), 75-82.

6. Chen, Q., **Chang, X.H.**, Fong, P.S.W. (2014). Impact of Value Evaluation Policy on Invention disclosure and Licensing Strategy. *Forecasting*, 33(6): 43-48, 53.

7. Chen, Q., **Chang, X.H.** (2013). Comparative study on university technology transfer under license contract. *Journal of Tongji University (Natural Science)*, 12, 1910-1916.

8. Chen, Q., **Chang, X.H.**, Li, J.C. (2013). Comments on China's innovation strategy and the coping strategies. *Science and Technology Progress and Policy*. 20, 155-160.

9. Chen, Q., **Chang, X.H.**, Li, J.C. (2013). Plans for opening up science and technology in some developed countries and regions and the lessons they offer. *Comparative Economic and Social Systems*, 2, 236-243.

10. Zhan, Z.H., Fong, P.S.W. Hu, M., **Chang, X.H.**, Liang, T., Ma, Z.C. (2015). Sustainability education in massive open online courses: A content analysis approach. *Sustainability*, 7, 2274-2300.

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List of Abbreviations

UITT: university-industry technology transfer

TTO: technology transfer office

R&D: research and development

S&T: science and technology

MoE: Ministry of Education

MoST: Ministry of Science and Technology

SAO: State Asset Office

CNKI: Chinese National Knowledge Infrastructure

AUTM: Association of University Technology Managers

Chapter 1 Introduction

This chapter introduces the research background and concepts related to university–industry technology transfer (UITT). It also presents the research aim, objectives and questions, as well as the research methodology, limitations and thesis structure.

1.1 Research background

'University-industry technology transfer is the process of transferring university scientific findings from one organization to another for the purpose of further development and commercialization[1]*.'*

Association of University Technology Managers (AUTM), US

1.1.1 University–industry technology transfer

In the earlier part of the last century, universities traditionally paid little attention to technology transfer and patent licensing because higher education institutions were not seen as an important source of industry technology. Before 1930, for example, many leading US universities (e.g. MIT, UC Berkeley, Pennsylvania State University) allowed their faculty members to independently patent and sell inventions/patents to partly compensate for their low salaries (Matkin, 1990). During this period, technology transfer from universities to industry was informal and disorganised. In most circumstances, the disclosure of patents for inventions created with the help of federal funding was not a mandatory requirement for university faculty. Amendments to this regulation were not implemented until after World War II; at the time, universities began transferring defence technologies to civil industry. After realising the potential profits that can be earned from university innovations, governments and universities began establishing formal patent policies. The most revolutionary policy changes occurred in the 1980s in the US. More than 10 laws were introduced to facilitate UITT, and most of them are

[1] This definition comes from the American Association of University Technology Managers, http://www.autm.net/Tech_Transfer.htm, 2014/2/20.

based on the principles articulated in the Bayh–Dole Act (1980): 'Each non-profit organization or small business firm may, within a reasonable time after disclosure as required by paragraph (c)(1) of this section, elect to retain title to any subject invention (Public Law 96-517-DEC.12, 1980)'. Following this proclamation, UITT in the US achieved great successes up to the end of the 20th century. Because of these achievements, the governments of other nations (e.g. OECD countries, such as Japan, and China) followed suit and developed similar patent policies in the last century to enhance the roles of universities in technology transfer.

Towards the last century, universities and their faculty have become increasingly involved in building national innovation systems under knowledge-driven economies (Nelson, 1993; OECD, 2002). A widely recognised understanding is that industry can benefit from basic and applied research in universities through open schemes (e.g. academic publications and conferences, employment of graduates), semi-open schemes (e.g. consulting projects, cooperative research and development projects and education training) and market-based schemes (patents and technology licences). Amongst these three avenues, market-based schemes have long been a particularly significant area of interest amongst academicians, industry practitioners and policymakers, even though such strategies are viewed as reflecting a narrow concept of UITT. University-based patents and technologies that come with economics incentives are regarded as an effective measure for bridging 'Darwin's Gap'. Unlike the two other avenues, market-based schemes, as the most formal, enables easier evaluation of the contributions of faculty and organisations because of the transparency and manageability of these schemes (Mowery and Shane, 2002; Thursby, Fuller, and Thursby, 2009).

1.1.2 Faculty invention disclosure

As stipulated in the Bayh–Dole Act of 1980, universities have the right to retain title to all the faculty inventions resulting from government-funded research; after the enactment of the Act, such provision became an explicit stipulation in employment contracts[2]. Faculty are obligated to disclose their inventions to university administration. Nevertheless, the current situation does not reflect strict adherence to the Act's stipulation, as indicated by the numerous high-value inventions that were undisclosed to technology transfer offices (TTOs) (Markman, Panagopoulos, and Gianiodis, 2007). Thursby, Fuller, and Thursby (2007) conducted a study for the National Bureau of Economic Research (NBER) and found that only 64.30% of US faculty patents are assigned solely to universities; this difficulty in acquiring exclusive patent licences results from consultancy arrangements. The author created a unique dataset that contains information on individual faculty members to theoretically calculate each faculty's invention disclosure rate. The non-university nature of patent assignment is unsurprising given the difference in economic returns accrued from patent rights. Upon invention disclosure, universities grant faculty inventors a share of 30% or lower, but without disclosure, faculty can retain 100% of the profits earned from inventions. Table 1.1 lists the exact proportions of patents that are not exclusive to universities in selected countries.

Table 1.1 Patents not exclusively owned by universities (%)

Country	US	UK	France	Spain	Italy	Netherland	Germany
Undisclosed	26.87	67.00	93.00	47.00	96.00	80.00	96.00

Source: Crespi, Geuna, and Verspagen (2006), Thursby et al. (2007).

This phenomenon can be attributed to three factors. (1) Some European countries (e.g. Sweden and Italy) did not sign the Bayh–Dole Act, and some other nations (e.g. Spain) stopped implementing said Act. The university faculty in these countries are allowed to apply for exclusive ownership of their inventions (Crespi et al., 2006; Damsgaard and Thursby, 2013). (2) In other countries, such as Canada and Japan, universities have the freedom to adopt different patent management systems; in these nations, therefore, faculty invention disclosure depends on university regulations (Kiskis, 2012). (3) In US

[2] In this research, I discuss only the inventions/patents resulting from government-funded research. In the R&D cooperation between university faculty and private firms, inventions are always owned by firms because of their research investment.

universities, applications for exclusive patent licences are regarded as originating from the nature of technology consulting projects, rather than from an intent to engage in lawless behaviour on the part of university faculty (Thursby et al., 2007, 2009).

1.1.3 Issues regarding university–industry technology transfer in Chinese universities

A survey conducted by Zhejiang University of Technology in 2005 illustrates that 30% of Chinese universities have been confronted with serious intellectual property (IP) losses as a result of the non-disclosure of inventions to universities. Zhou and Zhu (2007) examined 2,764 university patents, which were selected on the basis of specific keywords (i.e. ‘The patent applicant or contact address contains the words “university”, “college” or “school”’.). Their results (Table 1.2) show that only 75% of university patents are owned solely by universities; 1.85% are exclusive to firms; 8.72% are jointly owned by a university and a firm; and 13.28% are owned by individuals[3].

Table 1.2 Faculty patent assignment in Chinese universities

Assignee	University	University and firm	Individual	Firm	Others	Observation
Proposition	75.43%	8.72%	13.28%	1.85%	0.72%	2,764

In the middle of the last century, China introduced an education and technology system that is based on that implemented in the former Soviet Union. Under this planned economy, Chinese universities transfer their knowledge and inventions to industry without having to pay for any fees. After China’s market economic reform in 1976, however, this UITT feature was abolished because of the separation between production and R&D departments. As China’s universities endeavoured to keep pace with top universities in terms of scientific development, the quality of technology in Chinese industries remained at a considerably low level. This widening technological gap sometimes directly translated to sub-par UITT performance, thus giving rise to an urgent

[3] Note that their findings do not provide the reasons that prompt faculty choice of non-university assignment. In addition, their research is conducted at the university level rather than at the faculty individual level. Their dataset therefore does not classify inventor identities (e.g. university faculty, research student, firm research staff).

need for exhaustive investigations into how China's UITT performance can be improved.

From the perspective of invention disclosure, non-disclosure to universities possibly reduces the commercial value of university-owned patents, thereby exacerbating poor UITT performance in Chinese universities. Despite this growing problem, little research has been devoted to faculty invention disclosure in the context of China and to discussions of the relationship between invention disclosure and UITT performance. The current study aspires to fill these voids, motivated by the objective of facilitating UITT development in Chinese universities. The preliminary UITT-related issues pursued in this research are as follows. Is the phenomenon of non-university patent assignment more serious in China's universities than in Western institutions? What are the significant influencing factors for this severity? How can Chinese university administrations and the government prevent this problem?

1.1.4 Research focus

To solve the aforementioned practical issues, this research creates a dataset that comprises individual faculty-level information, following the data collection method of Thursby (2007). An empirical analysis is then carried out to investigate the reality that surrounds faculty invention disclosure and its influencing factors in the context of Chinese universities. To generate recommendations designed to help universities and the government manage the problems arising from invention disclosure, I concentrate on examining four processes: invention disclosure, patent quality checking, revenue management and licence contract design. For this purpose, I develop several theoretical models. The findings are intended to serve as reference in the formulation of policy measures for addressing the patent-related problems faced by Chinese universities.

1.2 Research delimitation

Patent for invention: Patent applications from university faculty in China include patents for inventions, utility models and presentation designs. Patents for inventions are generally more valuable than the two other types of patents because of the innovation involved in inventions. Accordingly, this research focuses primarily on the first type in examining the issue in question.

University invention: This research directs attention only towards inventions funded by the government. According to China's Patent Law and the university employment contract implemented in the country, these inventions should be owned by a university and not by individual faculty. This stipulation, however, does not apply to the exception clause in the ex-ante contract. Faculty are mandated to disclose their inventions to the universities that employ them.

Faculty invention (patent): More than one inventor is typically responsible for a given invention (patent). To simplify the research, I regard inventions as faculty creations only when a university faculty is the first inventor.

Faculty invention disclosure: Chinese university faculty are obligated to disclose inventions financed by the government to universities because patent application rights and ownership belong to the universities. For an application to count as having truthfully disclosed inventions to universities, a university should be one amongst several or the only patentee identified in a faculty patent document. Otherwise, faculty members may be suspected of attributing inventions to non-university assignees without university permission.

Non-university assignment: A university is not a patentee identified in a faculty patent document. It is the phenomenon of non-assignment of patents to universities.

1.3 Research motivation

This research is motivated by observations of serious problems regarding non-university assignment (Table 1.2), unreasonable patent management and poor UITT performance in Chinese universities. The government's current policies have also failed to effectively promote UITT in the country. Given this backdrop, this research aims to investigate these phenomena and their causes from the standpoint of invention disclosure and patent assignment. An empirical study on the top 35 patent applications from Chinese universities sheds light on the reality that surrounds the patent assignment practices of university faculty ('faculty patent assignment', hereafter). The study is also intended to examine the key influencing factors for the UITT process. Four theoretical game models are developed to simulate the decision-making process. Narrowing the gap in our understanding of faculty invention disclosure and fostering adequate management flow (i.e. ex-ante patent quality checking, reasonable revenue management and coordination contracts) are anticipated to facilitate significant progress in Chinese UITT.

1.4 Research aim and objectives

As previously stated, this research aims at truthfully illuminating the circumstances of faculty invention disclosure and stakeholder decision-making in the UITT process of Chinese universities. It also explores the moral hazard and adverse selection that affects stakeholders. In this regard, the research enquires into the disclosure practices of faculty and the licence contracts and policies implemented in universities. The research objectives are as follows:

(1) To establish an analytical framework for understanding faculty patent assignment, with specific consideration for non-university assignment, by
   - (i) defining the concepts of UITT and faculty patent assignment;
   - (ii) investigating the influencing factors of faculty patent assignment; and
   - (iii) investigating UITT development in China.

(2) To clearly elucidate the reality that surrounds faculty patent assignment by
   - (i) building a unique dataset and re-examining faculty patent assignment; and
   - (ii) examining influencing factors at the individual and organisational levels in China's universities.

(3) To build theoretical game models of decision-making regarding invention disclosure in accordance with the following goals:

(i) to investigate the optimal stage and type of invention disclosure for faculty;

(ii) to examine the influence of patent evaluation on faculty invention disclosure and university licensing strategies;

(iii) to examine the influence of university policies on faculty invention disclosure and UITT route selection; and

(iv) to design a contract that coordinates stakeholder decision-making with public interest.

(4) To triangulate the findings obtained from the interview survey, empirical studies and theoretical models for the following purposes:

(i) determining whether the theoretical game models are aligned with the other analyses; and

(ii) formulating policy recommendations.

1.5 Research questions under each objective

I formulate the following sub-questions in relation to the objectives:

(1) To facilitate understanding of UITT and faculty patent assignment

(a) How are UITT and faculty patent assignment defined in this research?

(b) What types of faculty patent assignment systems exist in China's universities?

(c) What are the influencing factors for faculty patent assignment, and how do these affect faculty decision-making as indicated in the literature review and interviews?

(d) How does UITT develop or progress in Chinese universities?

(2) To clearly elucidate the reality that surrounds faculty patent assignment in Chinese universities

(e) How many faculty patents are assigned separately to universities and industrial firms, jointly to universities and firms or separately to individual faculty in Chinese universities?

(f) What affects the decisions of faculty regarding assignment?

(3) To simulate stakeholder decision-making and the UITT process

(g) How are optimal disclosure stage and type chosen in Chinese universities?

(h) How does patent quality checking affect invention disclosure and licensing decisions?

(i) What is the relationship between faculty profit and invention disclosure?

(j) How do revenue policies affect patent assignment and UITT route selection?

(k) How is stakeholder decision-making coordinated?

(l) How do licensing contracts affect the decisions of faculty regarding invention disclosure?

(4) To triangulate the findings obtained from the interviews, empirical studies and theoretical models

(m) Do the theoretical findings correspond with the interview and empirical results?

(n) What improvements to the UITT process can Chinese universities and the government implement?

1.6 Research methodology

Given that the principal objective of this research is to investigate the actual circumstances that characterise patent assignment in Chinese universities, it follows the design-based research approach of Thursby et al. (2007). Quantitative research is conducted to ascertain the factors that influence faculty patent assignment. Four mathematical models based on game theory are also developed to explore the relationship between patent assignment and university policies, between invention disclosure and patent evaluation and between UITT and contract design.

1.6.1 Empirical research

Thursby et al. (2007) developed a data collection technique to determine how many university patents are assigned to non-university assignees. To address sub-questions (e)–(f), this research adheres to Thursby et al.’s (2007) baseline. The data collection and analysis approach stages are divided into two phases. First, I construct a special dataset based on the curricula vitae (CVs) of university faculty and on the database of the Chinese National Knowledge Infrastructure (CNKI). Assignment type, as the function of patent characteristics, individual characteristics and organisational and external environments, is a dichotomous or multiple-value variable. Hence, binary logistic and multinomial logistic regressions are conducted to analyse the effect of the three aforementioned factors.

1.6.2 Theoretical research

Empirical research explains a phenomenon in accordance with observed data. Because the present study is related to management science, theoretical models based on game theory are developed to exhaustively examine invention disclosure issues (e.g. disclosure stage and type, quality evaluation, licensing contract design, etc.). This section discusses four mathematical models based on principal–agent theory to answer sub-questions (g)–(l).

1.7 Significance and limitations

As indicated in the requirements stipulated in 'China's National Medium- and Long-term Science and Technology Development Planning (2006–2020)', improving the country's performance in terms of university technology transfer is a highly significant strategy. I hope for this research to aid the understanding of how faculty patent issues are managed. This study comprehensively analyses faculty invention disclosure from the perspective of faculty inventors, university administrations and firms. Using the approach developed by Thursby et al. (2007), I examine the top 35 patent applications from Chinese universities to determine how many faculty patents are non-exclusive to these institutions. The empirical study uncovers related influencing factors, including patent characteristics (i.e. claim, technology field and year of application), inventor attributes (i.e. professorship, age), university policies and business environments. Using the results as bases, I generate four theoretical models to simulate the decision-making process that underlies invention disclosure. Through these models, I develop recommendations on how to choose the optimal invention disclosure stage and type, verify the quality of inventions disclosed by faculty and create an adequate inventors' share of licence revenue. Guided by an in-depth understanding of invention disclosure and patent assignment, I draw key recommendations and policy implications designed to help Chinese universities effectively and efficiently manage faculty invention disclosure and patent assignment.

Similar to many studies, this research has limitations. First, the empirical analysis is based on faculty- and university-level data that are characterised by certain constraints. Some determinants, such as public funding, regional characteristics and co-inventors' backgrounds, are not taken into account. Bias may therefore exist in the empirical results. Future research should incorporate these factors into analyses; an example issue for investigation is the manner by which public funding influences faculty patenting. Second, the data for analyses may not be adequately representative of the population. This research probes into the top 35 patent applications from Chinese universities, but the country is home to more than 2,300 higher education institutions. In addition, whether the schools of mechanical engineering, telecommunications and life science are representative of entire universities requires verification through further testing. Furthermore, the forward and backward citations of patents are significant measurements of applied/basic inventions, but such information is unavailable in the context of Chinese universities. This study is therefore unable to determine whether non-university assignment in China is due to technology consulting projects. The future directions planned by our research group include improving the data collection process. I will look into the possibility of randomly selecting faculty patent samples from a specific university and continue to use the logit regression model to explore the relationships amongst influencing factors at the individual faculty, university and technology market levels. Finally, I disregard the influence of university incubators and TTOs on the sampled universities.

1.8 Thesis structure

This thesis consists of six chapters.

Chapter 1 provides the research background and some concepts related to UITT. The aim and objectives of the research are also presented in detail.

Chapter 2 contains the review of literature on faculty invention disclosure, its influencing factors and the history of Chinese UITT. This chapter likewise discusses the developed analysis framework for UITT that involves faculty inventors, universities and industrial firms.

Chapter 3 introduces the methodology of the research. Aiming at providing a comprehensive picture of faculty patent assignment in China's universities, this research follows the data collection approach developed by Thursby et al. (2007). The empirical analysis approach and mathematical models in the current work are also presented in this chapter.

Chapters 4 and **5** comprehensively discuss the study process. Chapter 4 illustrates the factors that drive non-university assignment; these factors were determined by empirical analysis, and the results are intended to answer research sub-questions (e)–(f). On this basis, I acquire answers to sub-questions (g)–(l) through modelling studies and develop new policy systems to improve invention disclosure and UITT performance in China. These issues are discussed in Chapter 5.

In **Chapter 6**, I triangulate all the findings to answer research sub-questions (m) and (n), provide new insights and policy recommendations for China's universities and government. This chapter concludes the theses with a presentation of limitations and potential direction for further studies.

The research framework and logical flow of the study are summarised in Figure 1.1.

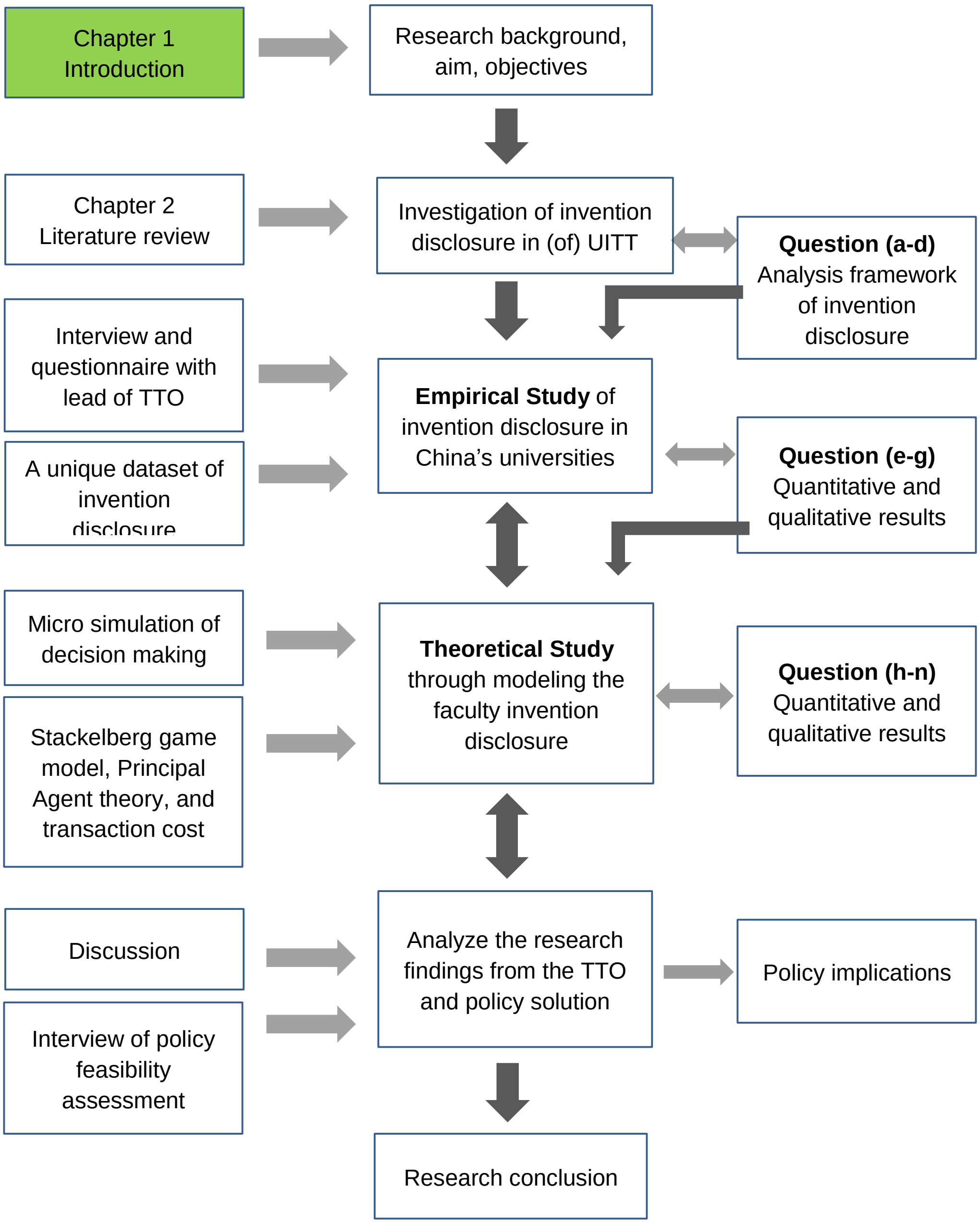

Figure 1.1 Logical flow of the research

Chapter 2 Literature Review

The literature review consists of three parts. The first introduces theories on UITT and faculty invention disclosure. The second part provides detailed information regarding invention disclosure, including that on disclosure stage, type, quality and influencing factors. The third segment provides an overview of Chinese UITT and discusses the literature gaps that the present research aims to address.

2.1 Theories on university–industry technology transfer

This section introduces the conceptual framework and six business models of UITT from a macroscopic level. After this, the microeconomic process that underlies UITT, as well as stakeholders' targets, conflicts of interest and courses of action, are described.

2.1.1 Conceptual framework for university–industry technology transfer

UITT has only recently become a key interest in the context of higher education, even though practitioners have been involved in this field for a long period[4] (e.g. Baldini, 2009; Henderson, Jaffe, and Trajtenberg, 1998; Jose et al., 2013; Richard et al., 2011; Rothaermel, Agung and Jiang, 2007; Thursby, Jensen, and Thursby, 2001; Thursby and Thursby, 2011). UITT pertains to the process of developing practical activities designed to convert university scientific research into real-world applications. This process involves three entities: universities, faculty inventors employed by universities and industrial firms. Figure 2.1 illustrates the conceptual framework of UITT. Faculty usually create inventions through their academic research (Jaffe, 1989). As intermediaries between faculty inventors and potential industrial partners, universities apply for research funding from social groups, encourage faculty to carry out advanced scientific research and promote technology transfer in various ways (i.e. education, patent transfer, publications and consulting services). This research focuses mainly on patent transfer because of the transparency that characterises this process (Link, Siegel, and Bozeman, 2007).

[4] In ancient times, Archimedes [287–212 BC] paid attention to applying science to practical problems.

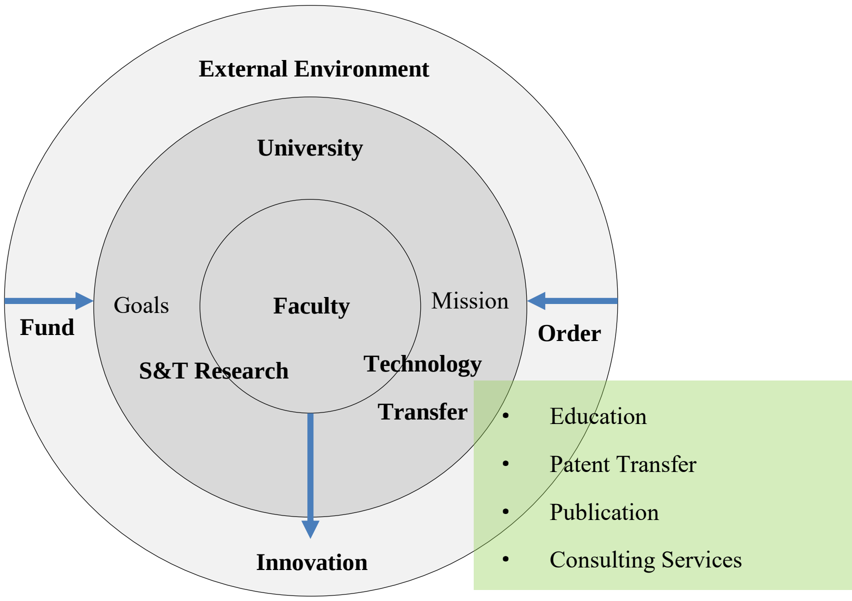

Figure 2.1 Conceptual framework for university–industry technology transfer

Source: Prabhu R., 2007. Knowledge creation and technology transfer in nanotechnology at research universities. The Pennsylvania State University, US.

2.1.2 Commercial modes

With respect to the UITT related to genuine technology transfer, universities employ six different business modes:

1. Industry-sponsored contract research
2. R&D collaboration
3. Technology consulting programmes
4. Licensing university technologies to industry
5. Joint development and commercialisation of university technology
6. Start-ups based on university technologies

Although these modes can be viewed as encompassed under UITT, this research disregards modes 1, 2 and 5 because university patents may or may not be transferred from a university to an industry. The remaining business modes are discussed in the succeeding paragraphs to illuminate faculty patent assignment.

Business modes 3 and 4 are appropriate for university technology transfer because technology consulting programmes, which are based on problem solutions or R&D

collaborations, easily produce new innovations for industry. Additionally, ownership of the final research output is typically granted to industrial firms because of the investment (funding) that they infuse into research. This observation is supported by Thursby et al. (2007), who found that most non-university assignments in the US result from university–industry technology consulting projects.

Business mode 6 is a typical route adopted by faculty inventors in introducing their technologies into the market. Under sufficient financial support, a university TTO and its faculty are motivated to participate in commercialising academic inventions by establishing start-ups. In mainland China, two types of start-ups based on university inventions are established. The first is the university-run start-up, which is always viewed as an established enterprise funded and controlled by universities. The start-up can take advantage of universities' various resources, such as research findings (e.g. patents, unique technologies), physical spaces (e.g. incubators, university science parks), social networks and the identities of universities as commercial brands. The second type is the faculty-run start-up, which is created by faculty inventors. In many cases, the faculty-run start-up leverages faculty's undisclosed inventions in gaining entry into the market.

2.1.3 University–industry technology transfer process based on patent transfer

With regard to traditional UITT, earlier research defines its process as a simple linear flow model with two steps: (1) the preparation stage, which includes invention disclosure and patent evaluation and (2) the implementation stage, which encompasses negotiation and collaboration on contract design between universities and industry (Zaltman, Duncan, and Holbek, 1973). Succeeding scholarship uses this simple model as basis and expands it into a more comprehensive technology transfer process to include invention disclosure, evaluation of commercial value, patent application, licence execution, start-up establishment and licensing contract design (Rogers, Takegami, and Yin, 2001; Siegel, Waldman, Atwater, and Link, 2003a). In these more specific processes, TTOs evaluate the potential value of faculty patents before transferring ownership to interested firms. Instrumental to the success of university technology transfer, therefore, are three participants: faculty inventors, who create inventions; TTO staff, who facilitate the process; and firms, which invest in technologies. Governments, which fund most university research projects, can also be viewed as one of the most indispensable stakeholders (Link and Scott, 2006).

Figure 2.2 presents the process of transferring university inventions from faculty inventors to firms, including established companies and start-ups. This general flow reflects a comprehensive process for all stakeholders' courses of action. The commercial route of UITT is presumed to start with an academic invention and depends on decisions regarding faculty invention disclosure. Before disclosing an invention to a TTO, faculty members independently search for potentially interested firms because this strategy enables the former to retain 100% of patent licensing revenue, as opposed to the aforementioned 30% granted to them by universities. Once a faculty's patent application is approved, the potential partner firm and faculty collaborate in immediately marketing the patent; successful UITT necessitates both the faculty's effort and the firm's technological investment (Aghion and Tirole, 1994; Crespi et al., 2006; Dechenaux, Thursby, and Thursby, 2011). Conversely, when faculty disclose inventions to their university, a TTO evaluates the commercial value of the inventions and decides on whether the faculty can proceed to patent application. A faculty patent can be used to establish a start-up, wherein a faculty member acts as the principal official or director, or it can be licensed to a firm by TTOs. Meanwhile, the faculty inventor and the firm decide on how much effort and funding to invest, respectively, after which the TTO and the firm sign a licensing contract.

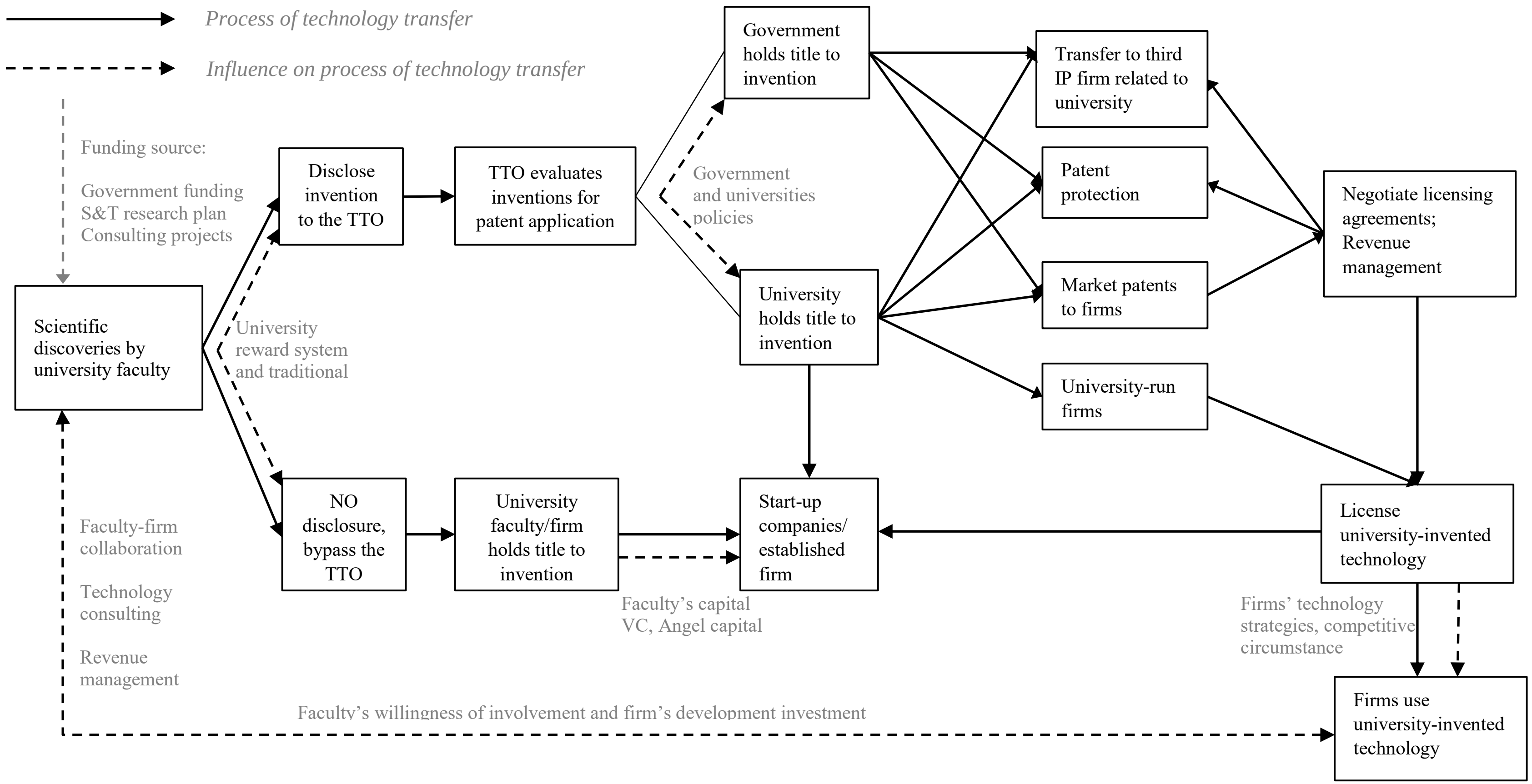

Figure 2.2 Process of university-industry technology transfers from faculty inventor to firm

Source: Bradley S.R., Hayter C.S., Link A.N., 2013. Models and methods of university technology transfer. The University of North Carolina, US, Working paper

2.1.4 Stakeholders' targets, conflicts of interests and courses of action

Conflicts of interest in universities are very common. This problem is not restricted to the level of university researchers but occurs amongst all UITT stakeholders as a result of differing targets and actions. To enable a comprehensive understanding of UITT, I illustrate the targets, conflicts of interest and courses of action of faculty inventors, university administrations (TTOs) and firms in Figure 2.3.

The actions taken by faculty inventors play the most significant role in UITT because the response of TTOs and firms depend on whether faculty disclose their inventions to universities. If they do not, the technology transfer chain will involve only faculty inventors and firms or faculty inventors alone. Because faculty are prohibited from owning their inventions, as mandated in the Bayh–Dole Act of 1980 or similar legislations, adverse selection may occur when they conceal high-value inventions and disclose only low-value creations to their universities (Markman et al., 2007). The worst-case scenario would be that the commercial value of all university-owned patents will diminish to levels lower than those of non-university patents. TTOs experience difficulties in introducing these patents to the technology market.

As an intermediary, university TTOs are required to bring scientific inventions from universities to the marketplace. As a bureaucratic entity, however, a TTO may occupy an adverse position (Kenney and Patton, 2009, 2011; Macho-Stadler, Martínez-Giralt, and Pérez-Castrillo, 1996). TTOs deal with pressure from university administrations regarding research funds, invention disclosures and patent incomes, amongst other issues. They are also obligated to establish a compromise with faculty inventors, who threaten to leave an organisation unless they are granted substantial research funding; this situation brings forth both favourable environments and inefficient decisions (Feng et al., 2012).

In the R&D collaboration between a university and industry pair, the ex-ante contract normally specifies that patent ownership is granted to firms on account of their technological investment (Cohen, Nelson, and Walsh, 2002). Moral hazard and market failure sometimes occur when faculty inventors provide a higher marginal contribution to the success of technology development than do firms (Aghion and Tirole, 1994; Crespi et al., 2006).

To conclude, all stakeholders involved in UITT have different individual and organisational objectives. These differences create a troublesome final patent assignment process amongst the three key stakeholders, rather than engendering one that is based on economic efficiency or effectiveness.

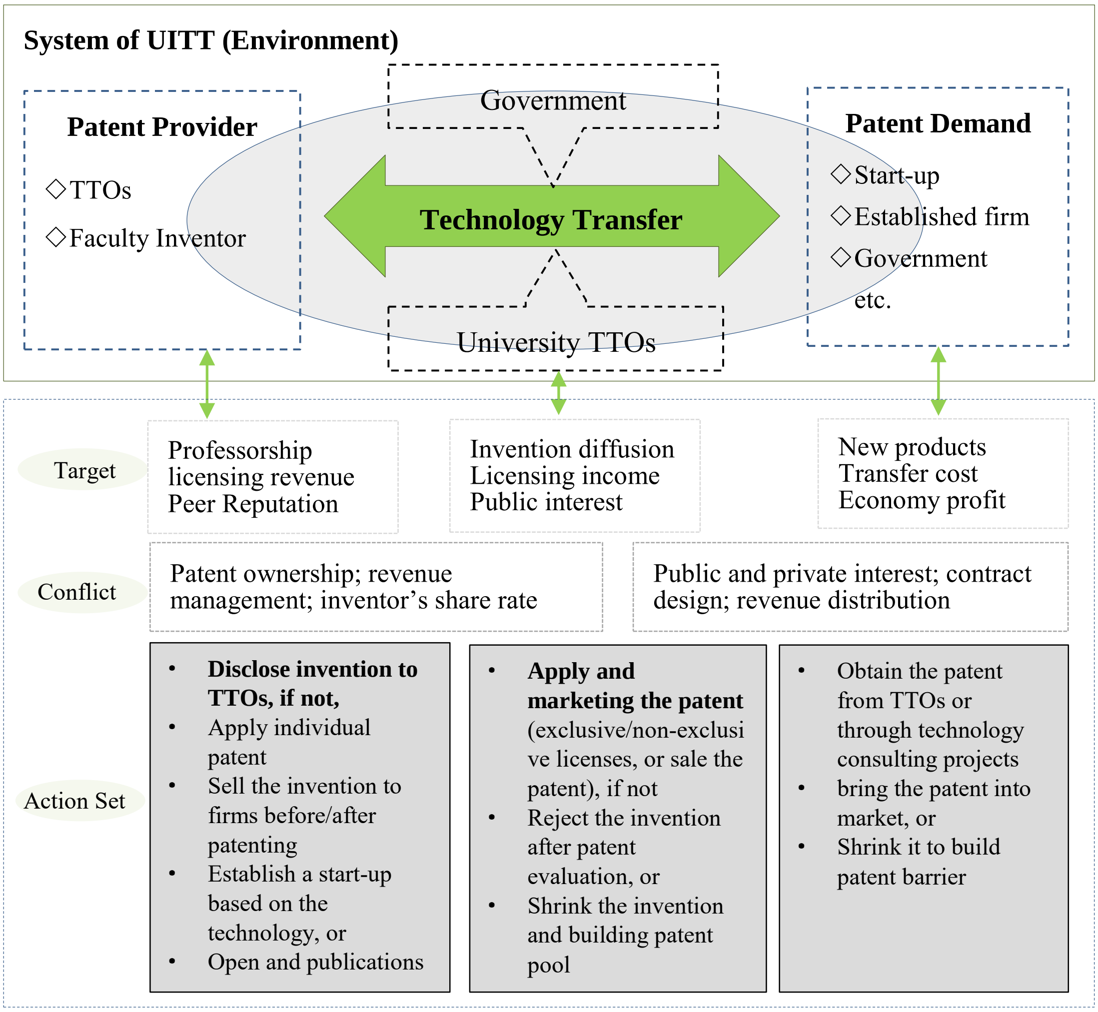

Figure 2.3 Targets, conflicts of interest and courses of action of faculty inventors, TTOs and firms

2.1.5 University–industry technology transfer in China

In 2012, China became the top patent application country in the world, and its Patent Cooperation Treaty (PCT) applications ranked third globally. By contrast, the country's

UITT performance was not as solid as its ranking in patent application. The survey conducted by Tsinghua University and Fudan University indicates that only about 10%–15% of faculty patents have been transferred to industrial firms. A significant question that arises from this situation is why Chinese UITT development is sluggish when so many patents exist in the country.

2.1.5.1 History of university–industry technology transfer in China

(1) Period 1: Mao Administration

During the infancy of Chinese UITT, the former Soviet Union was a significant benchmark for Chinese universities. During the administration of Chairman Mao, China relied primarily on technical aid from the Russian government. Chinese universities focused on problem solutions and basic research but paid minimal attention to research funding and market demand. Particularly under the orders of Chairman Mao, universities' top scientists and graduates worked on initiatives involving heavy and defence industries[5], such as the '156 Industry Projects'; these creators set aside basic research and genuine technology transfer. During this period, UITT mostly meant graduate employment.

(2) Period 2: 1980s–1990s

The tendencies that were prevalent during the Mao administration began to change in the post-Mao period as a result of China's reform and opening up policies. The new Chinese leadership consistently emphasised the central role of science and technology (S&T) in China's modernisation[6]. At that time, China had four goal categories for technology development: 'industry modernisation, agriculture modernisation, defence modernisation and science and technology modernisation'. The Chinese government recognised that these goals cannot be achieved without technology transfer from foreign countries. It was impossible,

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[5] University technology, apart form economy and market demand, led to fairly poor development of civil industry. As described by the US Congress, China is 'A country which has launched satellites into space but cannot manufacture water faucets of good working conditions'.

[6] In 1982, Premier Zhao Ziyang said that reaching China's overall economic goals by year 2000 would be impossible without major contributions from modern S&T. In 1988, Deng Xiaoping, who is the designer of China's reform and opening up strategy, declared that '[science] and technology are the primary productive forces'.

however, to directly import the most advanced technologies because foreign countries are characterised by ideologies and social systems that differ from those of China. The only feasible channel for technology transfer, therefore, was to send students and young scientists to Western universities and research institutions for advanced training. At the beginning of the post-Mao period, China's UITT translated to technology transfer from Western universities to China[7].

Meanwhile, the central government also shifted focus from defence to civil industries, encouraging all universities to contribute to China's four goals of modernisation. For example, to undertake extensive systematic applied research, such as studies on high-speed locomotives and large-scale integrated circuits, the Chinese Ministry of Science and Technology (MoST) initiated the establishment of 294 National Engineering and Technology Research centres. Formal business technology transfer from China's universities to industry (i.e. UITT), the third goal (i.e. society service) of China's universities, began in the mid-1990s.

(3) Period 3: 21st Century

In the past decades, China's rapid economic growth has created vigorous demand for sophisticated technologies. Nevertheless, the R&D infrastructure, personnel and innovative spirit of China's enterprises were insufficient for effectively responding to such demand. These technological conditions provided China's universities opportunities to transfer applied and basic research insights to industrial firms. This situation is expected to persist, even though the Chinese government has encouraged industry to independently innovate in various ways. Thus, the government still regarded universities and research institutions as the principal sources of the technological innovation necessary to accelerate the country's economic growth and the global competitiveness of Chinese enterprises. In this period, UITT meant introducing new technologies into the product market to benefit consumers, enhance social welfare (Akoi and Siegel, 2003; Lach and Schankerman, 2003) and continually support R&D (Hall, Jaffe, and Trajtenberg, 2001).

[7] Office of Technology Assessment, 1987. Technology transfer to China. Congress of the United States, p. 39.

2.1.5.2 Special characteristics of Chinese UITT

After the economic reform and opening up policy of 1978, China's universities began to emulate the development patterns prevalent in US universities for the purpose of securing a position amongst the top-level research universities in the world. Accordingly, stakeholders integrated the special UITT characteristics of the former Soviet Union and the US into Chinese UITT. First, China's universities are publicly funded and governed by the Ministry of Education (MoE), the Ministry of Industry and Information Technology (MITT) or local governments. All scientific outputs, such as unique technologies, patents and integrated circuit layouts, are defined as state-owned intangible assets that are controlled by State Asset Offices (SAOs). Second, although UITT is considerably encouraged by the Chinese government, the universities are not granted full authority to dispose of faculty patents. Whether a TTO can independently transfer technologies depends on the extent of licensing and number of licences issued. All significant technology transfers require approval from SAOs. Moreover, patent licensing income is to be surrendered to China's state treasury, after which the government redistributes this income amongst universities, faculties and TTOs as part of the fiscal budget.

2.2 Theories on faculty invention disclosure

2.2.1 The Bayh–Dole Act of 1980

Over the years after World War II, US universities and research institutions believed that federal ownership of faculty inventions funded by governments has become the most challenging observable obstacle to UITT (Kenney and Patton, 2009). On September 13, 1978, Senators Bayh and Dole proposed a federal patent policy that affords universities and small businesses the right to any patents resulting from government-funded research. In December 1980, then-US President Jimmy Carter signed the Bayh–Dole Act into law (Mowery et al., 2004). The Act substantially changed the manner by which government-financed technologies were commercialised and disseminated. It served as the new set of guidelines for university administrations, researchers and patent buyers (Siegel, Waldman, Atwater, and

Link, 2004). With respect to the university setting, the Act facilitated patenting and licensing in two ways: (1) on a case-to-case basis, universities could now own faculty inventions without having to acquire permission from the federal government[8], and (2) university administrations were now granted stronger authority in negotiating with industrial firms regarding exclusive/non-exclusive patent licences[9] (Mowery et al., 2004).

All legislations are the outcomes of social and political choice. Figure 2.4 plots the political history of the Bayh–Dole Act of 1980 in the US. In the 1940s and 1950s, US universities factored minimally in debates about federal patent policy because of universities' tradition of avoiding direct involvement in patenting and licensing activities[10] (Matkin, 1990). This disregard is also attributed to the low R&D federal funding provided to US universities (Mowery et al., 2004). In 1968, confronted with the concerns of society, the Federal Council for Science and Technology began directing attention towards the effects of federal patent policy on universities. During the 1970s, the DHEW, National Science Foundation and Department of Defence established the IPA, which allows universities to own federally funded faculty inventions, although this 'approved technology transfer capability' is decided case by case (Weissman, 1989).

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[8] In 1968, prompted by the criticism from the General Accounting Office, the Department of Health, Education and Welfare (DHEW) established the Institutional Patent Agreement (IPA), which affords university administrations the right to 'approved technology transfer capability'. This capability allows universities to retain title to inventions resulting from federally funded research.

[9] Before the Bayh–Dole Act, the DHEW paid more attention to universities' patenting and licensing activities, especially exclusive licenses that can raise tax payers' health education costs. In this period, therefore, the DHEW requested for IPAs to limit universities' negotiating power with regard to exclusive licenses.

[10] Before the 1930s, US universities and faculty inventors rejected patent rights because it was discordant with traditional university ethics.

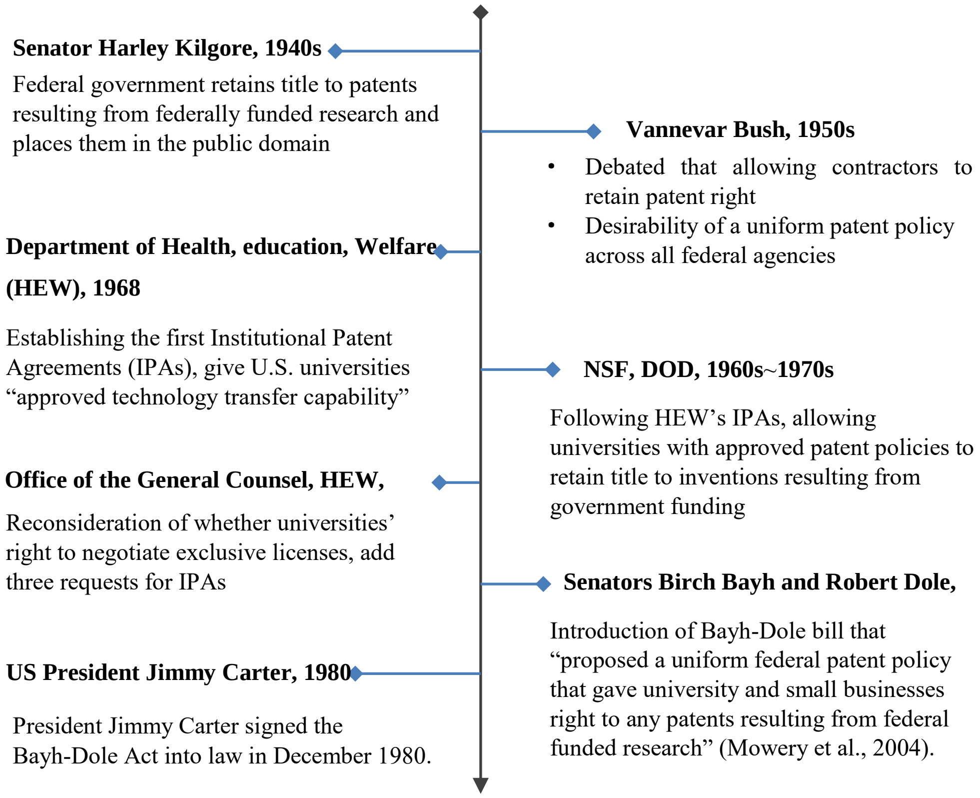

Figure 2.4 Political history of university invention ownership in the US

Source: Data from Mowery (2004), p85-99.

The Bayh–Dole Act of 1980 is widely regarded as a major revolution in federal policy on academic research. Similar to other legislations, however, the Act functions as a double-edged sword (Mowery and Ziedonis, 2002; Sampat et al., 2003). Even after 30 years, the most striking questions about the Act are those regarding its positive and negative effects and what may have happened had it not been enacted. To date, these issues have not been satisfactorily resolved. Using the extant literature (Aldridge and Audretsch, 2011; Grimaldi, Kenney, Siegel, and Wright, 2011; Kenney and Patton, 2009; Mowery and Ziedonis, 2002; Sampat et al., 2003; Tyler, 2013, etc.) as basis, I hypothesise on the possible positive and negative consequences of the Bayh–Dole Act on TTOs and university faculty in China (Table 2.1).

Table 2.1 Positive and negative effects of the Bayh–Dole Act (1980)

	University TTOs	University faculty
Positive effects	• Facilitate the marketing of faculty inventions • Have more bargaining power by integrating	• Getting professional UITT service • Increase the invention quantity

	faculties' inventions • Increase TTOs' income	• Enhance university scientists entrepreneurship
Negative effects	• Make TTOs focus on economic profit, rather than technology diffusion • Increase the information asymmetry	• Increase the transaction cost between faculty inventors and industrial firms • Increase the information asymmetry

2.2.2 University ownership and professorial privilege

In the context of certain European countries, determining patent ownership (university, firm or researcher) is the result of a bargaining process. During this process, the basic rule for economic efficiency is that patent ownership (entitlements) should be assigned to the stakeholder who is the most likely to make optimal market judgments. This section introduces two modes of invention ownership and summarises related arguments.

(1) University ownership mode

Upon the enactment of the Bayh–Dole Act of 1980, universities, as sources of innovation, were believed to stimulate economic development in the US (Kenney and Patton, 2009; Mowery et al., 2004). Although numerous drawbacks have been identified, this belief continues to drive efforts in ensuring that university ownership of inventions prevails under US IP systems. The Act grants universities two notable rights: (1) title to faculty patents and (2) the authority to negotiate with industrial firms for patent licences. Under this ownership mode, UITT is generally a linear process: faculty produce inventions, TTOs file faculty patent applications and market the patents and industrial firms commercialise these patents (Figure 2.5). TTOs act as intermediaries between faculty and firms (Hellmann, 2007; Hoppe and Ozdenoren, 2005) and between faculty and university administrations (Kiskis, 2012; Siegel et al., 2004). In this ownership mode, TTOs are the most critical players in the UITT process.

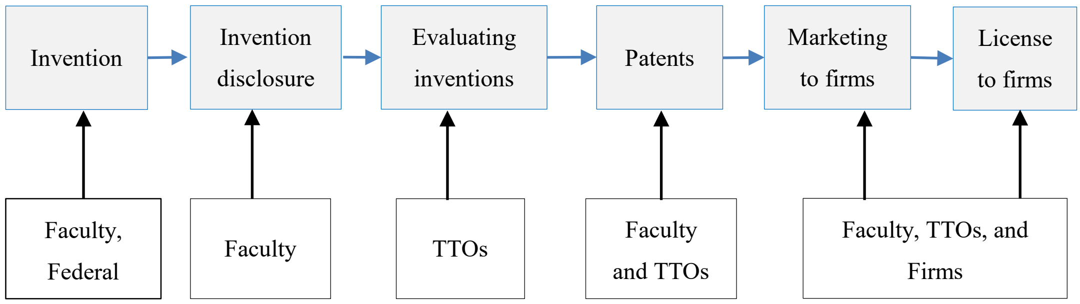

Figure 2.5 Linear model of technology transfer under university ownership

(2) Inventor ownership mode

The inventor ownership mode endows university faculty the right to own their inventions, a practice that was once widespread amongst European countries (Damsgaard and Thursby, 2013). To date, the inventor ownership mode remains popular in Sweden, Italy and Finland. Under this mode, faculty can elect to enlist the assistance of TTOs or any other organisation in commercialising their inventions. Even the more active involvement of faculty in the process, however, does not negate the value or necessity of TTOs. Technology transfer from faculty to industrial firms requires expertise on professional services, such as patent evaluation, marketing and IP issues (Kenney and Patton, 2009, 2011; Landry et al., 2013). Because the inventor ownership mode can reduce information asymmetry and because it presents lower transaction costs, it is deemed a more ideal mode than university ownership (Giuri et al., 2013; Kenney and Patton, 2009, 2011). Some of the inevitable disadvantages of this mode are as follows. (1) It decentralises decision-making on patent licensing, which may in turn, cause knowledge fragmentation that harms knowledge integration and product innovation (Crespi, 2006). (2) Inventor ownership encourages faculty to devote the bulk of their time on applied research instead of basic research; such concentration may be unfavourable for long-term interests.

Figure 2.6 depicts the UITT process under the inventor ownership mode. As indicated in the figure, university assignment is not a necessary condition for UITT. In addition, if faculty have richer contact networks and incur lower search costs, inventor ownership is a more effective UITT route because of reduced spending and faster response.

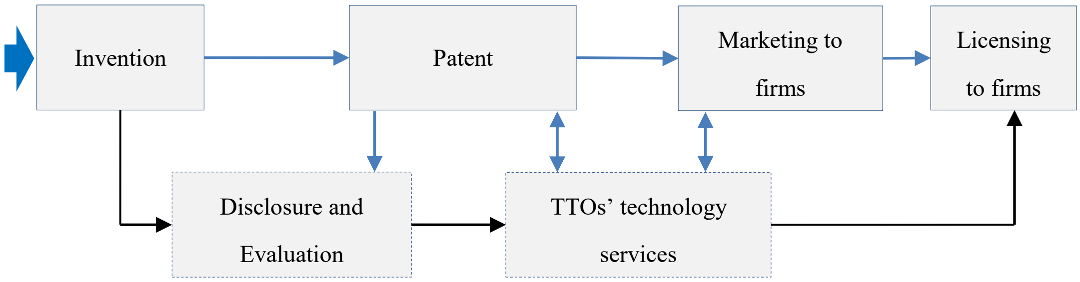

Figure 2.6 UITT under inventor ownership

(3) Arguments regarding the two ownership models

Crespi et al. (2006) compared university ownership with inventor ownership on the basis of Aghion and Tirole's (1994) theoretical model. The former presented results from the Patval database, addressed faculty patent assignment in six European countries and illustrated that the significant cause of non-university assignment is professorial privilege (Geuna and Nesta, 2006). In comparing six Canadian universities, Kenny and Patton (2011) and Kiškis (2012) found that the University of Waterloo, as the only inventor ownership university in Canada, more efficiently generates spin-offs on both per-faculty and per-R&D. Damsgaard and Thursby (2012) compared university ownership in the US and Sweden through a theoretical model that the authors developed. They found that when established enterprises present more advantages than do start-ups, then US regimes are less conducive to entrepreneurship than Swedish regimes. In some cases, however, the probability of successful commercialisation is higher in US institutional regimes.

Table 2.2 lists the advantages and disadvantages of the university and inventor ownership modes. Before the Bayh–Dole Act of 1980 was legislated, proponents argued that faculty inventions resulting from federally funded research required substantial investment and involved risky development before commercialisation. Given the bureaucratisation of federal ownership (Damsgaard and Thursby, 2013; Kenney and Patton, 2009), however, firms were denied exclusive licences by government agencies. Additionally, IPAs could not satisfy all the requirements of universities and firms. Thus, university and inventor ownership modes that endow universities or faculty title to federally funded patents and exclusive licences were deemed the most effective solutions to the problems that arose after the enactment of the Bayh–Dole Act (1980).

Table 2.2 Advantages and disadvantages of two kinds of invention ownership

	Advantages	Disadvantages
University ownership	• Provide more professional technology service • Integrate and create patent pool • Faster technology diffusion due to universities' public platforms and larger contact networks	• Increase the transition cost • Harm public interest because of TTOs' economic orientation • Perhaps worse performance of UITT as a result of unskilled TTOs staff • Chaotic patent assignment
Inventor ownership	• Decentralize decision making, reduce the system risk • Lower transition cost • Benefit of scientists entrepreneurship	• Possible negative influence on education and basic research • Patent fragmentation

2.2.3 Reasons that drive faculty invention disclosure

2.2.3.1 Legislation requirement

In mainland China, the central and local governments introduced several laws that require all faculty to disclose inventions/patents to universities. These laws include the 'Regulations of Promoting University Technology Transfer' (1999), 'Regulations of Intellectual Property Resulting from National Science and Technology Plan Funded Research' (2002), 'The Science and Technology Progress Law' (2007) and 'The Patent Law' (2008).

These national laws mandate faculty disclosure of all service or non-service inventions. In terms of service inventions, a university has the right to patent application and disposal, and faculty have the right to honour (i.e. recognition as inventor and building of peer reputation). With regard to non-service inventions, faculty are obligated to disclose these creations to universities and provide evidence that the inventions are independently developed without access to university facilities. Only after these requirements are satisfied are faculty allowed to independently apply for patents.

2.2.3.2 Advantages of university ownership

Chinese policymakers believe that university ownership poses several advantages. (1) A university can provide stronger professional protection for faculty inventions, and faculty can focus on their research rather than on procedural tasks, such as patent application, renewal and maintenance. (2) A university is also in a solid position to integrate and create patent pools, thus considerably enhancing the commercial value of faculty patents. (3) Finally, venture capitalists (VCs) are eager to collaborate with universities because of the credibility built by these institutions. VCs are discouraged from choosing faculty as partners by the possibility that they will suffer legal uncertainties regarding invention ownership.

2.2.4 Faculty invention disclosure and performance in UITT

The fact that faculty attribute their patents to non-university assignees suggests that university-owned patents do not reveal the complete picture of university involvement in the UITT process; a considerable number of academic creations invented by faculty are not owned by universities, but in most cases, by private firms or individuals (Julie, 2013; Lissoni, Llerena, and Makelevy, 2008; Lissoni, Lotz, Schovsbo, and Treccani, 2009). Hence, to facilitate UITT development, the relationship between invention disclosure and UITT should be clearly discussed.

First, faculty do not disclose inventions to universities possibly because of distrust, lack of time to participate in UITT or lack of business awareness. Under these conditions, non-university assignment and UITT performance exhibit a weak relationship. A TTO should encourage faculty to opt for a university disclosure mode that features professional management services. Second, when faculty attribute low-value patents to TTO but assign high-value patents to industrial firms, this adverse selection diminishes the quality of university-owned patents. In this situation, UITT performance and invention disclosure are positively related. Finally, from a transaction cost perspective, non-university assignment that arises from technology consulting projects can improve UITT performance to a certain extent. Figure 2.7 illustrates the relationship between invention disclosure rate and university licensing revenue for the top 35 patent applications from Chinese universities. The figure shows that invention disclosure rate is slightly positively related to licensing revenue.

Improving UITT performance therefore necessitates increasing faculty invention disclosure rates—a responsibility that falls on the shoulders of Chinese universities.

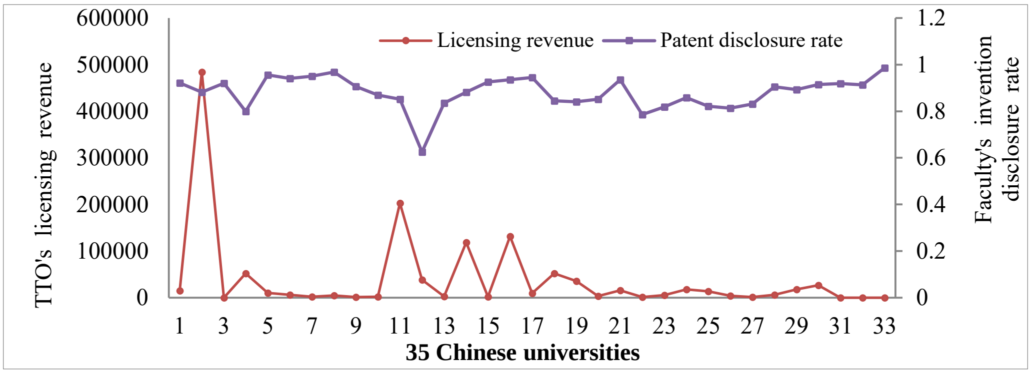

Figure 2.7 Correlation between invention disclosure rate and university licensing revenue in the top 35 patent applications from Chinese universities in 2012

2.3 Faculty invention disclosure strategy

2.3.1 Disclosure type

The commercialisation of university academic research has always been considered a natural stage in a knowledge-based economy, and over the last 40 years, this phenomenon has rapidly progressed. As a result, university faculty have involved (actively or passively) themselves in commercial activities to mitigate conflict in transferring technology from universities to industrial firms. During this process, several options are available to university faculty (Jensen, Thursby, and Thursby, 2003). They can disclose inventions to universities and take part in commercialisation with TTOs. They can disclose their inventions to industrial firms to earn higher economic returns. Faculty may also refrain from disclosing inventions or pursue further study to increase their technological readiness; this decision is prompted by various reasons, such as lack of trust, unfair revenue management and lack of understanding of commercial principles.

2.3.1.1 University assignment

As indicated in university employment contracts, faculty members should disclose all inventions to the higher education institutions with which they are affiliated and attribute government-funded creations to such institutions. Prior to the 1930s, however, US universities sometimes rejected invention disclosure because they felt ethically compelled to decline patent ownership (Matkin, 1990). In World War II, US universities realised the economic potential of patent ownership given the introduction of defence inventions/patents into civil industry. This development encouraged the institutions to establish formal patent policy. Upon the enactment of the Bayh–Dole Act of 1980, most countries required the assignment of faculty inventions to universities (Baldini, 2009; Mowery et al., 2004).

Some researchers argue, however, that poor UITT performance is due to flawed university assignment systems (Kenney and Patton, 2009). First, attributing patents to universities instead of faculty may reduce spillover effects from academic research. This phenomenon also goes against the traditional ethics and open science policies of higher education institutions, especially public universities (David, 1993; Damsgaard and Thursby, 2013). Second, granting universities temporary monopoly in efforts to secure profit demotivates researchers from conducting further studies. A case in point is the life science field, where the patenting of tools and experimental programmes for genetic research has negatively affected scientific progress. Finally, university assignment may result in university development strategies that disregard the importance of basic research (Henderson et al., 1998).

2.3.1.2 Industrial firm assignment

When faculty inventions have high commercial value, interested firms may infuse additional R&D investment to encourage faculty to collaborate with them. Before undertaking additional R&D, firms need to be convinced that such initiative will be a meaningful investment, particularly in terms of surpassing competitors. This is possible only when a firm is granted exclusive rights to inventions. Otherwise, technological externalities will enable competitors to use faculty creations to develop a competing product. To avoid these drawbacks, faculty patents should be assigned to interested firms in accordance with the ex-ante contract or to universities, with an exclusive licence granted to enterprises. Furthermore, whether an industrial firm can own an invention rests on the marginal effect of ownership on research success and on the bargaining power of both parties (Crespi et al., 2006). When faculty inventors choose firm assignment, three types of industrial firms can own technologies:

(1) University-run firms

University-run firms, such as science parks and incubators, emerged in the middle of the last century, enjoying increased development in knowledge-driven economies. Universities that strongly perform in applied research are generally the pioneer creators of university-run firms. Unlikely traditional companies, university-run firms are established, staffed, funded and managerially controlled primarily by university administrations. Because of their special position, they can optimally use universities' various resources, including financial assets, physical space, experienced manpower and social networks (Eun et al., 2006). Mainland China has two kinds of university-run firms: a 'discipline firm', which is run by schools under universities and is used as an avenue from which to increase research funding; and a 'third-party IP firm', which is granted an independent legal person status. Chinese universities assign faculty patents to these firms, after which they are sold or licensed to the technology market.

(2) Established firms

In many cases, faculty patents are assigned to established medium or large corporations. Unlike university-run firms or start-ups, established firms do not need to foster a relationship with universities or faculty inventors. They have built their reputations before patent application and have had a long-standing development history. Thursby et al. (2009) define such firms as those that have been operating for 10 years or longer at the time of patent application. During the UITT process, TTOs often act as important intermediaries (or dual agents) between established firms and faculty inventors (Panagopoulos and Carayannis, 2011).

(3) Start-ups that leverage faculty patents

The majority of theoretical and empirical research on UITT has focused on established firms as licensees, even though another important option is patent licencing to start-ups (Etzkowitz, 2003; Gregorio and Shane, 2003; Powers and McDougall, 2005; Showalter and Jensen, 2012). The start-ups established by faculty with financial support from VCs are ‘young’ companies; that is, the period between establishment and patent application spans less than 10 years (Thursby et al., 2007, 2009). Start-up assignment poses less adverse selection and moral hazard than does established firm assignment because the former endows faculty partial/complete ownership and shares (Dechenaux et al., 2011; DiGregorio and Shane, 2003).

2.3.1.3 University–firm assignment

In certain circumstances, faculty patents may legitimately be assigned to universities and firms as joint owners. To avoid potential conflicts of interest, two collaborating parties often sign an ex-ante contract to delineate the specifications of patent ownership. University–firm assignment promotes faculty participation because of universities’ requirement and firms need not worry that they will be deprived of control (Kroll and Liefner, 2008; Tang, 2008). From this perspective, university–firm assignment appears to be an ideal arrangement amongst faculty inventors, universities and firms. Nevertheless, this structure is viewed as unstable because a stakeholder with high power or marginal contributions to the success of technological commercialisation always desires complete ownership of faculty patents.

2.3.1.4 Individual faculty assignment

If university TTOs are poorly managed or so small that they lack employees who are sufficiently qualified in specific technologies, UITT performance may generate negative results and damage the reputations of stakeholders (Greenbaum and Scott, 2008; Owen-Smith and Powell, 2001). In this scenario, when faculty disclose their inventions to TTOs, tensions may arise; regardless of whether grievances are reasonable, TTOs may be accused of failing to satisfy faculty’s stringent requirements for technology transfer. To bypass TTO control and obtain satisfactory economic returns, faculty usually prefer to retain titles to patents and independently search for potential technology buyers. Conversely, when faculty are motivated to establish start-ups but do not have adequate financial resources or cannot find VCs to invest in their inventions, they may choose individual assignments as they wait for better opportunities.

Table 2.3 summarises the strengths and weaknesses of the four disclosure types.

Table 2.3 Strengths and weaknesses of four disclosure types

	Strength	Weakness
University assignment	• Low management and search costs • Larger platform for technology transfer • Expand patent opportunities widely with non-exclusive licenses	• Increase the transaction cost • Blockade future studies because of economic orientation of TTOs • Decrease basic research
Industrial firm assignment	• Faster to bring to technology market • Low transaction cost	• Moral hazard and adverse selection • Less public interest
University-firm assignment	• Balance the interest of all stakeholders	• Unstable relationship among all stakeholders
Individual assignment	• Low transaction cost • Low information asymmetry	• Need outside investment • Legal issue of IP

2.3.2 Disclosure stage

Most researchers have pointed out that faculty interests revolve around basic research; thus, the bulk of their inventions remain at the conceptual modelling or laboratory testing phase. During the preliminary exploration of an innovative idea or invention, faculty are compelled to decide on whether to disclose inventions to universities or firms and how. First, they can generate exposure for their inventions by publishing research papers or books at the technical concept stage; second, they can disclose their inventions to universities or find an interested firm to sponsor further research and commercial activities (Jensen et al., 2003); third, because the commercial value of inventions increases with technology readiness level, faculty can extend research (instead of disclosing their creations) to refine their inventions. They can then apply for patent protection or create a start-up with financial support from VCs. Figure 2.8 illustrates the disclosure stage for faculty inventors.

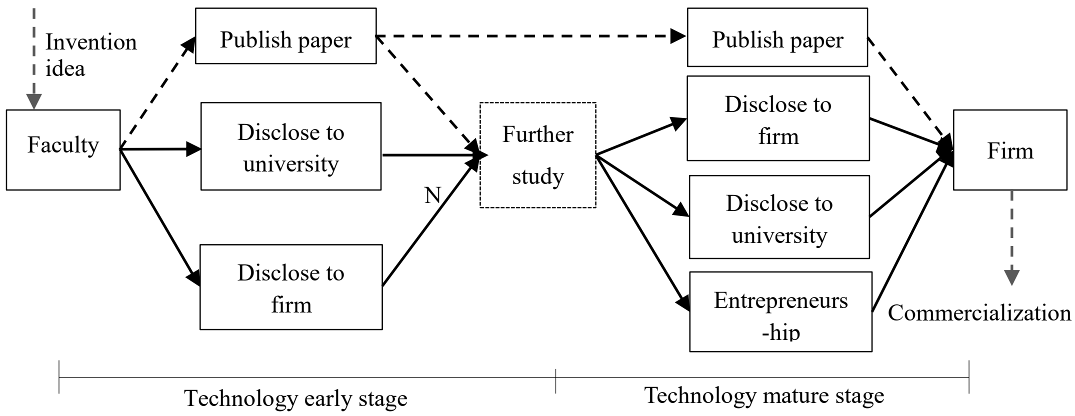

Figure 2.8 Disclosure stage of faculty inventors

From the viewpoint of faculty, invention disclosure is a complex problem that includes decisions about disclosure type (i.e. university or firm disclosure) and disclosure stage (Jiang, Thursby and Thursby, 2012; Owen-Smith and Powell, 2001). Occupying a research territory through invention diffusion is one of the fundamental drivers of disclosure to universities. With their initial invention ideas, faculty improve their academic reputations and increase research funding (Baldine and Grimald, 2005; Clancy and Moschini, 2013; Thursby and Thursby, 2011). Despite this seemingly straightforward process, however, the stage of disclosure to universities is replete with competition and challenges. China's 'winner-takes-all' scientific reward system incentivises disclosure, thereby presenting difficulties in decision-making (Murray and O'Mahony, 2007). Faculty would rather maintain confidentiality with regard to unique ideas, technological solutions and research approaches until after they have completed their work. Commercial incentives, such as industrial research funding or 100% licensing benefit, may limit the extent to which disclosure to universities is adopted (Cohen and Walsh, 2008; Thursby et al., 2009). Revealing an invention to a particular firm equipped with sufficient human capital and research resources (e.g. a large lab, unique databases and experienced researchers) is an attractive alternative (Etzkowitz, 2003; Jensen, Thursby and Thursby, 2011; Siegel et al., 2003a). Disclosure to firms also prevents fierce competition and provides collaboration support that accelerates progress in faculty research and increases the success rate of UITT (Audretsch, Bonte and Keilbach, 2008; Thursby, Thursby and Dechenaux, 2005). In sum, economic incentives, reputation, competition and collaboration are determinants of the type of invention disclosure adopted by faculty inventors.

Contrastingly, many previous studies have revealed that inventions disclosed by faculty remain at the conceptual modelling or laboratory scale and that R&D investment and further research are needed for these inventions to reach full application (Siegel et al., 2003a; Thursby et al., 2002; Thursby and Kemp, 2002). Considering preliminary invention disclosure at the early stage of UITT, faculty can build academic reputations, possibly with less competition but also fewer economic benefits from universities; they can also collaborate with interested firms, although China’s patent system can provide only temporary protection through the deferment of patent examination (Hellmann, 2007; Rudyk, 2013). If faculty disclose a more developed invention at a later stage, they obtain greater economic benefits from firms and encounter less competition from other competitors; however, their reputations are enhanced to a limited extent (Jiang et al., 2012). To sum up, economic incentives, reputation, competition and collaboration are additional factors that are closely associated with the invention disclosure stage wherein the maturity of faculty inventions is reflected.

2.3.3 Disclosure quality

Quality is one of the most important characteristics of a faculty patent and typically determines final patent assignment. A crucial requirement, therefore, is for faculty to precisely determine patent quality before making disclosure decisions. Four methods of evaluating patent quality are generally adopted.

The first method is measuring the commercial value of a patent. Schankerman and Pakes (1986) contend that commercial value inherently reflects patent quality for a specific technology buyer. This measurement is based on transaction price, which varies per buyer. Although each faculty invention is unique by virtue of its innovativeness, its quality changes with different users across various periods (Munari and Toschi, 2012). The second method is measuring innovativeness. Patent quality is reflected by the influence of a new patent on previous patents and its contributions to technological development. Many studies, such as those of Fuller (2008) and Thursby et al. (2007), normally use forward and backward citations as two important indicators of innovativeness. Measuring innovation also classifies creations into basic and applied inventions. The third method is determining the quality of a patent document. A well-designed patent document lends itself to a high possibility of approval and encourages protection for a large scope of technological creations. The final method is the measurement of patent maintenance and validity status. From an economic perspective, a patentee is required to renew a high-quality patent every year within the duration of the patent protection period.

The overall influence of patent quality on specific patent assignments generally depends on the measurement adopted by faculty. If, for example, a faculty member is an economic-orientated individual, he/she will likely attribute high-quality inventions to non-university assignees because this approach guarantees the faculty member a 100% profit. If a citation is used to evaluate patent quality, a faculty member tends to attribute applied inventions to non-university assignees possibly in conformance with the provisions of a consulting arrangement (Thursby et al., 2007). Little research has been carried out on the two other quality measurements.

2.4 Influencing factors for invention disclosure

Figure 2.9 shows that TTOs, university policies, individuals and external environments all exert a key influence on faculty patent assignment. The following sections illustrate how these influencing factors individually affect faculty patent assignment. Section 2.4.1 presents information about TTOs, and Section 2.4.4 focuses on university policies, including those on revenue management and invention ownership. Other influencing factors, such as individuals, geographical locations and intellectual eminence, are discussed in the remaining sections.

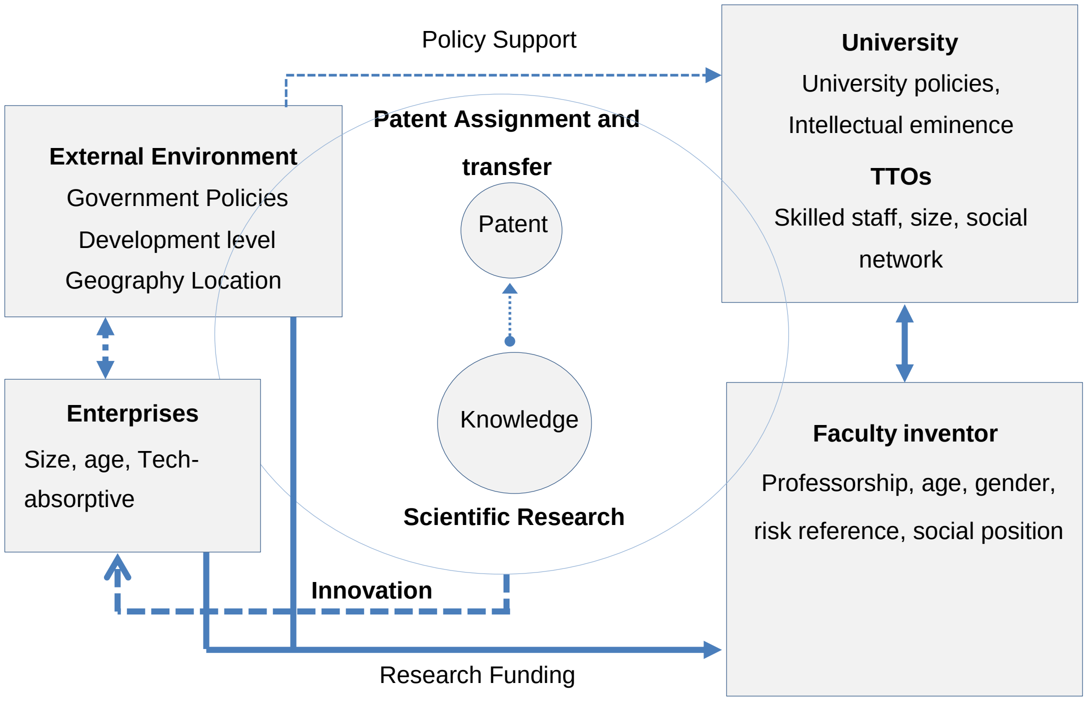

Figure 2.9 Influencing factors for faculty patent assignment

Source: Prabhu R., 2007. Knowledge creation and technology transfer in nanotechnology at research universities. The Pennsylvania State University, US.

2.4.1 Influence related to university TTOs

From a historical perspective, the emergence of TTOs is associated with government legislation on UITT and universities' goal of serving society, in addition to contributing to scientific research and education.

TTOs originated from the US, but in the early 20th century, US universities were unwilling to participate in patenting and licensing activities chiefly because such endeavours presented few benefits and raised the potential for criticism. Before 1980, therefore, most reputable US universities employed third parties to manage patent licensing. As previously stated, the Bayh–Dole Act of 1980 revolutionised patent licensing by enabling universities and research institutions to acquire ownership of faculty inventions funded by government agencies. With a rapid increase in patent applications, US universities realised the potential advantages of patenting and began establishing internal TTO departments (or technology licensing offices) in charge of managing invention disclosure and licensing (Jensen et al., 2003). The number of TTOs has sharply increased from 25 in 1990 to more than 200 in 2010 (AUTM, 2010). From then on, the patenting and licensing activities of US universities have also accelerated at a tremendous speed (AUTM, 2010; Nelson, 2001). The success of US TTOs in bridging academic research and industrial technological development encouraged other universities in Europe and Asia to follow suit. France, Germany, Japan and China modified their universities' IP policies on the basis of the principles of the Bayh–Dole Act and established numerous organisations equivalent to TTOs (Mowery and Sampat, 2005).

The characteristics of TTOs play a significant role i faculty invention disclosure. In terms of TTOs' age (i.e. years of operation), for instance, researchers have found that faculty favour invention disclosure to more established TTOs because they usually have more experience in and professional knowledge on UITT (Siegel, Wright, and Link, 2003b; Thursby and Kemp, 2002). Sometimes, a TTO's age also influences the licensing strategies adopted by faculty, which in turn, affects invention disclosure. For example, established TTOs prefer the number of UITT cases over licensing revenue. Chapple, Lockett, Siegel, and Wright (2005) found that in the UK, established TTOs prefer to reduce the licensing price per patent to improve the success rate of technology transfer. In addition, TTOs with professional staff and technology managers efficiently and effectively transfer faculty inventions. They easily gain the trust of faculty and build their reputation amongst academics, thus enabling them to encourage faculty to disclose inventions (Siegel et al., 2003b). According to a survey carried out by Anderson, Daim, and Lavoie (2007), faculty desire to disclose their inventions to independent TTOs because of their flexible operating strategies and channels. Furthermore, the size of a TTO's social network is positively related to faculty invention disclosure and UITT performance.

2.4.1.1 Managing invention disclosure

As stipulated in the Bayh–Dole Act (1980) and employment contracts, faculty inventors are obligated to disclose their inventions to TTOs. In a survey conducted by Jensen et al. (2003), however, the TTO directors of US universities believe that less than half of inventions are disclosed to their offices in a timely manner. A more serious issue is that most productive faculty are unwilling to disclose inventions and participate in UITT. Educating faculty about invention disclosure and persuading them to adopt this practice are therefore amongst a TTO's major responsibilities. In most cases, a TTO can be considered an agent responsible for managing faculty inventions by ensuring the equitable distribution of licensing revenue between faculty and universities (Thursby and Thursby, 2011). Siegel et al. (2003a) also confirmed that awarding royalties or equity licensing payments to faculty effectively encourages invention disclosure. With reference to inventions that are not self-licensed, Panagopoulos and Carayannis (2013) proposed a policy wherein a TTO directs faculty to inform the TTO about failing self-licensing efforts in order to achieve full disclosure. Managing faculty invention disclosure is therefore a TTO's primary task.

2.4.1.2 Verifying invention quality

A secondary responsibility of TTOs is to evaluate the commercial value of faculty patents. Only faculty inventors with creations that adhere to specific standards are provided opportunities to apply for patents with TTO assistance. Inventions that fail to satisfy requirements are shelved by TTOs (Jenson et al., 2003; Macho et al., 1996). During this stage, then, a TTO makes a series of decisions on patent evaluation. Some of the issues in this regard are determining the quality standard for patent application; ascertaining the method of selecting faculty inventions that are eligible for quality verification; and identifying the course of action for inventions that are deemed ineligible for evaluation (e.g. disposal vs. introduction into the technology market).

2.4.1.3 Designing licensing contracts

The other crucial functions of TTOs are to search for potential technology buyers, negotiate with them and design a particular type of licensing contract for marketing university-owned technologies. These roles have elicited considerable attention from researchers (for example, Chapple et al., 2005; Jensen and Thursby, 2001; Nelson, 2001; Thursby and Thursby, 2002; Siegel et al., 2003b). TTOs are required to specify payments from licensees to licensors, typically in the form of fixed fees, milestone payments, royalties, equity payments or annual dues. TTO-directed licensing negotiations have two special characteristics. First, payment items and extent of licensing depend on the commercial value of faculty inventions. Assessing this value is complex and susceptible to many uncertainties, both technical and commercial. In many circumstances, licensees and licensors differ in their perspectives on technological value and payment type. Such dissimilarities significantly influence faculty patent assignment. Second, standard licensing negotiations take place only between licensees and licensors, but TTO-directed licensing negotiations involve three stakeholders (universities, firms and faculty). Under this situation, complex conflicts of interest emerge. As dual agents, TTOs are duty-bound to avoid moral hazard and adverse selection. Thus, determining the manner by which a licensing contract is structured is one of the most difficult tasks of TTOs. Table 2.4 presents a few selected papers on university licensing contracts.

Table 2.4 Selected papers on contract design of patent licences

Authors	Portfolio Technology Transfer Contract				
	Equity	**Royalties**	**Fixed Fee**	**Milestone Payment**	**Annual Payment**
Dechenaux et al. (2011)			√	√	√
Dechenaux, Thursby and Thursby (2009)		√			
Crama, Reyck, and Degraeve (2008)		√		√	
Savva and Taneri (2011)	√	√			
Jensen et al. (2010)	√				
Jensen and Thursby (2001)	√	√			

Note: According to our interviews with heads of TTOs in China's universities, most of China's universities are risk aversion, thus, fixed fee and royalties is the most common payment used by them due to the uncertainties of technical and commercial value. This research will discuss faculty inventors' patent assignment from the perspective of contract design which mainly focuses on fixed fee and royalties.

2.4.2 Influence related to industrial firms

Fuller (2008) and Thursby et al. (2007, 2009) revealed that non-university assignment of faculty patents in the US is caused by the nature of technology consulting projects. That is, inventions are a result of cooperation between faculty and firms' R&D staff. Thus, firm characteristics also influence faculty invention disclosure (Callaert, Plessis, Looy, and Debackere, 2013).

If firms have played a crucial role in invention development (e.g. contributions to ideas and research funding), then firm assignment is reasonable and encourages firms to invest financial capital. Meanwhile, universities have the right to conduct further research without securing permission from firms. On this basis, if faculty do not disclose inventions to their universities, they are essentially colluding with firms to secure patent ownership, thereby forcing universities to relinquish the right to carry on with additional research (Venditti, Reale, and Leydesdorff, 2013). In many cases, faculty favour university–firm assignment over university assignment because of their desire to protect university rights. If the most marginal contributions to successful UITT originate from faculty, a good strategy is for them to exercise control over their inventions because their input is invisible and unpredictable (Aghion and Tirole, 1994). In this scenario, university or individual assignment may be an appropriate choice.

Using faculty and firm contributions to the invention process as bases, Conti (2009) designed a mechanism for arranging invention ownership. This mechanism operates under the premise that no conflicts of interest exist between faculty and universities. If a firm's contribution is larger than that of a faculty member, then invention ownership belongs to the firm, but the faculty has the right to choose the field where the invention is to be applied. If a faculty member's contribution is larger than that of a firm, the university or faculty member should own inventions, but the firm has the prior right to choose the research area for further exploration. Additionally, the firm is granted the prior right to buy subsequent series of inventions. Under this mechanism, the influence of industrial firms can be effectively regulated.

2.4.3 Influence related to individual faculty

For university faculty, acquiring professorship is regarded as the most decisive way to build a reputation. Studies on faculty patents show that disclosing inventions and assigning patents to universities are effective means of securing a professorial post (Smith, 2001; Siegel et al., 2003a). In mainland China, associate professors and lecturers are more strongly motivated to choose university assignment than are professors because the former aspire for academic achievement. By contrast, professors dislike university assignment and are equipped with more social resources and freedom with which to transfer their inventions.

The number of faculty patents is another critical factor for UITT. A current trend is that faculty members with numerous inventions under their belt prefer university assignment. This predilection may be attributed to the limited time and energy that productive faculty can devote to UITT (Allen, Link, and Rosenbaum, 2007). They need the professional technology transfer services offered by TTOs for them to efficiently manage their inventions; a prerequisite to TTO access is university assignment. Another special condition that characterises the context of China is that the faculty identified as the first inventor may not actually be the individual who exerts initial efforts in creation; that is, the assistants or students in a research team are typically the ones who first carry out the work. In this scenario, faculty inventions should be assigned to universities (As shown in our sample, 51.89% of the faculty patents assigned to universities are the inventors' first five patents.).

2.4.4 Influence related to university policies

From a policy standpoint, the most essential university policy is that on inventor shares that accrue to faculty when patents are assigned to and licensed by university TTOs. Substantial theoretical and empirical research on inventor share rates has uncovered the following insights: (1) A high inventor share rate motivates faculty to disclose inventions to TTOs (Gonza'lez-Pernia', Kuechle', and Pena-Legazkue', 2013; Jensen et al., 2003; Panagopoulos et al., 2011; Thursby et al., 2009) and (2) a high inventor share rate indirectly encourages faculty to amplify their efforts in guaranteeing the success of UITT (Crama et al., 2008; Jensen et al., 2001, 2003).

2.4.4.1 Inventor share of royalties

Royalties earned from patent licences are defined as the increasing function of the yield of new products. When faculty disclose their inventions and TTOs license patents, the former can receive a royalty revenue based on a rate stipulated in published university policies. This revenue distribution, whether reasonable or otherwise, means that faculty inventors can immediately earn part of the profits from their inventions and that such proportion increases with their share of royalties. In the recent 20 years, the inventor's share of royalties has posed critical effects on patent assignment, thus eliciting extensive research attention (Aghion and Tirole, 1994; Crama et al., 2008; Crespi et al., 2006; Fruedman et al., 2003; Gonza'lez-Pernia' et al., 2013; Panagopoulos et al., 2011; Siegel et al., 2003a, b; Thursby et al., 2009).

An inventor's share of royalties may be a fixed rate regulated by the central or local government or by universities' IPR management regimes. In general, this value ranges from 0.2 to 1. In some EU countries, such as Sweden, Italy, Finland and Hungary, faculty are allowed to own their inventions, thus earning them 100% of patent royalty profits. In spite of its advantages, a fixed inventor's share of royalties presents two major drawbacks in relation to university licensing activities. The first is that it can easily affect the marginal profit and yield of new products (Crama et al., 2008; Savva and Taneri, 2011). This influence cannot be disregarded, especially when a patent earns huge profits. In many cases, therefore, an inventor's share of royalties is a decreasing function of the amount of royalties received by a university. The second unavoidable downside is that royalty policy produces moral hazard and decreases faculty inventors' marginal contribution to the success of UITT (Dechenaux et al., 2009, 2011; Thursby and Thursby, 2011).

2.4.4.2 Inventor share of equity payment

When a university and faculty are not cash constrained, they may accept technological investments that are offered because of the value of their patents. In general, two types of equity policies are implemented.

First, the appraisal of technology as capital stock is a widespread economical practice in UITT (Gregorio and Shane, 2003; Jensen and Thursby, 2001). The advantage of this strategy for industrial firms is that a fixed or variable inventor's share of equity does not influence the marginal profit earned from new products. For faculty, this share rate encourages them to exert effort in moving UITT forward and guarantees them a constant residual value (Dechenaux et al., 2009; Savva and Taneri, 2012). As a win-win arrangement, equity policy therefore encourages faculty to disclose inventions and take part in UITT. Second, when a university wants to involve itself in the establishment of a new start-up that leverages faculty technologies, an increase in faculty inventors' stock shares in start-ups influences the activities of faculty inventors in two ways. (1) It can slow down the reduction in faculty activities because low contingent payments to university administration are accepted, especially under the prospect of high penalty costs (Hellmann, 2007). (2) If the new start-ups established by faculty are financially constrained, universities' willingness to take equity stock in exchange for up-front licensing fees can reduce the firms' cash expenditures, which in turn, decreases the probability that their inventions and start-ups will weaken (Gregorio and Shane, 2003). When universities are involved in new start-ups, faculty inventors' equity rates can increase the likelihood of university assignment.

These two university patent policies are positively related to university assignment, but understanding their differences remains an important issue for universities because the level of faculty involvement and effort varies with licensing type. For China's universities, the success of UITT is a more important goal than university assignment. Diverse patent policies should be used to stimulate faculty participation. Improving university assignment can then be pursued as a secondary goal (Savva and Taneri, 2012).

2.4.5 Influence related to external environment

2.4.5.1 Intellectual eminence of universities

The literature has provided two explanations for the relationship between the intellectual eminence of universities and faculty patent assignment. The first is that opportunities to sell patents to private firms are more readily available to reputable researchers than to scholars whose credibility is suspect (Gregorio et al., 2003). Private firms thus favour highly regarded researchers from eminent universities—a preference that is equally beneficial to faculty in terms of reduction in search costs. The second explanation is that a university's reputation enables researchers from distinguished universities to more easily establish start-ups and commercialise their inventions than can researchers from less eminent universities (Humberstone, 2009). In addition, because of information asymmetry and uncertainty, VCs tend to perceive renowned universities as more capable than less eminent universities in producing technology that is worthy of funding (Etzkowitz, 2003; Jensen and Thursby, 2001; Lowe, 2006). This is why spin-offs from famous universities always exhibit better performance (Gregorio and Shane, 2003; Pedro and Ferran, 2014).

2.4.5.2 Geographical location

That university technologies have been commercialised in different countries with varying performance levels is widely recognised. Commercialisation and performance differ in two ways as a result of dissimilarities in universities' geographical locations (Audretsch, Hülsbeck, and Lehmann, 2012). First, regions in different geographical locations are often dissimilar in terms of the ability to finance commercialisation activities, business culture and market demand for new products (Shane, 2004); Second, a university's relative competitiveness in academic and technological innovation also depends on location, which affects technology transfer from universities to local industries (Unico, 2004).

According to geographic economists, the geographical distance between a university where a particular technology is invented and the commercialising enterprise plays a crucial role in the success of UITT (Agrawal, 2001). The cruciality of location is one of the factors that drive numerous clusters of high-tech enterprises to establish offices or divisions near universities. These locations include Silicon Valley in San Francisco, Route 128 in Boston and the Research Triangle in North Carolina. In China, a prevalent perception is that faculty who work in universities that are located in highly competitive cities, such as Shanghai, Beijing and Guangzhou, are afforded more opportunities to opt for non-university assignment because the enterprises in these locations are seen as having a keen business sense and are home to a greater number of VCs and angel investors. In this research, the data show that the proportion of university assignment in these three major cities is only about 84.25%, a value less than the average level (85.66%).

2.5 Special issues and literature gaps

A considerable number of studies on UITT have focused on faculty invention disclosure in Western countries (e.g. Baldini, 2009; Gonza'lez-Pernia' et al., 2013; Henderson et al., 1989; Jensen et al., 2011; Thursby et al., 2001; Thursby, et al., 2011). Some have discussed faculty patent assignment in the US, Europe and Japan. By contrast, minimal effort has been exerted towards the context of mainland China. This section raises three important issues regarding China's UITT and faculty patent assignment.

(1) What is the reality of faculty patent assignment in China's universities?

As mentioned earlier, faculty patents are not solely assigned to universities, but little evidence on this issue has been provided specifically in the context of China's universities. Whether this problem is a serious phenomenon in China remains unknown. To address this problem, I look into the actual circumstances that surround faculty patent assignment in Chinese universities.

(2) How can we create appropriate policies for managing invention disclosure?

In many cases, poor UITT performance is a result of low commercial value. This situation dictates that TTOs verify the quality of inventions. On one hand, such evaluation may reduce invention disclosure rates because assessment also decreases opportunities for patent licensing and reduces licence revenues. On the other hand, because of the non-economic objectives of faculty (e.g. professorship, awards, reputation), some inventions with low commercial value may be patented and brought into technology markets if TTOs do not verify quality first. This problem may damage the reputation of universities. An interesting issue for exploration, therefore, is how TTOS can check invention quality to increase the disclosure of high-value inventions.

From a policy standpoint, two research issues require further investigation. First, many scholars have argued that an increase in an inventor's share of licence revenue can enhance invention disclosure and UITT performance because this share counts as an economic incentive. A caveat to this approach, however, is that increasing shares may also raise opportunity costs when faculty want to establish new start-ups. Second, proponents and opponents have presented the advantages and disadvantages of the university and inventor ownership modes. Because of relaxed IP management in China, faculty sometimes lean towards assigning high-value patents to industrial firms and disclose low-value inventions to universities. This behaviour has created many useless and 'dormant' patents with little licensing value for Chinese universities. An issue that arises is whether universities can allow for more flexibility in involving faculty in UITT. For example, they can permit faculty to disclose inventions and assign patents to any of these assignees: universities, industrial firms or individuals.

2.6 Summary

This literature review is intended to comprehensively elucidate faculty patent assignment and university technology transfer, as well as highlight some major differences in the practices adopted in Chinese and Western universities. In this section, I reflect on the insights obtained from the literature review by providing answers to questions (a)–(d).

As indicated in the review, the influencing factors for faculty invention disclosure and patent assignment originate from four aspects: TTO characteristics (e.g. size, age, skilled staff, etc.), industrial firms, university policies (i.e. inventor's share of licensing revenue and invention ownership) and external environments. In Chapter 4, these influencing factors are revisited to explain faculty invention disclosure in China's universities.

In the succeeding chapter, the research methodology, including the empirical research conducted, are presented. The chapter also discusses the data collection and screening methods, as well as the special dataset generated for the purpose of determining the reality of faculty patent assignment in China's universities.

Chapter 3 Research Design and Methodology

In this chapter, the research methodology is presented, after which the data collection process and screening methods are discussed. The chapter ends with an illustration of the analysis approach adopted in this study.

3.1 Introduction

To enable a thorough understanding of the reality that surrounds faculty patent assignment in China's universities, a special dataset is generated to illustrate the proportions of individual assignment to universities and industrial firms, joint assignment to universities and firms and individual assignment to faculty. An empirical model is used to explain the factors that influence patent assignment. After this, four mathematical models based on game theory are developed to determine how universities should manage faculty patent assignment, as well as how they can efficiency and effectively promote UITT.

In the sections that follow, the methodology chosen for this research is described. Section 3.2 introduces the framework on which the research methodology is based. Section 3.3 comprehensively explains the research design, data collection method and analysis approach for Study #1, which is aimed at illustrating the reality of faculty patent assignment. Section 3.4 describes the theoretical modelling methods, which are designed to simulate stakeholder decision-making. An outline of all the methods used ends the chapter.

3.2 Framework for research methodology

Given the difficulty in data collection, the majority of previous literature on China has concentrated on faculty patenting behaviour at the macroscopic level; such studies are unable to delineate the entire picture of faculty invention disclosure and patent assignment in the country. The methodologies adopted in earlier research are equally constrained by insufficient data. To overcome these limitations, I generate a unique dataset and analyse patent assignment and licensing practices from empirical and theoretical perspectives. To develop the appropriate research approaches necessary to achieve this purpose, I survey various research methods. As shown in Table 3.1, the case study method and correlational research are applicable to this study.

Table 3.1 Analysis of different research types

Research Type	Case study	Correlational research	Differential research	Experimental research
Characteristics	A descriptive, exploratory or explanatory analysis of a person, group or event	Focusing on quantifying the relationship between two specific variables	For given data, comparing two or more groups to explore their differences	Testing a hypothesis in a controlled context with more constraints
Applicability to this study	**Applicable** Provide specific case scenario to interviewees and elicit their opinions	**Highly applicable** Establish a special dataset and then carry out statistical analysis to explore the effects of variables	**Not applicable** This research does not compare invention disclosure in different settings.	**Not applicable** Faculty decision-making cannot be observed or investigated in a controlled context.

Figure 3.1 illustrates the framework that underpins the research methodology employed in this study. The interview and questionnaire (qualitative research), as well as the empirical research and theoretical game models (quantitative research), are discussed in detail.

Qualitative research is aimed at acquiring an in-depth understanding of a specific phenomenon and the factors that govern such phenomenon. The most commonly applied approach to analysing qualitative data is observer impression[11]. I use the conclusions drawn from the literature review to determine that an interview survey is a suitable data gathering technique. I conduct interviews with TTO staff, including the directors and technology managers of the TTOs, to obtain a basic description of faculty patenting behaviour in Chinese universities. At the same time, questionnaires are administered to the TTO respondents to acquire organisational characteristics, such as the TTOs' size, age (years of operation) and organisational structure. In the last stage of the research, I distribute

[11] Quoted from Wikipedia: http://en.wikipedia.org/wiki/Qualitative_research.

questionnaires to Chinese faculty inventors to confirm the theoretical findings and use the responses as bases for formulating policy recommendations.

Quantitative research refers to empirical investigation via statistical, mathematical or numerical or computational techniques[12]. In this study, a special dataset based on the top 35 patent applications from China's universities is established and then the reality of faculty patent assignment in the country is empirically investigated. After this, four theoretical game models (i.e. models for invention disclosure, patent quality checking, licensing revenue management and licensing contract design) are developed to simulate the stakeholder decision-making process. Finally, I triangulate the findings from the different analyses carried out. This thesis ends with the conclusions drawn from the results.

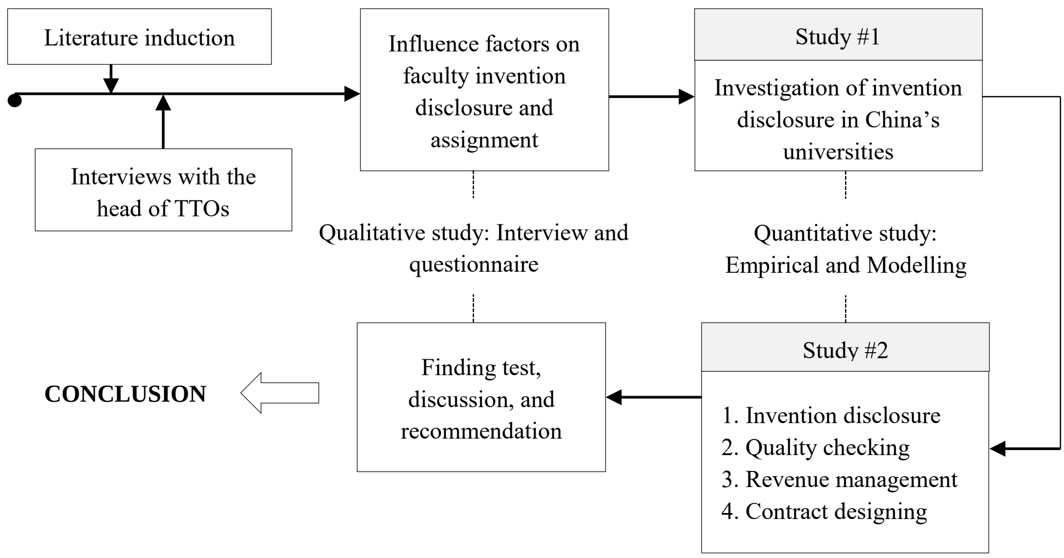

Figure 3.1 Methodology employed in the research

3.3 Study #1: Faculty patent assignment in China's universities

3.3.1 Research design

In this section, I provide answers to questions (e) and (f), that is, questions on the reality of faculty patent assignment in Chinese universities and its influencing factors. With the literature review as basis, I develop a preliminary framework for looking into patent

[12] Quoted from Wikipedia: http://en.wikipedia.org/wiki/Quantitative_research#cite_note-Given_2008-1.

assignment and the current situations in some countries. TTO directors and technology managers are interviewed and faculty are administered questionnaires to obtain detailed real-world patenting information. With consideration for the collected data, a unique dataset on patent assignment is established to facilitate the empirical study on faculty invention disclosure rates and influencing factors. Table 3.2 lists the research methods used for Study #1.

Table 3.2 Research methods used in Study #1

	Interview	**Questionnaire**	**Empirical study**
Advantages	- More interaction with interviewees; provides more specific scenarios - In-depth discussions and explanations	- Offer given options - Rapid but inexpensive data collection process - Covers large respondent sample	- More objective and scientific research - Verifiable study
Disadvantages	- Lengthy - Expensive - Difficult to invite potential interviewees without *guanxi*	- Low response rate - No interaction with the respondent	- Relying on data - Limited to some selected research aspects
Remarks	This study makes good use of the advantages. The TTO directors and technology managers are selected as interviewees because of their experience.	In this study, there are more than 2,000 faculty inventors. The questionnaire survey is a better alternative to the interview.	As indicated in the literature review, an interview survey and questionnaire survey can constitute a comprehensive analytical framework.

3.3.2 Interview with TTO staff

After the data are obtained from the questionnaire survey and the CNKI database, I conduct in-depth interviews with the TTO staff to solicit their views on issues regarding faculty patent assignment and the problems encountered in the UITT process. In 2012, during which Tongji University was setting up its plans to establish an independent TTO company, I participated in the preparatory group, which investigated six famous Chinese universities (Fudan University, Zhejiang University, Southeast University, Tongji University, South China University of Technology and Shanghai Jiao Tong University). During this investigation, I conducted six interviews with TTO staff. Their opinions reflect their understanding of UITT in practice and, directly or indirectly, indicate their concerns about poor UITT performance in China. The interview findings for this investigation serve as reference in formulating the purpose of the current research; the purpose aids the development of the research assumptions and the assessment of influencing factors. The results also enable me to draw preliminary inferences about faculty patent assignment and envision the UITT route needed by Chinese universities.

3.3.3 Questionnaire

To compensate for the limitations of the interviews, I carry out a questionnaire survey intended to elicit sentiments and perceptions regarding UITT performance and its influencing factors[13]. The questionnaires are administered to heads of S&T departments and TTO technology managers. The questionnaire responses provide information regarding the organisational characteristics of Chinese TTOs, including years of operation, size, employee educational background and experience, key success and failure factors and improvement in terms of UITT. This information is critical to understanding how the TTOs work and how UITT has developed in Chinese universities.

(1) Target respondents and sample selection

The target respondents are mainly heads of S&T departments and TTO technology managers, who are senior professionals in technology transfer. The names of the subjects are obtained from the top 35 patent applications from Chinese universities. A total of 35 questionnaires were sent to the target respondents, who all completed and returned the questionnaire forms. Thus, the coverage is considered adequate.

(2) Questionnaire design

The questionnaire is designed to solicit opinions about TTOs and UITT in Chinese universities. Two segments of the questionnaire, 'brief introduction of TTOs' and 'key

[13] Some Chinese universities have no independent TTOs, which are in charge of university technology transfer. Patent transfer is conducted by the Department of Science and Technology. Therefore, department heads or TTO technology managers are the target respondents in this research.

influencing factors for UITT success or failure', are intended to explore the problems encountered and possible solutions. Given that the heads of S&T departments and TTO technology managers participate in the UITT process and collaborate with other stakeholders, their perceptions provide insight into important implications for government policymakers and UITT participants.

3.3.4 Data collection and screening methods

This research investigates how invention disclosure is affected by the characteristics of faculty inventions, faculty inventors, university policies and external environments. Therefore, information on individual faculty, university policies and the surrounding environment is collected. A problem is that no single database that can provide sufficient for the requirements of this thesis exists. I therefore combine data from three sources to establish a special dataset. The first source is the faculty's CV database, which accumulates data from university websites and contains introductory information, including the ages, genders, current statuses and academic fields of the faculty. The second source is the CNKI[14] patent database, which can be accessed by downloading detailed information on Chinese patents granted to university faculty. This database contains the records of all granted patents from 1989 to the present time. Finally, a series of annual reports are reviewed to collect data on university policies and information on the competitiveness of the cities where universities are located.

The entire data collection process is depicted in Figure 3.2.

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[14] Compared with other patent databases, such as the State Intellectual Property Office of the Republic of China, the CNKI patent database allows batch downloading of patent data instead of downloading per item. This is very convenient for this research. I also checked the data quality of these two patent databases and found no difference between them.

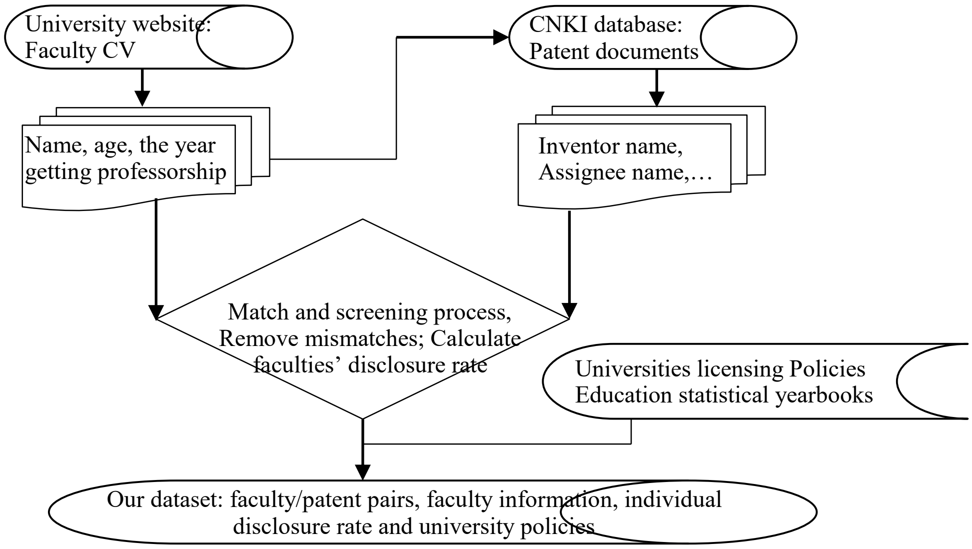

Figure 3.2 Data collection

Unlike the data collection conducted by Zhou and Zhu (2007), that carried out in the present work revolves around the individual faculty level. This enables me to acquire in-depth information regarding faculty invention disclosure because the faculty dataset identifies patent applicants (i.e. whether this is a faculty member, research students or a firm's research staff).

3.3.4.1 Curricula vitae of faculty

This study classifies the academic field according to different departments (i.e. departments of mechanical engineering, telecommunications and life sciences). This section presents faculty information, including age, gender, research field, educational background, current status and academic experience. A similar approach was adopted by Thursby (2007), who collected faculty data by reviewing their CVs. The author collected the CVs from 87 PhD granting departments of Research I universities.

Selection bias is inevitable in this dataset. Because no standard CV format is employed in China's universities, different faculty members differentially comprehend which information is required for inclusion in their CVs. Faculty may also highlight or omit significant information because they have different experiences and strategies for preparing CVs. Even so, I continue to believe that CV data collection is an effective way to obtain information on individual faculty. Note that I exclude faculty members with no working experience, including individuals who have never been employed by universities but have worked in such institutions for a given period as collaborators or part-time student employees (e.g. teaching or research assistants). Only faculty members who work in China's universities are selected. Finally, China's universities name their departments in different ways because of the diversity of disciplines covered by these institutions. For example, Tsinghua University calls the department of mechanical engineering the 'School of Mechanical Engineering', whereas South China University of Technology terms this department the 'School of Mechanical and Automotive Engineering'. The baseline adhered to in this work is that these departments provide similar majors.

3.3.4.2 CNKI patent database and data screening

I pair faculty names with current statuses and cities where the universities with which they are connected are located. To acquire more detailed information on the patenting practices of individual faculty, this study uses the name/city pairs as search criteria to identify faculty patents in the CNKI database. To illustrate why the CNKI database is chosen for this research, I compare the patent databases available in China (Table 3.3).

Table 3.3 Comparison of China's patent databases

	CNKI database-PSS	SIPO-PSS	Baiten-PSS
Advantages	- Authoritative database - Bulk download - Free of charge for all students and faculty	- Provides the most accurate patent data - Open to the public	- Provides original patent files and analysis service - Supports batch query
Disadvantages	- Does not provide patent maintenance time	- Does not support bulk download and batch query	- No bulk download - Expensive
Remarks	The bulk download feature is beneficial for this study because a huge number of faculty patents are needed to establish the special dataset.	Its biggest disadvantage for this study is that it does not provide a bulk download service.	Although bulk downloading is forbidden in this database, it provides information on patent maintenance time.

The CNKI database includes information such as patent name, patentee name, inventor name, contact address, patent code, application date, patent claim and patent abstract (Figure 3.3). In each patent for which a faculty member is the first inventor, the period analysed is that between 1989 and 2012. After data restructuring, the complete data sheet includes university name, faculty name, patentee name, technology field, contact address, number of inventors, number of claims, number of inventions and application date. Data screening is subsequently performed to match the faculty/patent pairs.

一种大型航空集装货物检查系统

【申请号】	CN200610011148.0	【申请日】	2006-01-11
【公开号】	CN101000312	【公开日】	2007-07-18
【申请人】	清华大学;清华同方威视技术股份有限公司	【地址】	100083北京市清华同方科技广场A座2907
【发明人】	康克军;胡海峰;陈志强;孙尚民;杨光;张凤君;毕勇;吴玉成;李建军;刘蓉翾		
【国省代码】	11		
【摘要】	本发明涉及一种大型航空集装货物检查系统,包括由射线源、准直 器、带探测器的横臂架、竖臂架组成的扫描架；由置于扫描架下方的 板式输送机和置于板式输送机前、后两端的上、下载辊式输送机构形 成的传送装置。其结构特点是,所述上、下载辊式输送机是由上平台、 下平台、活动叉架、伸缩杆及安装于上平台上的辊子单元总成组成而 形成可以上下移动高度的作业平台。当伸缩杆收缩时上平台处于低 位、伸缩杆伸长时上平台处于高位。解决了现有技术的检查系统占地 面积大、配套设备复杂的问题。具有运行成本低、兼容性好、适应范 围广的特点,不仅适用于检查航空集装货物,也适用于公路、火车、 海港等大宗货物的不开箱检查。		
【主权项】	1、一种大型航空集装货物检查系统,包括：由射线源(1)、准直 器(2)、带探测器的横臂架(3)、竖臂架(4)和辐射防护墙(5)组 成的固定龙门架形成的扫描架；由置于扫描架下方的板式输送机(8) 和置于板式输送机(8)前、后两端的上、下载辊式输送机构(7)形 成的传送装置；由置于扫描通道和传送装置以外,安装有扫描控制模 块、图像获取模块、运行检测器及其控制系统形成的数据处理和控制 单元；其特征在于：所述上、下载辊式输送机构(7)是由上平台(7-2)、 下平台(7-6)、活动叉架(7-3)、伸缩杆(7-7)及安装于上平台(7-2) 上的辊子单元总成(7-1)组成,活动叉架(7-3)的外上端和外下端 以铰轴一(7-9)、铰轴二(7-8)分别与上平台(7-2)和下平台(7-6) 的侧平面铰接,活动叉架(7-3)的内上端和内下端置有导轮一(7-4) 和导轮二(7-5),导轮一(7-4)和导轮二(7-5)分别置于上平台(7-2) 和下平台(7-6)侧平面开设的滑道内并且可使各导轮滑动,伸缩杆 (7-7)的两端分别与活动叉架(7-3)的两支杆铰接并且使伸缩杆(7-7) 收缩时上平台(7-2)处于低位、伸缩杆(7-7)伸长时上平台(7-2) 处于高位。		
【页数】	11		
【主分类号】	G01N23/04		
【专利分类号】	G01N23/04;G01N23/00		

Figure 3.3 Example of a Chinese patent file

The approach to data screening is described as follows. (1) Faculty with no patents are eliminated from the dataset. To avoid the repetition of names for two or more universities, I exclude patent/faculty pairs that contain the names of faculty under different universities that are located in the same city. (2) I also exclude patent/faculty pairs in which faculty names are repeated in two or more departments, regardless of whether the faculty members are employed on a part-time basis in the other divisions. (3) When a faculty name appears in both the university and external enterprise fields, and the first four figures of the zip code in the patent document is not the same as that of the university, the patent/faculty pair is omitted. Finally, (4) for a given faculty inventor, I check every one of his/her patents with reference to the patent classification code. The patents that are significantly different from the others are eliminated.

3.3.4.3 Email to university technology transfer office

Policies on university technology transfer vary because of differences in the research levels and goals stipulated in China's national innovation system. To collect information regarding university policies, especially university share rate policy and organisational characteristics, I administer questionnaires to the TTOs in charge of the top 35 patent applications from

China's universities. First, I obtain contact information, including directors' name lists, email addresses and the daytime telephone numbers of TTOs, from the Torch High Technology Industry Development Centre[15]. Then, I send the questionnaires by email to the leaders or technology managers of the TTOs[16].

3.3.5 Analysis approach

To investigate the determinants of faculty patent assignment, two assignment equations are formulated. In these equations, the patent owner (university, industrial firm or faculty) is expressed as a function of the main determinants identified by previous literature and by the interviews and questionnaires. Two empirical models are used to determine the correlation between the probability of assignment to a particular type of organisation and a set of influencing factors discussed in the literature review. Table 3.4 presents a review of selected empirical studies on faculty patent assignment.

Table 3.4 Selected papers on university patent assignment

	Author	Data source	Methodology
US	Thursby et al. (2007)	NRC*, NBER	Binary Logit Regression
	Thursby et al. (2009)		Multinomial Logit Regression
US	Fini, Lacetera, and Shane (2010)	NRC, AUTM	Probit regression
Europe	Crespi et al. (2006)	PatVal Database	Interview, Propensity score matching

Given that the dependent variables are coded as 0 or 1, a binary logistic model wherein a patent is assigned to a university (1) or to another assignee (0) is used. Faculty, organisation and environmental characteristics are the independent variables. I also consider a more comprehensive scenario, in which patent assignment, as the dependent variable, is assigned four values (1=assigned to university, 2=assigned to an industrial firm, 3=jointly assigned to a university and a firm, 4=unassigned but owned by faculty). In this case, a multinomial logistic model is used to determine the influencing factors for faculty patent assignment.

[15] In 1988, the Chinese central government implemented a torch plan aimed at developing high-technology industries. In October 1989, the Torch High Technology Industry Development Centre was established by the MoST. This torch centre has been playing a significant role in developing high-tech TEC SMEs and high-tech business incubators.

[16] The email survey can be found in Appendix A.

3.4 Study #2: Modelling faculty invention disclosure

3.4.1 Research design

Because of concerns over university assignment and poor UITT performance in Chinese universities, this research establishes an effective management approach to improve the current situation in China. For Study #2, I develop a game model that simulates faculty decision-making on invention disclosure, with consideration for peer competition, reputation, economic return and firm cooperation. To improve invention quality, patent checking is used to screen inventions and discard low-value creations. During this process, faculty invention disclosure is influenced by TTOs' screening decisions and licensing strategies (i.e. only high-quality inventions are licensed and poor-quality inventions are disposed of). A key element in this game model is the proportion of patent value checking from 0 to 1. In addition, Study #2 analyses the inventor's share of royalty/equity on the basis of game theory and principal–agent theory. Moreover, Study #2 focuses on how universities can optimise profits from the technology transfer chain in accordance with public interest.

3.4.2 Simulation of decision-making process with game models

Although empirical analysis can exhaustively explain phenomena and directly delineate developments on the basis of surveys and dataset examinations, some disadvantages, such as lack of precision in assessment and forecast, remain. An interesting approach, therefore, is to apply a game theoretic model to simulate the participants' decision-making processes; the simulation is intended to enable improved understanding of these processes' effects on invention disclosure, patent assignment and UITT (such as Aghion and Tirole, 1994; Jensen, Thursby, and Thursby, 2008; Eric and Thursby, 2013, etc.). This research uses game models as methods for theoretical explanation.

The Stackelberg game model is employed to represent the interactions between faculty and TTOs (Kabiraj, 2005; Crama et al., 2008). In the patent licensing process, safeguarding a university's reputation that licenses only high-value patents necessitates patent checking by TTOs. Information asymmetry exists because faculty are unaware of how many inventions are to be checked. A reasonable assumption is that faculty invention disclosure is closely related to patent checking rate. The Stackelberg game model is therefore an appropriate representation, wherein a TTO functions as the leader and a faculty inventor is the follower.

The game model based on principal–agent theory is used to simulate the decision-making of faculty, TTOs and industrial firms. In this model, successful UITT depends on faculty effort and firm investment, whilst a TTO, as an intermediary organisation, is responsible for encouraging the first two parties to commit adequate effort to the process. The selection of this game model is informed by considerations that correspond with the assumptions of principal–agent theory: (1) Moral hazard exists between faculty and firms because the former's input is difficult to observe and estimate; (2) as a dual agent for faculty and firms, a university TTO is risk neutral and exerts no direct influence over the success rate of UITT. The results derived from this game model can unearth new insights for faculty, university TTOs and industrial firms. The findings can also shed light on implications for policymakers.

The game model related to revenue management is used to design licensing contracts. In the UITT process, licensing contract design is the most technical and significant task of TTOs, which have to avoid adverse selection and moral hazard in developing the contract. To date, many studies use game theory as basis in examining licensing contract components, such as royalties, equity payments, milestone payments and annual fees. A mathematical model is developed in this work to determine the best strategy for commercialising faculty patents.

3.5 Triangulation analysis

Triangulation analysis is often used to confirm the validity of the results obtained through two or more research methods in a study. It can facilitate the validation of data through cross-checking and between-method checking[17]. The present study uses methodological triangulation, which is one of the four basic triangulation models identified by Denzin (1978). This approach is employed to interpret faculty invention disclosure and patent assignment.

[17] Quoted from Wikipedia: http://en.wikipedia.org/wiki/Triangulation_(social_science).

Figure 3.4 summarises the research methodology of this work. Specifically, it illustrates the analyses carried out with different methods and indicates the key issues that are addressed under each method.

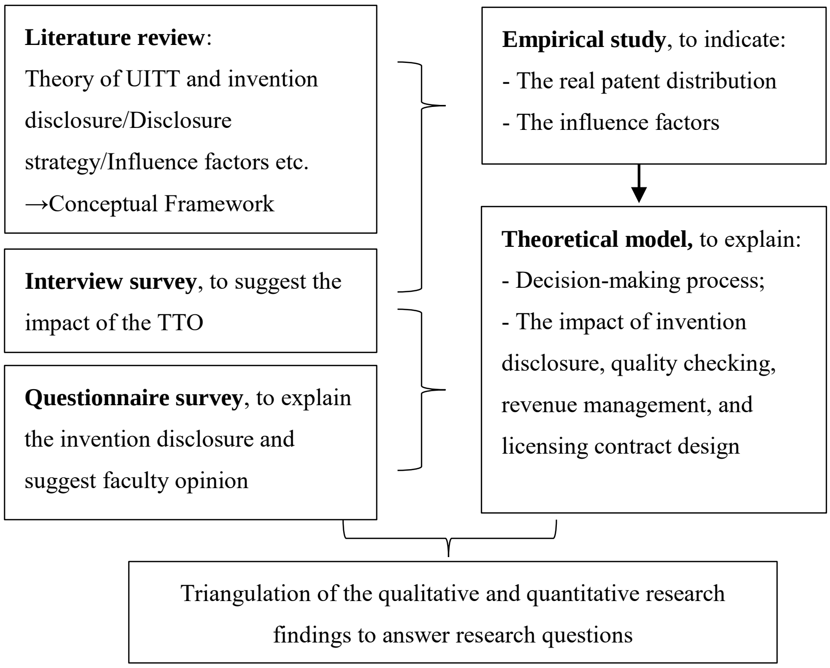

Figure 3.4 Research methodology and triangulation

3.6 Summary

This chapter discusses the research design and methodology, as well as the analytical approaches, employed in this study. Given that the objective of the work is to investigate faculty patent assignment, it focuses primarily on China's universities and adopts the approach developed by Thursby et al. (2007). Because this study is also related to management science, three mathematical models are developed on the basis of the Stackelberg game model [for questions (h) and (i)], principal–agent theory [for question (l)] and transaction cost theory (for questions (m) and (n)]. The next chapter introduces the empirical research, which encompasses the data collection and statistical description, as well as the conclusions drawn from the findings.

Chapter 4 Study #1: Faculty Patent Assignment in China's Universities

4.1 Background to faculty patent assignment

In the past few decades, faculty patent assignment in UITT has become a focal matter for academics, industry practitioners and policymakers. Most studies (e.g. Julie, 2013; Lissoni et al., 2008, 2009; Thursby et al., 2007, 2011) indicate that in most cases, a considerable share of faculty patents are not owned by universities but are instead owned by industrial firms or individuals.

Non-university patent assignment is driven by a number of factors. First, the invention ownership system is differentiated by whether ownership is determined by whether a creation is *university-owned* or *university-invented* (Crespi et al., 2006). Some European countries adopt a knowledge system centred on inventor ownership (professorial privilege) (e.g. Finland, Hungary, Italy, Sweden, Slovenia). The fact that faculty assign their patents to non-university entities rather than to universities is reasonable and legal (Damsgaard and Thursby, 2013; Geuna and Nesta, 2006; Lissoni and Montobbio, 2012; Mowery and Sampat, 2005). By contrast, US faculty patents are owned by the universities that employ academic inventors. Nevertheless, Thursby et al. (2007, 2009, 2011) pointed out that non-university assignment in the US does not violate university regulations because a large proportion of faculty patents are generated from technology consulting projects and are funded by industrial firms. Czarnitzky et al. (2012) also found that patent attribution to non-university assignees is practiced in German universities and associated with short-run profits. The authors concluded that firms cannot identify and exploit basic faculty inventions because of the lack of absorptive capacity on the part of the firms. In summary, scholars have extensively analysed faculty patent assignment in different countries and the factors that may explain non-university assignment. To my surprise, however, such research in the context of mainland China is scarce. People have little knowledge of the faculty patent assignment situation in Chinese universities.

Chinese universities have been tremendously successful in patent creation, as indicated by the fact that patent applications in the country have increased 7.89-fold in the recent 10 years (National Bureau of Statistics of China, 2002, 2012). In 2012 alone, China became the top patent application country, and its PCT international patent applications ranked third in the world. Nevertheless, this excellent performance is not echoed by the country's UITT. Tsinghua University and Fudan University conducted a survey and found that only about 10%–15% of faculty patents from Chinese universities are transferred to industrial settings (State Intellectual Property Office of China, 2005). I think a possible obstacle to UITT in China is non-university assignment, which diminishes the quality of university-owned patents to levels that prevent commercialization. This observation holds true, especially when high-quality faculty patents are assigned to non-university assignees.

In this section, I endeavour to paint a comprehensive picture of faculty patent assignment in China's universities. As previously discussed, a unique dataset is established for this purpose. The dataset comprises information on individual faculty and is used as basis in investigating the determinants of different types of faculty patent assignment (university assignment, firm assignment, university–firm assignment and individual assignment).

This section empirically explores the number of faculty members who assign patents to non-university assignees and their reasons for engaging in such practice. To begin, 18,435 patented inventions created by 2,002 university faculty members are examined. The analysis shows that 13.16% of the faculty/patent pairs are not assigned solely to Chinese universities (5.28% are assigned to private firms; 5.73% are jointly owned by universities and firms; and 2.15% are owned by individual faculty). To further look into these statistical figures, I interview the TTO directors, who attribute this phenomenon primarily to inflexible revenue management and bureaucratic formalities, amongst other factors. After the interviews, I examine faculty patent assignment as a function of invention and inventor characteristics, university policies and intellectual eminence, after which I apply binary and multinomial logit regression modelling to patent assignment. In particular, I probe into the four types of assignment: (1) university assignment, (2) firm assignment, (3) university–firm assignment and (4) individual assignment. The results indicate that patent assignment changes with research field, patent claim and number of inventors. For a given patent, final assignment varies with university royalty and equity policies, intellectual eminence and inventor characteristics.

The rest of this chapter is organised as follows. Section 4.2 provides the interview results, and Section 4.3 reviews propositions. Section 4.4 describes the research design and estimation of the present study. Section 4.5 presents the logit regression model and empirical results. Sections 4.6 and 4.7 contain the discussion of the results and the summary, respectively.

4.2 Interview with university TTOs

Most researchers who focus on Chinese UITT agree that faculty play a significant role in the technology transfer process. This section elucidates faculty patenting activities and the factors that influence such occupations. The insights on which this explanation is grounded are the interviews with the TTO directors.

4.2.1 Interview design

4.2.1.1 Participants

A university TTO is responsible for managing faculty invention disclosure, carrying out university incentive schemes and promoting UITT. It is normally regarded as the intermediary between a university and a faculty member. A necessary requirement, therefore, is to interview TTO directors because they are well-versed in the factors that influence faculty decision-making on patent assignment.

Seven interviews are conducted in seven Chinese universities, including Southeast University, Zhejiang University and Fudan University (Table 4.1). A total of 29 respondents participated in the interviews.

Table 4.1 Seven interviews with TTO directors and technology managers[18]

	University	Interviewees
April 9, 2012	Southeast University	Vice president Director, Department of university assets management Director, Associate Director and two technology managers, Department of Science and Technology Director, Science Park
April 11, 2012	Zhejiang University	Director and a project manager, Department of Technology Development and Transfer Assistant to the Dean, counselor and vice director, Industrial Technology Research Institute Four technology managers, The University TTO
April 14, 2012	South China University of Technology	Director, Vice-Director, and a technology manager, Department of Science and Technology Vice-Direct, Department of Social Science Vice president, Science Park
June 4, 2012	University of Shanghai for Science and Technology	Vice director, Department of Science and Technology Three technology managers, The TTO President, Science Park
June 19, 2012	Shanghai University of Sport	President and Vice president, Science Park
June 26, 2012	Shanghai University of Finance and Economics	Vice president, Science Park
July 11, 2012	Fudan University	Director, Department of Science and Technology, The TTO

The personal experiences and social networks of the interviewees are essential. In mainland China, decision-making on patent assignment depends partly on the '*guanxi'* between faculty and the above-mentioned respondents and between faculty and non-university assignees. TTO directors are selected as respondents because licensing strategies and commercial plans for faculty patents are carried out only by senior and high-ranking officials.

4.2.1.2 Interview questions

The interview questions are designed to enable investigation into three major features of the UITT process: faculty patenting activities, licensing revenue management and university

[18] In 2012, when I was focusing on the research topic, 'the faculty invention disclosure in mainland China', I took part in the research programme, 'collaborative innovation and university technology transfer', jointly funded by the MoE and MoST in 2012. Part of the survey results are derived from this programme. My thanks go to Pre-Vice-President Prof. Li and Dr. Bao for their direction and the experiences that they shared.

patent management systems. Three propositions regarding these features are developed, and related open-ended questions are designed to test each proposition. The propositions and open-ended questions are developed on the basis of the literature review (Chapter 2). Tables 4.2–4.4 list the propositions and questions.

The interview responses serve as reference in developing the conceptual model and analysis framework that underlie the enquiry into the determinants of faculty invention disclosure and patent assignment. The succeeding empirical analysis is designed on the basis of the interviewees' responses.

(1) Proposition 4.1 (IS) and related questions on faculty invention disclosure

Table 4.2 Faculty invention disclosure in Chinese universities

Proposition 4.1 (IS)	**The non-university patent assignment is common in China's universities.**
Q1	How many faculty patents are assigned to non-university assignees?
Q2	For the faculty invention, what strategy the faculty mainly adopt?
Q3	Why faculty choose non-university assignment? Do you think this non-university assignment is inappropriate or illegal?
Q4	From the perspective of university administration, do you think the university should prevent this faculty behaviour?

Zhou and Zhu (2007) pointed out that many faculty patents are not owned by university administrations. Proposition 4.1 puts forward the notion that non-assignment in China's universities is observed to a considerable extent by the interviewees because they are involved in faculty patent management.

Q1 elicits explanations for non-assignment by enabling the interviewees' to share their subjective opinions on how many faculty patents have been attributed to non-university assignees. Q2 is used to address one of the most important questions about assignment decision to enable the determination of whether faculty attribute inventions on the basis of quality or quantity. Q3 is designed to determine the factors that discourage faculty from disclosing inventions to their universities; it is also used as basis in putting forward a preliminary evaluation of this choice (i.e. whether the decision is appropriate). Q4 asks for the interviewees' views on how to address the non-assignment problem. These open-ended questions are designed to corroborate Proposition 4.1.

(3) Proposition 4.2 (IS) and related questions on licensing revenue management

Table 4.3 University licensing revenue management

Proposition 4.2 (IS)	**The university licensing revenue management has the significant impact on faculty's decision-making of patent assignment.**
Q5	How to distribute the licensing revenue between the university, the TTO, and the faculty?
Q6	Do you believe the current incentive system could effectively encourage faculty to disclose their inventions voluntarily? Do you think it is necessary to improve the revenue management in your universities?
Q7	What benefit the university obtains from the university technology transfer?

From the viewpoint of policy, licensing revenue management in universities is one of the key factors that affect faculty patent assignment. The willingness of faculty to disclose inventions generally increases with the inventor's share of licensing revenue.

Q5 queries licensing revenue distribution amongst faculty, TTOs and universities. It is also designed to verify whether unreasonable conditions exist. If the current revenue management is evaluated as unreasonable, Q6 is raised to ascertain whether the incentive systems in China's universities can motivate faculty to disclose their inventions to TTOs. Considering that a TTO is a dual agent that facilitates interaction between faculty and universities and between faculty and technology buyers, Q7 is posed to the interviewees to determine the benefits provided by universities and the motivation that drives or fails to drive disclosure.

(3) Proposition 4.3 (IS) and related questions on patent management system

Table 4.4 Patent management system in mainland China

Proposition 4.3 (IS)	**China's current patent management system plays negative impact on the university assignment.**
Q8	How many organizations are involved in university patent management?
Q9	For the faculty patent, who are the real patentees and owner in mainland China?
Q10	Do you think there is some organization that plays negative role on invention disclosure?
Q11	Do you think the current organization structure is ok?

In the middle of the last century, the Chinese government introduced educational and science and technology systems that are based on the structure adopted in the former Soviet Union. The patent management system in the country is a general feature that induces non-university assignment because of its planned economy-related characteristics.

Q8 is aimed at acquiring an overview of the entire UITT process, from invention to commercialisation. On the basis of the responses to this question, Q9 is raised to determine the true owners of faculty inventions. Q10 is designed to analyse the roles of organisations in this process and to ascertain whether each of them has negatively or positively affected invention disclosure. Q11, the last question in the interview, is intended to encapsulate the attributes of the current patent management system in China's universities.

4.2.1.3 Questionnaire

To supplement the interview data, a questionnaire that comprises 18 objective questions is administered to the respondents. The questionnaire is divided into two major segments. The first centres on a brief introduction to the university TTOs, including their sizes, years of operation, employee backgrounds and development stages. The second segment revolves around the TTOs' organisational tasks, key performance indicators (KPIs) and social networks. This questionnaire is anticipated to clearly depict the reality that surrounds faculty patent assignment in China.

4.2.2 Interview results

4.2.2.1 Faculty invention disclosure

Table 4.5 illustrates that non-university assignment is a common practice in China's universities. The interviewees state that this type of assignment has become one of the important routes towards UITT (Q1). The responses to Q2 indicate that Chinese faculty primarily intend to assign high-quality inventions or patents to non-university assignees. Low-quality inventions are likely disclosed to universities in a timely manner. The answers to Q3 comprehensively illustrate non-university assignment on the basis of university policies, management systems, faculty salaries and economic returns. The interviewees estimate that more than half of non-university assignments are inappropriate. The responses to Q4 suggest that universities and TTOs have no plans of preventing non-university assignment or filing lawsuits. This decision is attributed to three principal reasons. First, if a university has not participated in and advanced UITT from the beginning, then it has no motivation to argue the inappropriateness of faculty behaviour. Second, universities and TTOs typically lack experienced technology managers. They are sometimes more inadequately equipped than faculty in terms of efficiently transferring patents. Third, in a wider context, whether faculty inventions are owned by universities or non-university assignees, different UITT channels all enhance a university's reputation. If conditions permit (e.g. no state secrets, homeland security effects), therefore, university administration would tolerate non-university assignment.

Table 4.5 Results of interviews regarding faculty invention disclosure

Proposition 4.1 (IS): The non-university assignment is common in China's universities.		
	Questions	**Responses**
Q1	How many faculty patents are assigned to non-university assignees?	Hard to say, but it is a common phenomenon here, as only about 10% of total university-owned patents are transferred by the TTO.
Q2	For the faculty invention, what strategy the faculty mainly adopt?	I believe part of high quality patents are assigned to non-university assignees by the faculty, while the low quality invention must be disclosed to the university as a result of some non-economic profit. For the faculty invention disclosure, there exists moral hazard as a result of information asymmetry.
Q3	Why faculty choose non-university assignment? Do you think this non-university assignment is inappropriate or illegal?	Many reasons, such as low salary, huge economic return, inflexible management, lack of trust, lack of absorptive capability, unreasonable policies, consulting projects et al., I believe more than half of non-university assignment is inappropriate.
Q4	From the perspective of university administration, do you think the university should prevent this faculty behaviour?	The university will not prevent the non-university assignment, unless TTOs have put effort in UITT. In many cases, TTOs tolerate this phenomenon since we lack experienced technology managers, and cannot provide better solutions for UITT.

4.2.2.2 Current licensing revenue management

According to the 'Science and Technology Law' introduced by the MoST, allocating shares of licence revenue (at least 20%) to inventors is a reasonable requirement because these inventors conduct innovative work. With respect to a faculty-oriented perspective, substantial research confirms that increasing an inventor's share rate effectively promotes invention disclosure. Table 4.6 shows the open-ended questions related to this issue and the interviewees' responses.

Table 4.6 Results of interviews regarding university licensing revenue management

Proposition 4.2 (IS): The university licensing revenue management has the significant impact on faculty decision-making of patent assignment.

	Questions	Responses
Q5	How to distribute the licensing revenue between the university, the TTO, and the faculty?	It depends on the type of licensing contract. Generally, the inventor share of royalty payment is larger than that of equity. The inventor share rate could be a fixed number, such as 33%, or a decreasing function of licensing revenue. The most important thing is how to make price for a specific faculty patent.
Q6	Do you believe the current incentive system could effectively encourage faculty to disclose their inventions voluntarily? Do you think it is necessary to improve the revenue management in your universities?	Although TTOs have increased the inventor share rate recent years, the current incentive system cannot promote the faculty invention disclosure effectively. It still needs time to test these policies. I believe the TTO should improve the regulation of revenue distribution, but not increase inventor share rate.
Q7	What benefit the university obtains from the university technology transfer?	Economic return, reputation, and the contact network with industry firms

The responses to Q5 provide an overview of the situation that characterises revenue management in Chinese universities. Generally, the respondents state that university policies stipulate a fixed share rate rather than allow for negotiations with faculty on a case-to-case basis. As shown in Figure 4.1, the inventor share rate in many universities remains at a low level (20%).

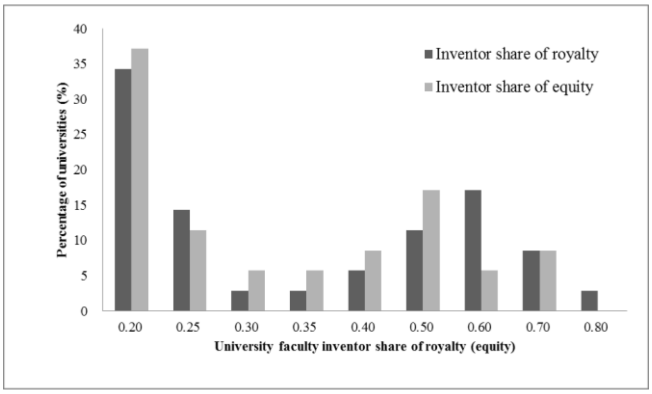

Figure 4.1 Percentage of universities by inventor share of royalty/equity

The answers to Q6 suggest that many of the interviewees are concerned over the inflexible revenue management implemented in universities. Specifically, they believe that this system demotivates faculty from disclosing their inventions because creators who come up with high-quality inventions intend to earn a high share rate. The current incentive system stimulates disclosure only for low-quality inventions. Another serious problem is how licensing revenue is distributed. Many of the interviewees complain that the Ministry of Finance require public universities to turn over all licensing revenues to the central government. A university can then apply for government grants in the succeeding financial year to reward all the stakeholders involved in invention. This grievance indicates that licensing revenue distribution necessitates government permission—a regulation that prevents universities from adopting flexible economic incentive schemes.

The answers to Q7 indicate that universities and TTOs can obtain some unique benefits from faculty invention disclosure and UITT. First, they can earn economic returns by selling valuable faculty patents. Second, participation is beneficial in that it will enable universities and TTOs to refine their reputation by way of experienced staff and established history. Finally, faculty invention disclosure and UITT enable stakeholders to cultivate large-scale networks comprising industry contacts, which can produce more research funding and technology consulting projects.

4.2.2.3 University patent management

Table 4.7 illustrates the negative effects of the Chinese patent management system on faculty invention disclosure. Many of the interviewees criticise the unreasonable organisational structure and inflexible management system currently in place in China's higher education institutions.

Table 4.7 Results of interviews regarding university patent management

Proposition 4.3 (IS): China's current patent management system plays negative impact on the university assignment.

	Questions	Responses
Q8	How many organizations are involved in university patent management?	It depends on the patent value and the sponsor. For the government-funded patents, over eight organizations are involved in UITT. For the patent resulting from the consulting project, only the TTO would participate.
Q9	For the faculty patent, who are the real patentees and owner in mainland China?	It also depends on the sponsor. For the patent resulting from the consulting project, the enterprise normally is the patentee and owner. For the patent funded by the government, the university is the patentee while the government agent is the true owner in many cases. But now this situation is improving. The government maybe gives up their ownership in the future.
Q10	Do you think there is some organization that plays negative role on invention disclosure?	Yes. For example, government inflexible management system plays the negative role on the faculty invention disclosure.
Q11	Do you think the current organization structure is ok?	No, there still exist many organizations to be improved.

Many Chinese universities are public institutions controlled by central government agencies (i.e. MoE, MoST, MITT) and local governments. The responses to Q8 provide introductory information on all the organisations involved in faculty patent assignment and UITT. These organisations are academic departments, schools, TTOs, university administrations, SAOs, university-owned enterprises, local governments, MoE, MoST and MITT. Amongst these organisations, SAOs function as intermediaries between universities and the government. These offices have the authority to decide on exclusive/non-exclusive licensing and patent sale.

The responses to Q9 illustrate that China has adopted a semi-federal invention ownership mode (Figure 4.2), wherein invention ownership is only partly assigned to university administrations. Although China's universities have been allowed to retain title to inventions resulting from federally funded research, the government remains the final decision-maker regarding ownership.

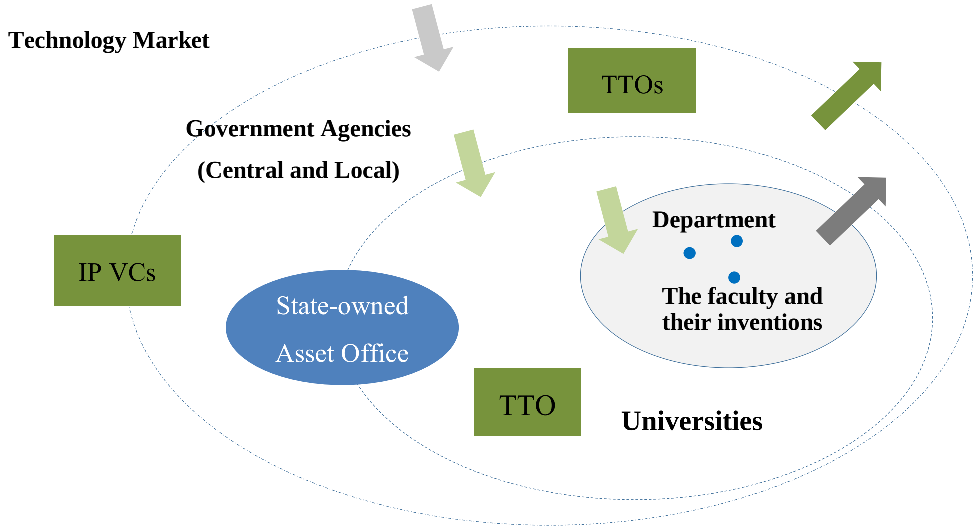

Figure 4.2 Semi-federal ownership model in mainland China

For Q10 and Q11, many interviewees declare that in China, patent transfer from a university to an industrial firm requires approval from SAOs on a case-to-case basis because in Chinese public universities, faculty patents are state-owned intangible assets. This approval mechanism is similar to the IPA that was in place in the US before the legislation of the Bayh–Dole Act (1980). Given these bureaucratic formalities, this process entails considerable time on the part of faculty and industrial firms and increases overall transaction costs.

4.3 Proposition development

This section describes the main determinants of faculty patent assignment based on previous research. From the individual level, this section classifies the determinants into seven categories: (1) invention characteristics; (2) faculty inventor characteristics; (3) university intellectual eminence; and university licensing policies related to revenue management, and then proposed four propositions. In addition, from the organizational perspective, three propositions related to university characteristics, R&D expense, and city competitiveness are proposed. Figure 4.3 summarizes all propositions in this chapter.

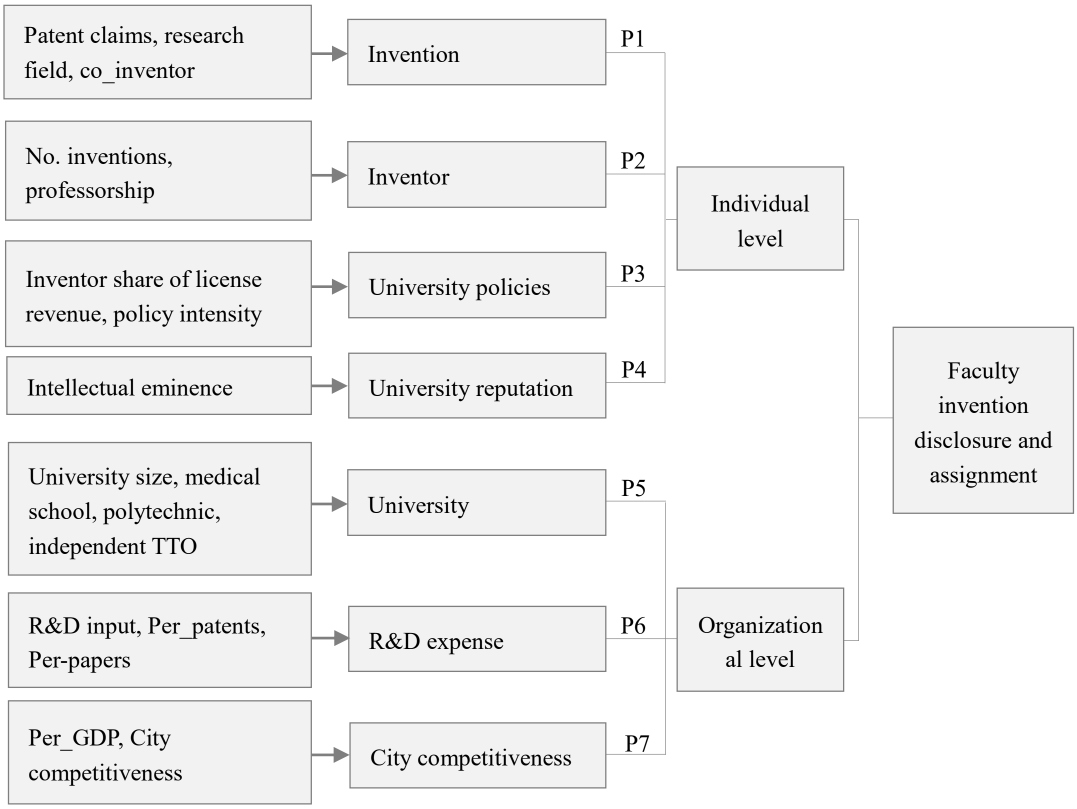

Figure 4.3 Research propositions proposed in this chapter

4.3.1 Individual level

4.3.1.1 Invention characteristics

The first argument for invention characteristics in faculty assignment activities is patent quality. The fact that high-quality inventions are less likely to be reported to university administrators has been confirmed by previous studies (Jensen et al., 2003; Markman et al., 2007). This is not surprising because it enables faculty inventors to keep 100% of the licensing revenue rather than about 30% via disclosing the high-quality patent. From another aspect, in recent years, most of China's universities have focused their efforts on a smaller number but higher-quality faculty patents, in order to balance the numerous patents and limited experience of technology transfer managers (Liu and Jiang, 2010). In this case, although meeting with great interest, it seems that it is not easy for faculty to sell or license their high-quality patents directly by bypassing the universities' monitoring systems. Therefore, it is hard to say whether the patent quality has a positive or negative influence on invention disclosure and university assignment.

Second, to link academic inventions with potential interested firms, faculty inventors have to pay search costs and rely on all their co-inventors' contact networks, which are indicated by the number of co-inventors. The assumption of university assignment is that TTOs have lower search costs and larger networks than all faculty listed on a given academic invention (Crespi et al., 2006; Hellmann, 2007). This implies that TTOs can make a larger marginal contribution to the success of transferring a given technology than faculty inventors. For the same reason, when faculty inventors have a closer and richer contact network with private firms (for example, some of the co-inventors are from firms), they may not choose university assignment but instead search for interested firms by themselves, commercializing their inventions directly.

Third, several studies have provided empirical evidence of different patent assignment in different research fields (Fini et al., 2010; Fuller, 2008; Geuna et al., 2006; Jensen et al., 2008; Thursby et al., 2007; Thursby et al., 2009). In particular, pharmaceutical, biotechnology, and semi-conductor firms rely more closely on university patents since technology-intensive firms need more advanced technologies and know-how from university laboratories (Boardman et al., 2012; Kim, Lee, and Marschke, 2005). Compared with other research fields, such as life science or telecommunications, university faculties in these research fields can find potential firms with lower search costs and have more opportunities to assign their patents to these firms (Zucker, Darby, and Armstrong, 2002). Thus, in the initial test, I proposed that:

Proposition 4.1a (ES): The patent quality has a significant influence on faculty patent assignment activities in China's universities.

Proposition 4.1b (ES): The number of inventors has a negative impact on university patent assignment in China's universities.

Proposition 4.1c (ES): Faculty patent assignment differs by research field in China's universities.

4.3.1.2 Intellectual eminence

The second argument for faculty patent assignment is university intellectual eminence. Two explanations of university intellectual eminence have been given in previous literature. The first is that more competent researchers have more opportunities to sell their inventions or patents to private firms than less competent researchers (Gregorio and Shane, 2003). This is because eminent universities usually employ more top researchers than less eminent universities. In addition, eminent universities are well known and their inventions can easily be tracked. Therefore, private firms prefer to find more competent researchers in more eminent universities, which is helpful in enabling faculty to decrease search costs at the same time. The second explanation is that universities' reputations make it easier for researchers from more eminent universities to create enterprises and commercialize their inventions than researchers from less eminent universities (Humberstone, 2009). Because of information asymmetry and uncertainty, venture capitalists tend to believe that more eminent universities produce more technology that is worthy of funding than less eminent universities (Etzkowitz, 2003; Jensen and Thursby, 2001; Lowe, 2006). That is why spin-offs of famous universities always perform better (Gregorio and Shane, 2003; Pedro and Ferran, 2014). Therefore, I proposed that:

Proposition 4.2 (ES): Better intellectual eminence increases the likelihood of outside patent assignment in China's universities.

4.3.1.3 Universities policies

The third argument for faculty patent assignment is that universities differ in their patent policies towards revenue management. Specifically, extant literature has suggested the importance of three policies: one type of royalty policy and two types of equity policies.

First, the share of licensing revenue between faculty inventors and universities has a crucial impact on patent assignment, and has drawn the most attention from researchers in the last two decades (Aghion and Tirole, 1994; Crama et al., 2008; Crespi et al., 2006; Fruedman et al., 2003; Gonzalez-Pernia et al., 2013; Panagopoulos et al., 2011; Siegel et al., 2003a, b; Thursby et al., 2009). When faculty inventors disclose patents to their universities, they can earn profits from their inventions by selling or licensing technologies through royalty fees. In general, university policies require that profits should be distributed among faculty inventors, the university administration, departments, and TTO staff. This revenue distribution, reasonable or not, means that faculty inventors can earn part of the profit from their inventions immediately, and that it increases with their share of royalty fees.

Second, when universities seek to make a technology investment, technology appraisal as capital stock is a common business practice. Non-university investors are also more likely to invest in companies in which universities are the major stockholders, as this tie will reduce the information asymmetry between inventors and investors (Gregorio and Shane, 2003; Jensen and Thursby, 2001). What is more, the use of equity policies will not influence the marginal profit of new products, which is good for the product yield decision. Equity policies give faculty share options that could ask for more future profit instead of present profit, and stimulate them to put more energy into the commercialization of their technologies (Dechenaux et al., 2009; Savva and Taneri, 2012). Therefore, if faculty inventors and TTOs are not cash-constrained or risk-averted aversion, higher equity could also encourage faculty to disclose patents and take part in technology transfer involving universities.

Third, when universities would like to help faculty inventors create new start-ups based on their inventions, an increase in faculty's stock proportion of new start-ups could improve their disclosure rate (Hellmann, 2007). Unlike established firms, new start-ups are always cash-constrained. Universities' willingness to take equity stocks in exchange for up-front licensing fees could reduce the cash expenditures of faculty's new firms; prevent them from hiding or shrinking their inventions and start-ups (Gregorio and Shane, 2003). Therefore, increasing faculty's equity in new start-ups could improve their disclosure rate.

In short, although these three university patent policies are positively related to university assignment, understanding their differences is a more important task for university administrations in mainland China, because different types of licensing policies require different levels of faculty involvement and effort. This is why university administrators prefer to give faculty inventors more choices in order to promote university assignment and UITT (Savva and Taneri, 2012). Hence:

Proposition 4.3a (ES): University-employed faculty inventors are more likely to assign their patents to the university if they receive a higher share of the royalties or equities.

Proposition 4.3b (ES): University royalty policy and equity policy clearly have different influences on faculty patent assignment.

4.3.1.4 Faculty inventor characteristics

For the university faculty, professorship is considered as the most crucial reputations. Many studies of faculty patent show that disclosing and assigning patents to universities is one of the most effective ways to get the title of professor (Siegel, 2003a; Smith, 2001). From this perspective, associate professors and lecturers have more motivation to disclose inventions to the TTO and choose university assignment to gain more academic achievement. By contrast, professors do not have to do like this because of his/her current position. In addition, professors always have more social resources and network to assign their patents to non-university assignees.

The number of patents invented by the university faculty is another critical factor. Jensen et al., (2003) have illustrated that the productive faculty is less likely to disclose inventions to their universities since the invention disclosure and UITT would cost their much time and have a negative impact on their further research. However, some researchers argued that the productive faculty need more professional technology transfer service to manage their inventions efficient as a result of limited time and less energy. In this sample a trend is also presented that productive faculties were more likely to choose university assignment. In China's universities, another unique scenario is that faculty as the first inventor may not be the true "first-inventor" when the invention was created by the assistants or students in his/her research team. In this case, the faculty patents cannot be hidden and have to be disclosed to the TTO. As shown in this sample, 51.89% of faculty/patent pairs assigned to universities are the inventors' first five patents. So, for the inventor characteristics, it proposed:

Proposition 4.4a (ES): Associate professor and lecturers are more likely to disclose their inventions to university than professor.

Proposition 4.4b (ES): The productive faculty inventors are more likely to disclose their invention to university.

4.3.2 Organizational and city level

4.3.2.1 University organization characteristics

Many studies have pointed out that the faculty invention disclosure differs in the research fields. Especially, the faculty in life science are less likely to disclose their patents to the TTO than those in other fields (Thursby et al., 2007). From the organization perspective, it means that the university with medical school has a lower faculty invention disclosure rate. In addition, the polytechnic university has produced more applied technologies. The faculty in these universities always have more opportunity to choose non-university assignment since their inventions have higher readiness level than basic research. From the perspective of university size, the larger university normal has more specific standards since there are much more faculty inventions to be managed. So the non-university assignment is less acceptable for university administration if it is illegal or inappropriate. Last but not least, the independent TTOs always have more outstanding performance than the internal ones as they is enterprise operation. Hence, it proposed:

Proposition 4.5a (ES): The university with medical school has a lower faculty invention disclosure rate.

Proposition 4.5b (ES): The polytechnic university has a lower faculty invention disclosure rate.

Proposition 4.5c (ES): The university with independent TTO has a lower faculty invention disclosure rate.

Proposition 4.5d (ES): The university size is positive related to the faculty disclosure rate.

4.3.2.2 University research input and output

In China, the patent applications mainly concentrated on China's top universities. 26.5% of total faculty inventions are owned by Tsinghua University, Fudan University, Shanghai Jiao Tong University, Zhejiang University, Wuhan University, and South China University of Technology. In these six universities, the average patent applications and published papers per person are significant higher than those in other universities. For the influence of R&D expense, it represents the faculty productiveness. Thus, the university with richer R&D funding have higher faculty invention disclosure rate. So, it proposed:

Proposition 4.6a (ES): The average patent applications and published papers per faculty inventor is positive related to the average faculty invention disclosure rate;

Proposition 4.6b (ES): The university with richer R&D funding has a higher faculty invention disclosure rate.

4.3.2.3 City competitiveness

It has long been common wisdom that faculty in China's high competitive cities like Shanghai, Beijing and Guangzhou etc. will get more chances to choose non-university assignment than those in other cities, because of the gap in commercial awareness, venture capital and supply chain system. The dataset also indicates that the proportion of university assignment in these three cities is about 84.25%, less than the average level (85.66%). So, I proposed:

Proposition 4.7 (ES): The faculty in high competitive city prefers non-university assignment.

4.4 Research design

4.4.1 The sample

In order to investigate the distribution of faculty patent assignment and its influencing factors, this study selected 2,002 professors from schools of mechanical engineering, telecommunications and life science in the top 35 Chinese patent application universities as the research sample. Specifically, these 35 universities, under the "985 Project" or "211 Project" governed by China's Ministry of Education, owned a large number of patents accounting for 51.01% of total university patents during the period from 2002 to 2012. In this research, academic invention characteristics, university eminence, university policies, and faculty individual information are needed. However, there is no single database that is able to provide enough data to meet these requirements. Therefore, this research combined three data sources to establish a unique dataset following the steps below.

To begin with, the university faculty curriculum vitae (CVs) dataset was collected from universities' websites, which contain faculty's self-introductions including age, gender, current status, administrative position, and research field. Next, this study obtained information about faculty patent applications from the China National Knowledge Infrastructure (CNKI) patent database, which provides detailed information of Chinese patents granted to university faculty inventors. In addition, this study used a series of university open documents and Education Statistical Yearbooks (2002-2012) to collect university intellectual eminence and university policies. For the whole process of data collection and some possible bias, please see the Supplementary Description under Data Collection.

4.4.2 Descriptive analysis

Figure 4.4 gives the information of the average faculty invention disclosure rate during the period from 1985 to 2012. The figure also illustrates 2002 is a turning point. More specifically, the faculty invention disclosure fluctuated greatly before 2002, and it decreased to 60% in 1996. However, after 2002 it become stable and increasing since the changed government policy that the faculty inventions resulting from government research funding belongs to their universities.

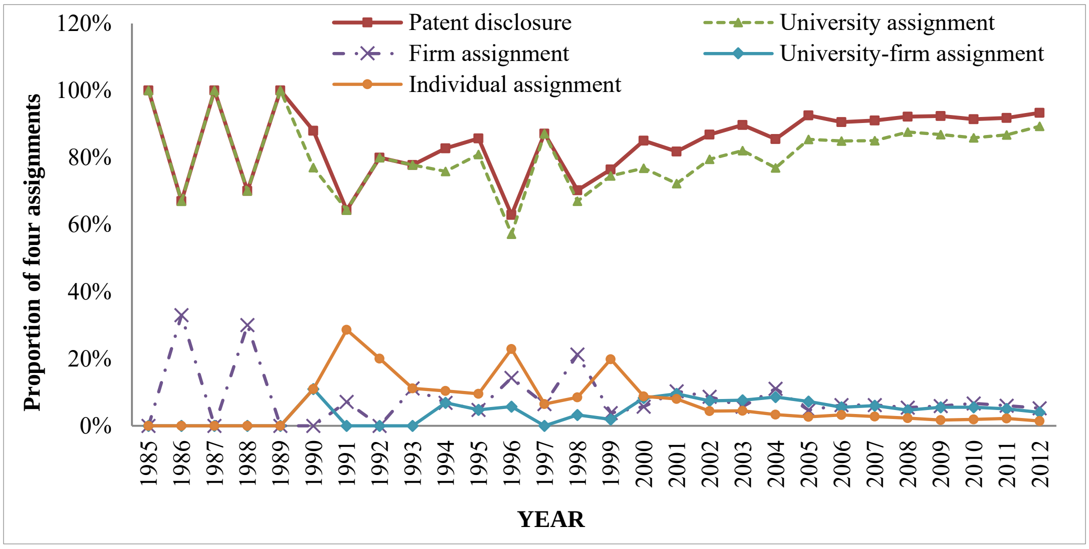

Figure 4.4 Proportion of four types of patent assignments and disclosure in 1985-2012

The data collection produced 18,435 faculty/patent pairs while 2,002 different inventors were surveyed in the period from 2002 to 2012. In specific, 4.12% of pairs have only one inventor, 13.70% have two inventors, 19.64% have three inventors, 21.77% have four inventors and the rest have five or more inventors. It is worth noting that the faculty/patent pairs were collected according to application dates, but not authorization dates. The reason is that faculty inventors always make the assignment decision and then apply for their patents. It is the fact that some of the patent applications in 2012 are still not be granted. The distribution of patents assignment by research field was categorized as follows.

Table 4.8 describes the distribution of faculty/patent pairs that classified according to research fields (i.e. life science, mechanical engineering, and telecommunication). 17.83% of pairs are from faculty inventors who are employed in life science discipline. 40.41% are from faculty inventors in mechanical engineering and the rest pairs are from telecommunication. It seems that faculty inventors from life science tend to assign fewer patents to universities than faculties in mechanical engineering and telecommunication. What is not shown in Table 4.8 is the fact that the annual growth rates of firm assignment in life science, mechanical engineering, and telecommunication are 10.43%, 35.12% and

24.98%, respectively. It indicates that firm assignment in mechanical engineering and telecommunication are catching up with life science.

Table 4.8 Faculty/patent pairs by research field

Research Field	Faculty	Total pairs	Patent assignment (%)			
			UNIV	FIRM	UNIVandFIRM	UNASSIGN
Life science	357	3,308	79.32	10.61	7.89	2.18
Mechanical engineering	809	7,233	88.84	2.72	5.90	2.50
Telecommunication	836	7,894	88.12	5.38	4.66	1.82
Total	2,002	18,435	86.84	5.28	5.73	2.15

* UNIV means university assignment; FIRM means firm assignment; UNIVandFIRM means university-firm assignment; and UNASSIGN means individual assignment.

Figure 4.5 shows the percentage of faculty/patent pairs that were solely assigned to universities in three research fields from 2002 to 2012. Prior to 2005, it is clear that university assignment remained at a low level (except in mechanical engineering). During the period from 2006 to 2012, university patent assignment in mechanical engineering and telecommunications increased steadily, with annual growth rates of 3.06% and 6.58% respectively. By contrast, university patent assignment in life science fluctuated considerably during this period, because patents in life science are easier for universities and enterprises to commercialize than those in other research fields. For instance, Nankai University established a university-owned biotech company and transferred 88 life science patents to this company in 2004 (the lowest point in Figure 4.5).

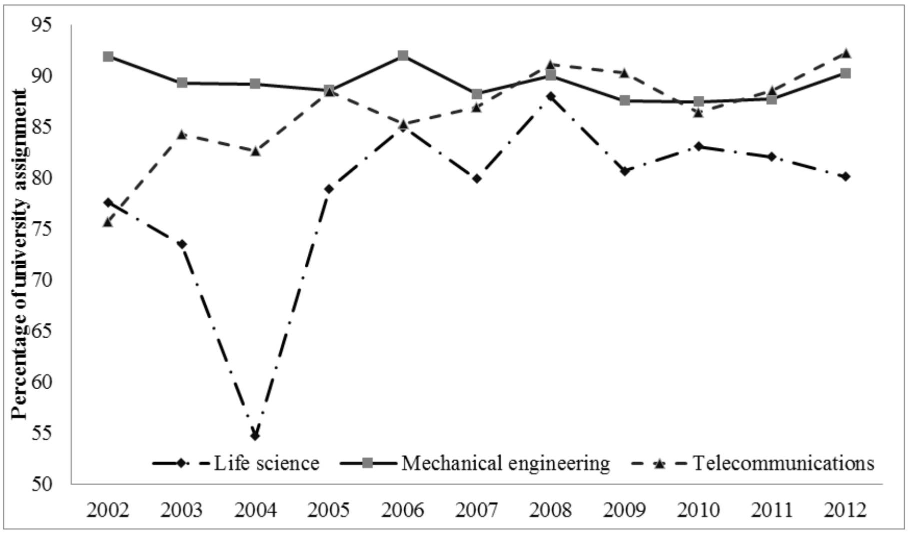

Figure 4.5 Faculty/Patent pairs solely assigned to universities in three research fields

In the dataset, 84.90% of patents are invented by university faculties who own the title of professor. Figure 4.6 illustrates the influence of university professorship on patents assignment. It was found that university assignment in 35 top patent application universities experiences sharp fluctuations. The most interesting fact is that faculty's disclosure rate drop to nearly 80% when the length of time as professors is equal to positive/negative three. Figure 4.7 gives the percentage of university assignment by faculty's professorship in each year. It shows that before 2006, the university assignment of associate professors and lecturers is larger than that of professors; however, the opposite happens from 2007 to 2012. It also indicates that university professorship have a significant impact on patent assignment.

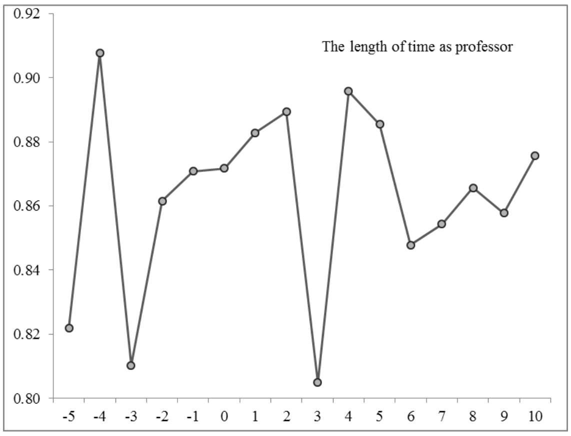

Figure 4.6 Percentage of university assignment according to length of time as professors

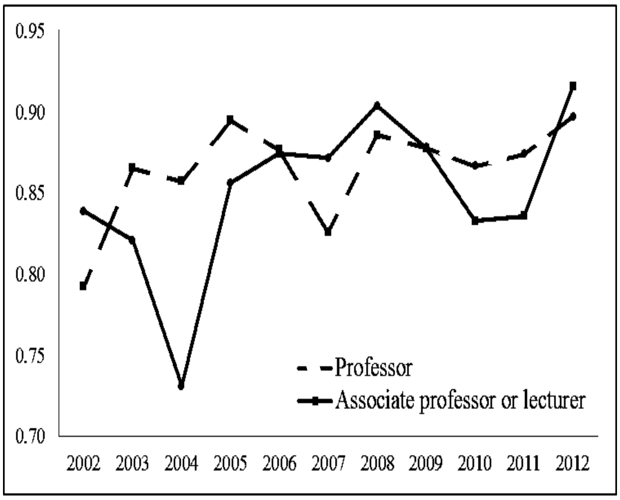

Figure 4.7 Influence of professorship on percentage of university assignment

Figure 4.8 and 4.9 give the information about the relationship between university assignment and university policies. It clearly shows that two thirds of China's universities in the dataset still have a low inventor share of royalty or equity. In special, universities with low inventor share policies in Figure 4.9 are more concentrated than those in Figure 4.8. And the amount of universities that increase the inventor share of royalty is larger and has the higher percentage of university assignment. In addition, in Figure 4.8 I found universities with higher inventor share of royalty have a better performance of university assignment than others, however, the similar trend cannot be observed in Figure 4.9.

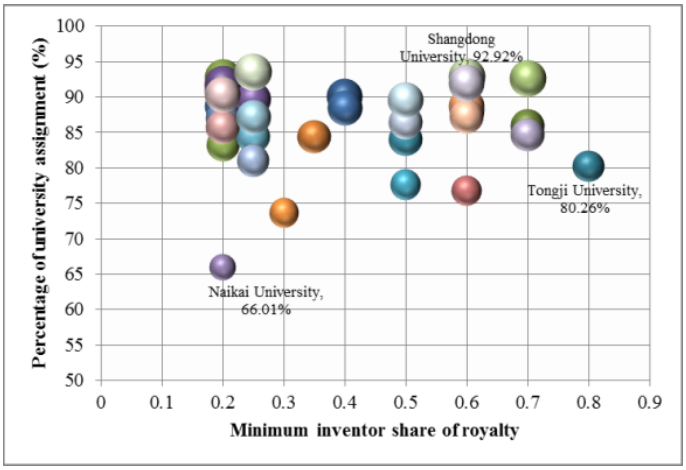

Figure 4.8 Percentage of university assignment by the minimum inventor share of royalties

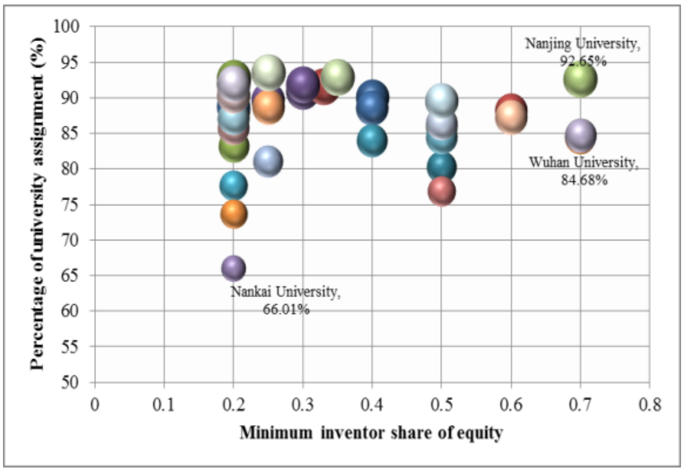

Figure 4.9 Percentage of university assignment by minimum inventor share of equity

Figure 4.10 shows that the average patent claims in the four types of patent assignment. University assignment has the most patent claims (5.26), followed by university-firm assignment. The patent owned by faculty individual has the least patent claims (3.54). It possibly implies that the patent disclosed to universities by faculty has higher quality than that assigned outside.

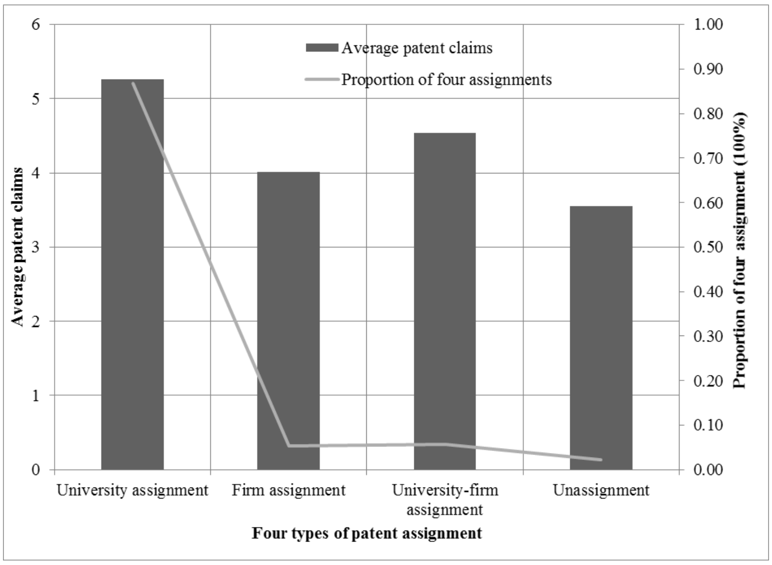

Figure 4.10 Relationship between patent claims and assignment

As shown in Figure 4.11, this study chose those faculty patents whose application year is 2002 to compare the patent maintenance time of university versus non-university assignment. First, faculty patents disclosed to universities have shorter patent life as their maintenance time is less than seven years. Meanwhile, up to June 30th 2014, 32.50% of patents assigned to outside entities is still in force. It suggests that non-university assignment patents have a longer economic life and perhaps implies that Chinese faculties disclosed high quality inventions to non-university organizations or individuals more often than to their universities.

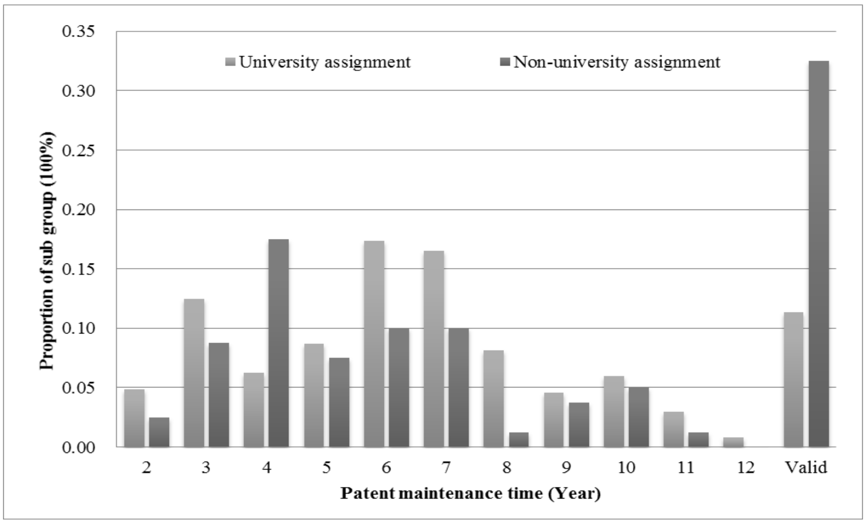

Figure 4.11 Relationship between patent maintenance time and assignment

Table 4.9 gives the distribution of faculty's patent assignment in the 35 top patent application universities. The mean number of faculty/patent pairs is 527. Tsinghua University has the largest number of faculty/patent pairs at 2,140, accounting for 11.61% of the total, followed by Shanghai Jiao Tong University with 1,039 pairs. Jiangnan University has the fewest pairs (78) in this sample. In terms of university assignment, the percentage in these top 35 universities is over 80%, except for Sun Yat-Sen University (77.64%), Peking University (73.67%), the East China University of Science and Technology (76.83), and Nankai University (66.01%).

Table 4.9 Faculty patent assignment by university from 2002 to 2012

	University	Patent pairs	Patent Assignees (%)			
			UNIV	FIRM	UNIV &FIRM	UNASSIGN
1	Tsinghua University	2140	90.09	2.57	4.77	2.57
2	Beijing University of Aeronautics and Astronautics	923	88.30	2.17	6.18	3.36
3	Huazhong University of Science and Technology	1011	85.95	5.44	6.03	2.57
4	University of Science and Technology of China	154	90.91	5.19	1.95	1.95
5	Tongji University	304	80.26	12.17	5.59	1.97
6	Harbin Institute of Technology	774	91.99	0.78	5.68	1.55
7	South China University of Technology	853	88.51	3.87	4.45	3.17
8	Dalian University of Technology	414	91.55	3.14	3.86	1.45

9	Tianjin University	538	92.75	3.90	1.67	1.67
10	Northwestern Polytechnic University	332	91.87	6.93	0.60	0.60
11	Shanghai Jiao Tong University	1039	84.02	6.16	9.34	0.48
12	Shanghai University*	418	84.45	8.85	6.22	0.48
13	Donghua University*	391	88.75	0.77	10.23	0.26
14	Southeast University	784	88.14	3.83	6.51	1.53
15	Central South University	221	83.26	1.36	3.62	11.76
16	Ocean University of China	136	89.71	2.94	3.68	3.68
17	Sun Yat-Sen University	662	77.64	9.37	10.57	2.42
18	Peking University	509	73.67	21.02	3.14	2.16
19	Beijing University of Technology*	331	87.01	1.21	6.95	4.83
20	East China University of Science and Technology*	164	76.83	14.02	6.10	3.05
21	Nanjing University	408	92.65	2.21	3.43	1.72
22	Nankai University	506	66.01	31.82	1.19	0.99
23	Xiamen University	225	84.44	2.22	12.00	1.33
24	Jilin University	221	88.69	1.36	0.00	9.95
25	Sichuan University	385	81.04	10.13	6.23	2.60
26	Fudan University	796	85.80	3.27	9.17	1.76
27	Shandong University	466	92.92	3.43	1.29	2.36
28	Wuhan University	359	84.68	11.98	2.51	0.84
29	Jiangnan University*	78	87.18	6.41	3.85	2.56
30	Zhejiang University	753	87.25	2.52	9.96	0.27
31	Zhejiang University of Technology*	287	86.41	2.44	6.62	4.53
32	Hunan University	404	90.35	4.46	2.97	2.23
33	University of Electronic Science and Technology of China	108	93.52	0.93	5.56	0.00
34	Xi’an Jiao Tong University	820	91.95	0.98	5.85	1.22
35	Chongqing University	518	89.58	0.97	7.53	1.93
Total / Average		18435	86.84	5.28	5.73	2.15

* As shown in Table 4.2, universities marked with an asterisk are not “985 Project”, but belong to “211 Project”. In addition, Shanghai University, Donghua University, Beijing University of Technology, and Zhejiang University of Technology are governed by local governments, but not China’s Ministry of Education (MoE).

Of all the 18,435 faculty/patent pairs in the sample, 2,426 were not solely assigned to universities by faculty inventors. This study examined whether there is a relationship between faculty inventors and private firms. It was found that only 158 pairs of outside assignment, accounting for 6.51%, had the same name as the start-ups’ legal persons or stakeholders. However, I believe that the truth is higher than this figure, since it is easy for faculty to hide their start-ups in order to avoid contingent payments to university administration in Chinese universities. I also checked the links between universities and private firms since many new start-ups are established in universities' incubators or science parks. I found that 248 firms had close relationships with China's universities. Even so, I have to admit that I could not cover all the links among faculty inventors, universities and private firms. It was also hard to collect information on whether the faculty (or the university) was the principal or shareholder in a firm. Thus I am convinced that all the data about outside assignment in this dataset is at the lower bound of reality.

4.4.3 Dependent variable

In this section, the faculty patent assignment is correlated to invention characteristics, intellectual eminence, and university licensing policies. The dependent variable is a dichotomous variable when faculties assigned the patent to the university (coded as "1") or not assigned to the university (coded as "0") in a given university in a given year.

4.4.4 Independent variables

4.4.4.1 Individual level

(1) Characteristic of inventions: value of patent, research field, number of inventor

In order to measure the value of patents invented by university faculties, citation is considered as one of the most representative indicators (Ho, Saw, Lu, and Liu, 2013; Thursby et al., 2007, 2009). However, Chinese patent applications are not required to provide with citation documents. Thus, this research uses the number of patent claims instead of citations as a measure of patent value, which is also employed in Thursby's research.

In this section, university faculty inventors are all from three research fields: life science, mechanical engineering, and telecommunication. The dummy variables are used to indicate these three research fields (Mechanical engineering = 1 if faculty inventors come from schools of mechanical engineering, Telecommunication = 1 for faculty inventors in schools of telecommunication, and life science is regarded as the reference research field in this section).

To measure whether faculty inventors' contacts network influence their disclosure rate, I defined social contacts network as the number of co-inventors who take part in the invention activities. This variable can be extracted from patent documents in the CNKI database.

(2) Characteristics of the faculty inventor: number of invention, the length of time as professors, faculty position, year application, age and gender

Because I expect that faculty inventors with more inventions are more likely to assign their patents to private firms. This research examined the exact number of inventions while faculty inventors make each patent assignment decision. In the dataset, when the number of invention is less than five, the ratio of university assignment versus outside assignment is 6.89, and then decrease to 6.09 while the number of invention increase to 10. Therefore, I conclude that productive faculties are more welcomed by private firms than other faculties with less output. This number of invention can be obtained by calculating all faculty-invented patents in CNKI database.

In previous section, I have found professorship influence patent assignment significantly. Because this sample is a multilevel/panel dataset that relate to faculties' whole career life, it is hard to use a static indicator variable to control the impact of professorship in every year. Therefore, the length of time as professors was used as an alternative variable. This variable is equal to patent application year minus the year when faculty get the title of professor. For example, in the year of application for a given patent, the number of "3" implicates faculty inventor has been a university professor for three years, while "-3" means faculty inventor will become a university professor in the third year in the future. By doing this, it can be found the differences in patent assignment with different faculty status.

Because I are convinced that faculty position has advantageous and disadvantageous role in patent assignment. First, faculties as leaders in their respective departments, have to comply with their schools' invention reporting systems to set good examples. On the other hand, position always provides faculties with more research resources and social connections which are helpful in commercializing their patents by themselves. In this sample, faculty position can be collected from universities' websites and faculties' CVs. This research used a dichotomous variable to control the influence of faculty position by coding president (or vice-president) as "1", and the rest coding as "0".

In 2006, China's universities were first considered as one of the most important innovative subject in the national innovation system. Since then, a number of favourable policies have been introduced by central and local governments to improve the performance of UITT. In order to control the influence of these policies development, a year application variable is employed. This data also can be collected from CNKI database.

It is clear that outside assignment is significantly higher when faculties' ages are between 35 to 55 years old in the dataset. To account for this variation, I include age variable for all patents. Meanwhile, I want to control the impact of gender by employing a dichotomous variable (male coded as "1", and female coded as "0").

(3) Intellectual eminence

To measure whether university eminence affects faculty's disclosure rate, this research examined the average discipline assessment score of all first-level disciplines in three research fields in these 35 universities. Because all research fields were assessed by China's Ministry of Education (MOE) every five years (i.e. in 2002, 2007, and 2012). I update the scores three times.

(4) University licensing policies: the inventors' share of royalty and equity

In order to find out the relationship between university royalty policies and faculty disclosure rate, the inventors' share of royalty from licensing profit was examined. The inventors whose technologies are licensed by TTOs could receive royalty revenue based on a rate which is stated in published university policies. The royalty rate may be a fixed sum, or perhaps a decreasing function of the amount of royalty received by the university. Under most circumstances, inventors share of royalty rate is affected by the output of new products, inventors cannot make sure the exact share of royalty that they will receive. Therefore, like Gregorio and Shane (2003), the minimum share of royalty rate was used as an independent variable. In addition, because some universities use a monotonically decreasing function to distribute the inventor share according to the total licensing revenue, this study use the amount of royalty that inventor would receive from a patent valued RMB 1 million as the benchmark for inventors share of royalty.

When university administration adopts technology investment, the inventor equity rate that received from university was examined in order to measure if university equity policies influence faculty disclosure rate. Unlike inventor share of royalty, equity policies will not generate a cash flow which influences the marginal profit of new inventions. For faculty inventors, they would receive a continuous licensing profit which could encourage their participation. Meanwhile, private firms do not need to pay up-front and annual fees. That is why it is considered the more effective way. I obtain the exact inventor share of equity from universities' published policies.

When university would like to invest in more capitals, but not limited to technology investment, to help faculty establish a new start-up, I examined the inventor equity of the new start-ups. Most evidence suggests that in this case faculty inventors should get less equity of start-ups because there are capital constraints. Finally, this research also test an alternative measure of equity policies that inventor share of after-tax profit in new start-ups. In the dataset, nine universities, including Shanghai Jiao Tong University and Peking University, share the after-tax profit of new start-ups with faculty inventors. Table 4.10 presents summary statistics for all variables included in this section.

Table 4.10 Descriptive statistics for all independent variables

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
Research field	18435.000	1.249	0.739	0.000	2.000
Number of inventors	18435.000	3.372	2.127	0.000	20.000
Claims	18435.000	5.117	6.328	1.000	106.000
Intellectual eminence	18435.000	77.651	9.793	62.470	97.500
Minimum inventor share of royalty	18435.000	0.356	0.183	0.200	0.800
Inventor royalty revenue per 1 million	18435.000	36.116	18.748	20.000	80.000
Minimum inventor share of equity	18435.000	0.309	0.136	0.200	0.700
Inventor equity of the start-up	18435.000	0.064	0.182	0.000	0.900

Inventor share of after-tax profit	18435.000	0.018	0.083	0.000	1.000
Number of inventions	18435.000	16.171	31.054	0.000	280.000
The length of time as the professor	18435.000	6.027	5.271	-10.000	57.000
Faculty position	18435.000	0.308	0.461	0.000	1.000
Year application	18435.000	2008.369	2.773	2002.000	2012.000
Age	18435.000	45.658	6.660	26.000	87.000
Gender	18435.000	0.894	0.308	0.000	1.000

4.4.4.2 Organizational level

In order to investigate the influence from the organizational level, I analyse the influence of university characteristic, R&D expense and output, and city competitiveness. In this section, I choose the data from the sample during the period from 2008 to 2012. I employ the average faculty invention disclosure rate as the independent variable, and then use the Multiple Linear Regression (MLR) to investigate the impact of dependent variables.

(1) Characteristics of the university

To examine the influence of university characteristics, four independent variables are considered. I use the variable Medical school to indicate whether the university has a medical school (Medical school=1 if have, otherwise is 0), and use the variable Polytechnic to mark the polytechnic university (Polytechnic=1 if yes, otherwise is 0), and use the variable Independent_TTO to indicate whether the TTO is independent with the university administration. Lastly, I use the variable University_size to examine the impact of university size on faculty disclosure rate.

(2) University R&D expense and output

To examine the influence of university input and output, I use two variables, Per_patent and Per_paper to indicate the average patent applications per faculty and the average published papers per faculty. Meanwhile, the variable R&D_stock is considered as the indicator of university R&D expense. The value of these three variables can be obtained from the Yearbook of University S&T Statistical Data (2008-2012).

(3) City competitiveness

To examine the impact of city competitiveness, I use two variables, including Per_GDP and City_competitiveness, to investigate their influence. The value of Per_GDP can be obtained from the yearbook in each province. The value of City_competitiveness is quoted from the "White Book on Urban Competitiveness (2008-2012)" published by Chinese Academy of Social Science.

In order to exclude the influence of price fluctuation, R&D_stock and Per_GDP need to be deflated by Customer Price Index (CPI) deflator. In special, the university R&D expense normally includes scientific labour, fixed assets without the build infrastructure investment and so on. So its deflator should consider the influence of capital depreciation rate, price index of investment in fix assets, and CPI. In this study, I consider the scientific labour and the equipment cost have the same descending trend in the university R&D expense. So the R&D price deflator is:

$$PR = (P + W)/2$$

The variable P is the price index of investment in fix assets, W is the CPI index. For the R&D capital depreciation rate, much research considered it is a fix constant, however, in this section I use 18%, 15%, and 12% to indicate the different economic development level in the eastern China, middle-China, and western China. Thus, based on the data of 2008, the R&D_stock each year is as below:

$$RD_{it} = (1 - \delta)RD_{i(t-1)} + E_{it}$$

The variable RD_{it} is the R&D_stock of the university i in year t, the variable δ is the capital depreciation rate, and E_{it} is the added R&D expense each year. Thus, from the organizational level, Table 4.11 shows the descriptive statistics.

Table 4.11 The descriptive statistics in the organizational level

Variables	Observations	Mean	Std. Dev.	Minimum	Maximum
Disclosure_rate	165	0.5926	1.0000	0.8657	0.0777
University_size	165	3.05	4.14	3.56	0.34
Independengt_TTO	165	0.00	1.00	0.36	0.48
Polytechnic	165	0.00	1.00	0.42	0.50

Medical_school	165	0.00	1.00	0.55	0.50
R&D_stock	165	4.91	6.59	5.92	0.32
Per_patent	165	0.03	2.63	0.25	0.28
Per_paper	165	0.10	4.81	0.62	0.55
Per_GDP	165	1.44	8.39	4.57	2.03
City_competitiveness	165	2.00	54.00	17.05	13.94

4.4.5 Estimation and model specification

In order to investigate the determinants of patent assignment, the assignment equation is regarded as the function of explanatory and control variables. First, the dependent variable was coded as 0 or 1. In most previous studies, the binary logit regression model has been considered as the most appropriate technique for the analysis of dichotomous variables (Fini et al., 2010; Thursby et al., 2007, 2009). In this section, the binary logit regression model was also used to find the correlation between the probability of assignment to a particular type of organization and a set of influencing factors. Second, a more comprehensive assignment will be studied while patent assignment as dependent variable has four values (coded as 1 if assigned to university, coded as 2 if assigned to private firm, coded as 3 if assigned to university and private firm jointly, and coded as 4 if assigned to individual). In this scenario, the multinomial logit regression model will be employed. Third, following Thursby's study, I also conduct research on outside assignment while firm assignment includes established firm assignment and start-up assignment (coded as 0 if assigned to start-up, coded as 1 if assigned to established firm, coded as 2 if assigned to university and firms jointly, and coded as 3 if assigned to individual). The start-up assignment is considered as the reference assignment, and the analysis approach is also the multinomial logit model.

Table 4.12 Selected papers focusing on the issue of faculty invention disclosure

Countries	Selected papers	Database*	Analysis approach
US	Fuller, 2008; Thursby et al., 2007, 2009	NRC, NBER	Binary Logit Regression Multinomial Logit Regression
US	Fini et al., 2010	NRC, AUTM	Probit regression
EU	Crespi et al., 2006	PatVal Database	Interview, Probit regression, and Propensity Score Match

* NRC: National Research Council; NBER: National Bureau of Economic Research; AUTM: Association Of University Technology Managers.

In order to investigate the organizational impact factor, the MLR approach is employed since the average faculty invention disclosure rate is a continuous variable.

4.5 Analysis result

4.5.1 Result of binary logit regression in the individual level

Table 4.13(a) and 4.13(b) presents the results of the binary logit regression analysis. In these tables, Model 1 provides the principal model that covers all independent variables. Models 2-10 provide a series of robustness check explanatory and control variables. In summary, the results illustrate that invention characteristics and university licensing policies (except for inventor share of after-tax profit) have a significant impact on faculties patent assignment, but provide weak evidence that intellectual eminence influences faculties' assignment decision. For control variables set, I found that all factors except for age also influence the patent assignment significantly.

Among Models 1 to 10, they show that the value of patent is positively related to the university assignment at the significance level of 1%, which is in line with Proposition 4.1a (ES). However, like Jensen's (2003) study, due to the lack of evidence about the patent citation, it is suspect that all university-owned patents in China are more commercially viable than university-invented patent. Perhaps university-owned patents get more professional service from TTOs, thus, the claim contention could cover more technology protection scope than university-invented patents. The findings also provide adequate support for the conclusion that patents with more inventors are more likely to be assigned to the outside at the significance level of 1% among models 1-10. For a given patent, inventor's social network is very important for patent distribution. The more inventors could greatly reduce faculty's search cost, and increase their marginal powers of owning patents. That is why the number of inventors is negatively related to university assignment. Another explanation is that in many cases parts of co-inventors are from private firms because of R&D cooperation or technology consulting projects between universities and industrial settings. Under this scenario, patents were always assigned to private firms as a result of prior agreements.

In terms of Proposition 4.1c (ES), the research field significantly predicts the patent assignment. The estimated coefficient for this factor, shown in Model 1, implies that different patent assignments occur as a result of different research fields. In specific, the probability of the outside assignment in mechanical engineering and telecommunication is 0.536 and 0.491 times less than that in life science. From this result, it reflects the fact that faculties in mechanical engineering and telecommunication still cannot transfer their inventions without disclosure because of some uncertain reasons, such as difficulty in shrinking or hiding their patents, or weaker connection with private firms etc. For China's university administrations, the results suggest that they should pay more attention to faculty activities in life science in order to manage faculties' patents and safeguard interests of universities.

In the binary logit regression model, the findings provide little evidence that higher intellectual eminence could increase the probability of outside assignment. The coefficient on the variable of MoE's discipline evaluation score is positive, but is close to zero at the significance levels of 5 or 10%. It seems that the level of academic research has a weak relationship with faculty's entrepreneurship in China's universities in the dataset.

The findings also test the Proposition 4.3a (ES), and suggest that two sets of university royalty policies – minimum inventor share of royalty and inventor royalty revenue per 1 million – appear to influence patent assignments significantly. The coefficient on the minimum inventor share of royalty is significant at 1% among Models 1 to 10. It implies that increase in inventor share of royalty per unit leads to the probability of university assignment increase of 0.3. The most interesting fact is that the coefficient becomes negative when royalty are measured by the amount accrued to faculty inventors on a patent valued RMB 1 million. It implies that patent assignment depends on different calculation method. Increasing the inventor share of royalty per RMB 1 million could not improve the overall disclosure rate effectively.

The other university policies that appear to influence patent assignment are equity policies. First, when I consider the patent is assigned to a third party as technology investment, increase in the minimum inventor share of equity per unit will raise the probability of university assignment by 1.039 times. Second, when university is involved in developing new start-ups as company founders, increasing the inventor share of equity in new start-ups per unit only will raise the probability of university assignment 0.313 times at 5% significance level. Lastly, it is found that inventor share of after-tax profit as alternative variable has no impact on patent assignment in all models.

Table 4.13(a) Results of the binary logit regression analysis

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
Characteristic of invention					
Mechanical engineering	0.536***	0.538***	0.526***	0.534***	0.507***
Telecommunication	0.491***	0.489***	0.488***	0.488***	0.474***
Life science			Omitted		
Number of inventors	-0.218***	-0.214***	-0.212***	-0.217***	-0.215***
Claims	0.028***	0.028***	0.028***	0.028***	0.028***
Intellectual eminence					
MOE discipline evaluation score	0.005**	0.005*	0.005*	0.005**	0.005*
University licensing policies					
Minimum inventor share of royalty	0.330***	0.297***	0.268***	0.331***	0.335***
Inventor royalty revenue per 1 million	-0.022***	-0.020***	-0.019***	-0.021***	-0.022***
Minimum inventor share of equity	1.039***	1.07***	1.102***	1.038***	1.002***
Inventor equity of a start-up	0.313**	0.071		0.309**	0.307**
Inventor share of after-tax profit	0.195		0.044	0.197	0.208
Control variables					
Age	0.023	0.021	0.018		-0.008**
Gender	-0.362***	-0.363***	-0.364***	-0.363***	
The length of time as the professor	0.116***	0.116***	0.116***	0.124***	0.146***
Faculty position	-0.225***	-0.221***	-0.219***	-0.225***	-0.236***
Number of inventions	-0.067***	-0.068***	-0.067***	-0.068***	-0.074***
Year application	0.044***	0.043***	0.043***	0.044***	0.049***
Observations	18435	18435	18435	18435	18435
ROC	0.6221	0.6223	0.6224	0.6220	0.6203

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

Table 4.13(b) Results of the binary logit regression analysis

Variables	Model 6	Model 7	Model 8	Model 9	Model 10

Characteristic of invention					
Mechanical engineering	0.538***	0.548***	0.567***	0.566***	0.546***
Telecommunication	0.491***	0.481***	0.515***	0.481***	0.533***
Life science			Omitted		
Number of inventors	-0.213***	-0.216***	-0.208***	-0.220***	-0.210***
Claims	0.028***	0.029***	0.030***	0.029***	
Intellectual eminence					
MOE discipline evaluation score	0.005**	0.004	0.005*		0.006**
University licensing policies					
Minimum inventor share of royalty	0.323***	0.299***	0.302***	0.346***	0.344***
Inventor royalty revenue per 1 million	-0.021***	-0.020***	-0.019***	-0.022***	-0.022***
Minimum inventor share of equity	1.011***	1.121***	1.09***	1.092***	1.071***
Inventor equity of a start-up	0.310**	0.296**	0.279**	0.268**	0.264**
Inventor share of after-tax profit	0.151	0.200	0.249	0.131	0.181
Control variables					
Age	0.095***	-0.007*	-0.006	-0.008**	-0.008**
Gender	-0.341***	-0.374***	-0.386***	-0.357***	-0.359***
The length of time as the professor		0.129***	0.188***	0.156***	0.152***
Faculty position	-0.206***		-0.251***	-0.228***	-0.232***
Number of inventions	-0.045*	-0.247***	-0.049***	-0.066***	-0.070***
Year application	0.051***	0.041***		0.046***	0.050***
Observations	18435	18435	18435	18435	18435
ROC	0.6232	0.6250	0.6212	0.6236	0.6129

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

4.5.2 Result of multinomial logit regression in the individual level

In this section, I consider faculty inventors assign patents to universities, private firms, both universities and firms, or unassigned (owned by inventors themselves). Therefore, the multinomial logit regression model was employed to illustrate more relationship between patent assignments and factors in Table 4.14(a) and 4.14(b). In addition, in order to find more details about the outside assignment, the university assignment is excluded. And then, following Thursby's definition that established firm is ten years or older at the time of patent application, the private firms are divided into start-ups and established firms.

The multinomial logit regression model has the assumption "Independence of Irrelevant Alternatives" (IIA), which requires each type of patent assignment to be independent with others. I test whether this assumption is valid for the data by using the conditional logit regression model and Hausman Test (Hausman, 1978; Hausman and McFadden, 1984). The result shows that there is no significant difference among all outputs, in which some of value has been excluded form dependent variable. I also employed the nested logit regression model which is more general for multinomial data. The P-value also supports the IIA assumption. Therefore, I think that the multinomial logit regression model is appropriate in this section.

The results of multinomial logit regression model are presented in Table 4.14(a) and 4.14(b). All coefficients are shown as relative risk ratios (RRR). If the RRR of any independent variables is greater than one (or smaller than one), an increase in the given independent variable will lead to increase (decrease) the risk ratio of the target assignment versus the reference assignment. In model 1 university assignment is considered as the reference assignment to illustrate the empirical results of patents assigned to university versus those to private firm (FIRM/UNIV), university versus those to both university and private firm (UNIVandFIRM/UNIV), and university versus those to individual (UNASSIGN/UNIV). Meanwhile, model 2 gives the empirical results where start-up assignment is the reference assignment.

Regarding to the patents claim in Table 4.14(a), the RRR is smaller than one at 1% level in FIRM versus UNIV, UNIV&FIRM versus UNIV, and UNASSIGN versus UNIV in model 1. It suggests that university-owned inventions are important than those of university-invented from the perspective of protection scope. This finding is in line with the results in Table 4.13(a-b). An interesting thing is that the number of claims has little influence in comparisons of model 2. It indicates that little attention has been paid when faculty inventors make the outside assignment decisions. It also confirmed my opinion that faculty tends to exaggerate patent commercial value while choosing university assignment.

The findings also provide significant evidence that the number of inventors influences patent assignment. First, increase in the number of inventors could increase the probability of university assignment in the comparison of FIRM versus UNIV and UNASSIGN versus UNIV, but decrease in UNIV&FIRM/UNIV in model 1. It implicates that only when some of inventors find interested firms before the dates of patent application or parts of inventors come from private firms because of R&D cooperation or technology consulting projects, they will choose university-firm assignment instead of university assignment. In terms of Proposition 4.1b (ES), this result makes some correction for China's universities. In model 2 I also find increasing the number of inventors could increase the likelihood of established firm assignment and university-firm assignment. Meanwhile, the RRR of UNASSIGN versus START.UP is smaller than one indicates that faculty inventors prefer start-up assignment to individual assignment. Therefore, I can infer that the faculty preference assignment under the impact of the number of inventors is as below: university-firm assignment→university assignment→established firm assignment→start-up assignment→individual assignment.

Considering the effect of research fields, Table 4.14(a) and 4.14(b) shows its significance at the comparison of FIRM/UNIV, UNIV&FIRM/UNIV, and UNASSIGN/START.UP at a 1% level. Compared with faculty in life science, faculty in mechanical engineering and telecommunication prefer university assignment. Meanwhile, they are also less likely the start-up assignment than faculty in life science at 1% level. These results, although not significant across all comparisons in Table 4.14(a) and 4.14(b), may still give the information that faculty inventors in mechanical engineering and telecommunication prefer university or individual assignment than faculty in life science, which tests the Proposition 4.1c (ES) directly.

Regarding to university intellectual eminence, in section 4.1 I have found its positive but weak significance on university assignment. In Table 4.14(a) and 4.14(b) the empirical results could give more evidence. More specifically, in the comparison related to university assignment in model 1, the RRR of intellectual eminence is smaller than one in FIRM/UNIV, but larger than one in UNIV&FRIM/UNIVE at 1% level, as well as that in UNIV&FIRM/START.UP in model 2, however, intellectual eminence plays little influence in the rest comparisons. It seems that universities with greater intellectual eminence wholly or partly own more faculty patents than private firms and individuals.

Regarding to university royalty policies, the findings suggests that only they can play impact in the comparisons related to university in model 1, but have little influence in model 2. Increasing the minimum inventor share of royalty could promote faculty inventors to assign their patents to university. Similarly, I find three kinds of university equity policies also play little impact on faculty patent assignment except for the variable of minimum inventor share of equity. In terms of Proposition 4.3c (ES), understanding the difference between royalty and equity policies is very important. Compared with share policies, although the equity rate give faculty inventors a more attractive share option, it require faculty to pay for more time cost for the success of technology transfer. That is why royalty policies and equity policies have different level of influence on patent assignment in model 1 and model 2. Finally, from the perspective of university policy, I find these models is more appropriate for comparisons involving university assignment.

Table 4.14(a) Results of the multinomial logit regression while the university as reference

Variables	**Model 11** (RRR, UNIV as the reference assignment)		
	FIRM/UNIV	**UNIV&FIRM/UNIV**	**UNASSIGN/UNIV**
Characteristic of invention			
Mechanical engineering	0.335^{***}	0.677^{***}	1.165
Telecommunication	0.551^{***}	0.612^{***}	0.946
Life science		Omitted	
Number of inventors	0.855^{***}	2.034^{***}	0.523^{***}
Claims	0.971^{***}	0.984^{***}	0.931^{***}
Intellectual eminence			
MOE discipline evaluation score	0.977^{***}	1.012^{***}	0.993
University licensing policies			
Minimum inventor share of royalty	0.622^{***}	0.650^{***}	2.121^{***}
Inventor royalty revenue per 1 million	1.025^{***}	1.028^{***}	0.979^{*}
Minimum inventor share of equity	0.372^{***}	0.420^{**}	0.123^{***}

Inventor equity of a start-up	0.886	0.480***	1.519
Inventor share of after-tax profit	0.817	0.735	1.349
Control variables			
Age	1.002	1.002	1.034***
Gender	1.995***	1.069	1.782***
The length of time as the professor	0.956***	0.996	0.954***
Faculty position	1.726***	0.956	1.338***
Number of inventions	1.004***	1.000	0.985***
Year application	1.033**	0.904***	0.974***
Observations		18,535	
κ^2		1178.69 (48)	

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

Table 4.14(b) Results of the multinomial logit regression while the start-up as reference

Variables	**Model 12** (RRR, UNIV as the reference assignment)		
	ESTAB.F /START.UP	**UNIV&FIRM /START.UP**	**UNASSIGN /START.UP**
Characteristic of invention			
Mechanical engineering	1.361	2.360***	3.755***
Telecommunication	0.978	1.156	1.644***
Life science	Omitted		
Number of inventors	1.408***	2.413***	0.620***
Claims	0.945**	1.011	0.974
Intellectual eminence			
MOE discipline evaluation score	0.982*	1.029***	1.012*
University licensing policies			
Minimum inventor share of royalty	1.458	1.254	5.650***
Inventor royalty revenue per 1 million	0.971**	0.989	0.937***
Minimum inventor share of equity	4.598	1.939	0.133**
Inventor equity of a start-up	0.979	0.597	1.954
Inventor share of after-tax profit	1.505	1.346	2.161
Control variables			
Age	1.002	1.009	1.040***
Gender	1.003	0.602**	1.071
The length of time as the professor	1.005	1.034**	0.989
Faculty position	0.604	0.541***	0.746**
Number of inventions	0.985***	0.995**	0.978***
Year application	1.055***	0.880***	0.917***

Observations	2429
κ^2	766.43 (48)

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

4.5.3 Result of MLR in the organizational and city level

As shown in Table 4.15, I consider the influence from the organizational level through developing three models. And then each model has two sub-samples depending on the TTO's independent status.

First, the university size has a positive impact on faculty invention disclosure rate (significance at 1% or 5% level), it indicates that the more university size, the faculty are more likely to disclose their inventions, especially when the TTO is independent with the university administration. As shown in Table 4.15, I cannot find the willingness of faculty invention disclosure has any difference between polytechnic university and other universities. Lastly, the university with medical school indeed has a lower faculty invention disclosure rate at the significance of 1% which proves the Proposition 5a (ES). This conclusion also supports the Proposition 4.1c (ES) that the faculty in life science are more likely to choose non-university assignees.

For the university R&D input and output, the R&D_stock has played a weak influence on faculty invention disclosure. Only when the TTO is not independent with the university administration, the variable Per_patent and Per_paper is positive related to the faculty invention disclosure rate (significance at 5%).

From the perspective of city competitiveness, when the TTO is not independent with the university, the variable Per_GDP has a weak but positive relationship with the average rate of faculty invention disclosure (correlation is 0.011, significance at the 10% level). On the other hand, the variable City_competitiveness has a positive impact on faculty invention disclosure rate at the significance level of 5%.

Table 4.15 Result of MLR in the organizational level

Variable	Model 13		Model 14		Model 15	
	Indep_TTO	Dep_TTO	Indep_TTO	Dep_TTO	Indep_TTO	Dep_TTO

University_size	0.116**	-0.003	0.124***	0.045**	0.154***	0.048
	(0.044)	(0.024)	(0.046)	(0.029)	(0.042)	(0.029)
Polytechnic	0.001	0.001	-0.21	-0.012	0.016	-0.014
	(0.028)	(0.018)	(0.033)	(0.018)	(0.031)	(0.017)
Medical_school	-0.108***	-0.048**	-0.109***	-0.064***	-0.086***	-0.061***
	(0.155)	(0.019)	(0.034)	(0.019)	(0.033)	(0.019)
R&D_stock			0.006	-0.005	0.006	0.004
			(0.001)	(0.001)	(0.001)	(0.001)
Per_patent			0.046	0.055**	0.124	0.038
			(0.086)	(0.024)	(0.094)	(0.026)
Per_paper			-0.004	0.034**	0.003	0.022
			(0.017)	(0.016)	(0.016)	(0.016)
Per_GDP					-0.001	0.011*
					(0.009)	(0.006)
City_competitiveness					0.003**	0.001*
					(0.001)	(0.001)
R^2	0.196	0.107	0.226	0.204	0.411	0.243

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

Caldera and Debande (2010), Lach and Schankerman (2008) employed the robust test approach that exact part of sample data randomly to check the model robustness. In this section, I also choose part of data from 2008-2009 randomly to analyse the robustness. Compared with the result in Table 4.15, the test shows that all variables have the same impact. Therefore, I believe this approach is appropriate for the analysis.

4.6 Model Discussion

4.6.1 Faculty's real strategy of patent assignment

In section 4.4, the empirical results suggest that China's faculty intends to assign high-quality invention to universities since patents disclosed to universities have more claims. In order to re-examine this conclusion, in this section I consider patent validity and maintenance time as the other two indicators of patent quality by using binary logit regression model. As shown in Table 4.16, the variable of patent claims is positive related to university assignment in model 16, 17 and 18 at the significance of 1% or 5%, however, patent validity and maintenance time have the negative relationship with university assignment. Since all these three variables are the indicator of patent quality, the opposite results in Table 4.16 generate a crucial question that whether China's faculty assigns high quality to non-university assignees.

Table 4.16 Results of the patent claims and maintenance time

Variables	Model 16	Model 17	Model 18	Model 19
Characteristic of invention				
Mechanical engineering		0.442	0.127	0.430
Telecommunications		1.542***	1.136***	1.421***
Life science		Omitted		
Number of inventors		0.140*	0.100	0.143*
Patent claims	**0.113****	**0.163**		**0.157*****
Patent validity	**-0.457*****		**-0.418*****	**-0.416****
Patent maintenance time	**-0.087*****		**-0.074*****	**-0.073*****
Intellectual eminence				
MOE discipline evaluation score		0.033**	0.031**	0.027*
University licensing policies				
Minimum inventor share of royalty		4.145**	3.594**	3.851*
Minimum inventor share of equity		-4.219*	-3.265	-3.392
Control variables				
Age		-0.017	-0.003	-0.010
Gender		0.062	0.094	0.009
Length of time as professor		0.060*	0.031	0.033
Administrative position		-0.603**	-0.476	-0.446
Number of inventions		0.026*	0.027*	0.031*
Observations		451		
R^2	0.113	0.200	0.205	0.245

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

In order to analyse this question, first, most of the patents disclosed to universities by faculty are developed from their basic or original research (Czarnitzki, Hussinger, and Schneider, 2012), so they have more justification for their claim to protect a wider technology scope. On the other hand, when faculty decide to choose non-university assignees, negotiation is needed on the issue of protection scope, in order to ensure that their future studies will not infringe the assignees' license, and to reserve the right to apply for related patents. This is why university assignment patents have more claims.

According to Thursby's research (2007), most non-university patent assignments in US research universities are the result of faculty consulting projects. Their decisions, reached through investigating the backward and forward citations, are that non university-assigned patents are less basic than university-owned patents. However, Chinese patent data does not provide further citation information as in the US. As a limitation, this study was also unable to obtain details about each faculty's research and consulting projects for the study sample. Therefore, in this study, this study could not arrive at a conclusion as to whether non-university assignment is due to consulting arrangements or not. In addition, this study could only collect patent information which listed faculty as the first inventor. This has the disadvantage that many patents resulting from Chinese universities' consulting projects were excluded because the faculty was not listed as the first inventor.

Compared with patent claims and citation information, patent validity and maintenance time are the more appropriate measurements of patent quality from an economic perspective. Patents disclosed to universities have less economic life means that universities do not renew patent right because of their limited commercial value and the expenses for patent maintenance. The non-university assignees will tend to keep the patent right longer as a result of economic profit produced by faculty patents. Meanwhile, the variable of patent validity also tests this conclusion and shows in Table 7. I also checked patents randomly and found that most of them were not conducted in collaboration with private companies or in relation to consultancy assignments. Thus, I believe that this explains why faculty prefer to disclose high-quality inventions to non-university assignees before patent application.

4.6.2 Consulting arrangement vs. inappropriate non-university assignment

More importantly, in this study I found Chinese faculty inventors intend to assign high-quality patents outside of universities while assigning low-quality patents to universities. However, in China the university faculty has no right to apply, own, and distribute their patents. This behaviour also significantly decreases the quality of university-owned patents and partly causes the poor performance of Chinese UITT. From these perspectives, I believe China's faculty chooses non-university assignment is inappropriate. This conclusion also was supported by other researchers in the case of western countries.

4.6.3 Influence of faculty professorship

There is a widespread view that associate professors and lecturers are more motivated to create patents and assign them to universities in order to be appointed professor as soon as possible. However, until now, I have found no empirical evidence to support this view. In this research, I find that faculty's professorship influences patent assignment significantly (see Tables 4.13(a), 4.13(b), 4.14(a), and 4.14(b)). However, the truth is that associate professors and lecturers do not always assign more patents to universities than do professors, especially in recent years when the invention disclosure rate of associate professors and lecturers has been lower than that of professors. Therefore, I infer that there must be reasons behind this change.

One reason why associate professors and lecturers prefer outside assignment could be the homogenization of university royalty and equity policies. As shown in Table 4.17, the coefficient of inventor share of royalty of associate professors and lecturers (0.930, 0.754) is larger than that of professors (0.242, 0.259). Meanwhile, the inventor share of equity is negatively related to associate professors and lecturers (-2.456, -2.466), but positively related to professors (1.500, 1.519). This indicates that associate professors and lecturers prefer royalty policies, while professors prefer equity policies. Compared with professors, associate professors and lecturers have limited experience and energy to take part in technology transfer activities because of the pressure to publish research papers. In addition, they are generally more cash-constrained than professors. Thus, the evidence suggesting that different faculty prefer different licensing policies has raised several interesting and important policy questions that need more thorough investigation, such as whether an increasing share of licensing revenues could improve the faculty disclosure rate? How to manage faculty inventors' patent assignment activities by using different royalty and equity policies? In my opinion, university administrations should adopt different royalty and equity policies for faculty inventors with different status. Specifically, in order to encourage more faculty disclosure, the inventor share of equity should be significantly larger than that of royalties because professors create most inventions, meanwhile, participating in UITT should be considered as a working achievement for associate professor to get the professorship status.

Table 4.17 Influence of professorship on faculty invention disclosure

Variables	**Professor**		**Non-professor**	
Characteristic of invention				
Mechanical engineering	0.582***	0.621***	0.568***	0.392**
Telecommunication	0.500***	0.531***	0.447***	0.373**
Life science	Omitted		Omitted	
Number of inventors	-0.223***	0.231***	-0.196**	-0.188**
Claims	0.032***	0.033***	0.020**	0.016
Intellectual eminence				
MOE discipline evaluation score		0.000		0.027***
University licensing policies				
Minimum inventor share of royalty	0.242**	0.259***	0.930***	0.754***
Inventor royalty revenue per 1 million	-0.020***	-0.020***	-0.026**	-0.021*
Minimum inventor share of equity	1.500***	1.519***	-2.456***	-2.466***
Inventor equity of a start-up	0.238*	0.203	0.458	0.760*
Inventor share of after-tax profit	-0.284	-0.332	1.483*	1.759**
Control variables				
Age	-0.001	-0.002	-0.006	0.000
Gender	-0.506***	-0.526***	0.113	0.006
The length of time as the professor				
Faculty position	-0.242***		0.031	
Number of inventions	-0.020	-0.037*	-0.267***	-0.307***
Year application	0.056***	0.061***	0.043**	0.042**
Observations	2783	2783	15652	15652
ROC	0.6397	0.6344	0.6084	0.6203

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

4.6.4 Influence of faculty position

I find evidence that faculty's administrative position has a significant influence on patent assignment. Specifically, faculty with administrative positions (dean/vice-dean of schools) in mechanical engineering and telecommunications are more likely to choose university assignment than lower-ranking faculty in these schools. In addition, the inventor share of royalty has more influence on higher-level faculty, but the equity policy has more effect on faculty in lower positions, as shown in Table 4.18. This conclusion is consistent with Chinese university regulations that no faculty in any administrative position can participate in any commercial activities because of their positions as civil servants. Combined with the influence of faculty's status, I find that professors with administrative positions are positively related to university assignment, while the coefficient for faculty without administrative positions is negative but not significant. In short, I conclude that faculty without administrative positions are more sensitive to university policies than faculty with positions in China's universities.

Table 4.18 Influence of faculty position on their invention disclosure

Variables	President/Vice-President		Non-President	
Characteristic of invention				
Mechanical engineering	0.761***	0.845***	0.378***	0.313***
Telecommunication	0.610***	0.686***	0.360***	0.355***
Life science	Omitted		Omitted	
Number of inventors	-0.102**	-0.081*	-0.300***	-0.297***
Claims	0.013*	0.010	0.038***	0.037***
Intellectual eminence				
MOE discipline evaluation score		-0.002		0.008***
University licensing policies				
Minimum inventor share of royalty	0.686***	0.641***	0.240**	0.210*
Inventor royalty revenue per 1 million	-0.028***	-0.025***	-0.024***	-0.022***
Minimum inventor share of equity	0.575	0.647	1.407***	1.263***
Inventor equity of a start-up	0.354	0.371*	-0.226***	0.293*
Inventor share of after-tax profit	1.737**	1.392*	-0.391	-0.272
Control variables				
Age	-0.022***	0.003	0.003	0.004
Gender	-0.871***	-0.803***	-0.166*	-0.179**
The length of time as the professor	0.404***		-0.006	
Faculty position				
Number of inventions	-0.149***	-0.078**	0.011	0.005
Year application	0.009	0.034**	0.066***	0.066***
Observations	5670	5670	12765	12765
ROC	0.6537	0.6401	0.6228	0.6214

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

4.6.5 Chinese institutional and legal system

China's education and technology systems were all introduced from the former Soviet Union in the middle of last century. A university is a public corporation, so university-owned patents are under the control of the government's "State-owned Assets Management Office". On the other hand, China's university employment contracts normally specify that faculty's on-duty inventions belong to the university. China's Science and Technology Law, similar to the Bayh-Dole Act of 1980, also rules that inventions funded by the government belong to the university. In addition, the patent licensing income has to be turned over to the state treasury in China. The government then redistributes this income between the university, faculty, and TTO in the form of the fiscal budget.

In this complex institutional system, Chinese faculty have limited freedom to apply, own, sell or license their academic patents independently. Thus, it is not surprising that faculty prefer to assign high quality patents to non-university assignees in order to keep 100% of the licensing revenue, even though this is inappropriate. More seriously, faculty's arrangement for non-university assignment decreases the quality of university-owned patents and partly contributes to the poor performance of Chinese UITT. Thus it seems that China's institutional system is one of the significant reasons for non-university assignment. There is room to improve this system through giving faculty more rights.

4.7 Summary

According to requirement of "China's National Medium and Long Term Science and Technology Development Planning (2006-2020)", improving the performance of China's universities technology transfer is considered as one of the most significant strategies. In this chapter, although still exists much limitation, based on China's top 35 patent application universities from 2002 to 2012, I make clear how many university-invented patents have not been solely assigned to university and the related determinants by developing a unique faculty/patent dataset. Table 4.19 summarizes test results of all the propositions.

Table 4.19 Summary of all propositions

Proposition	Accept	Reject	Not significant
Proposition 4.1a (ES): The commercial value of patent plays a significant influence on faculty assignment activities in China's universities.	√		
Proposition 4.1b (ES): Faculty inventors' social contracts network has		√	

negative influence on university assignment in China’s universities.			
Proposition 4.1c (ES): Faculty patent assignment is also different by research fields in China’s universities.	√		
Proposition 4.2 (ES): The more eminence of universities increases the likelihood of outside assignment in China’s universities.		√	
Proposition 4.3a (ES): The higher inventor share of royalty or equity will enhance the university assignment in China’s universities.	√		
Proposition 4.3b (ES): There is clear different level of influence on patent assignment among three kinds of universities policies in China’s universities.	√		
Proposition 4.4a (ES): Associate professor and lecturers are more likely to disclose their inventions to university than professor.		√	
Proposition 4.4b (ES): The productive faculty inventors are more likely to disclose their invention to university.		√	
Proposition 4.5a (ES): The university with medical school has a lower faculty invention disclosure rate.	√		
Proposition 4.5b (ES): The polytechnic university has a lower faculty invention disclosure rate.			√
Proposition 4.5c (ES): The university with independent TTO has a lower faculty invention disclosure rate.			√
Proposition 4.5d (ES): The university size is positive related to the faculty disclosure rate.	√		
Proposition 4.6a (ES): The average patent application and published papers per faculty inventor is positive related to the average faculty invention disclosure rate;			√
Proposition 4.6b (ES): cThe university with richer R&D funding has higher faculty invention disclosure rate.			√
Proposition 4.7 (ES): The faculty in high competitive city prefers non-university assignment.		√	

Compared with prior work that focused on faculty patenting by searching patents assigned to universities, I concluded that faculty patent assignment has four types. This allowed us to find that 13.16% of faculty/patent pairs are not solely assigned to universities. The contribution of this chapter are as follows: (1) it mainly focuses on faculty patent assignment in the context of Chinese universities; (2) it points out that China’s faculty intends to assign high-quality patents to non-university assignees but assign low-quality patents to the TTO; (3) it pays more attention to university licensing policies, such as royalty policies, equity policies and related alternative policies, in order to give more useful and operational policy implications.

Focusing on the issue of non-university assignment and the phenomenon that the faculty assign high-quality inventions to non-university assignees, in the next chapter, I would give some solutions through developing series of mathematical models from the TTO perspective.

Chapter 5 Study #2: Modelling Faculty Invention Disclosure

Based on the phenomenon of invention disclosure and research findings in Chapter 2 and 4, Chapter 5 develops four theoretical game models to provide more theoretical support and forecasting from faculty and university perspective. Based on the dataset of Chinese faculty/patent pairs in Chapter 4, the first game model simulates faculty decision-making of invention disclosure. The second game model discusses how to check the patent quality to improve the invention disclosure and the success of UITT. After then, the third game model proves the impact of licensing revenue and non-economic profit on faculty invention disclosure based on a more comprehensive UITT process. The last game model introduces the concept of university technology transfer chain, and explains how to coordinate stakeholders' behaviour to improve the invention disclosure and the public interest.

5.1 Process of UITT

As shown in Figure 5.1, a whole process of transferring faculty scientific invention to established firm or start-up needs to go through several decision-making, such as ***invention disclosure***, ***commercial mode selection***, ***patent quality checking***, ***license/sale contract design***, and ***revenue distribution***. Faculty inventor, university, TTO staff, and industrial firm are all involved in this process.

In Chapter 5, I assume all stakeholders are all "economic person", and attempt to simulate their decision-making process based on game theory. Meanwhile, I use the faculty/patent pairs of Chinese universities to test the theoretical research findings. In Figure 5.1, the faculty should make a disclosure decision and choose a preferred commercial mode firstly, then the following decisions would be made by TTOs and industrial firms. Because the faculty could estimate other stakeholders' decisions in advance, the following decisions plays significant influence on faculty disclosure strategy. Therefore, it is convinced that the invention disclosure should be considered from the perspective of whole process of UITT.

Not only the disclosure to whom, when, and how should be considered, other stakeholder's strategies also should be investigated.

Compared with the empirical study in Chapter 4, this chapter reflects a more comprehensive and complex action set of all stakeholders, thus it could provide more microscopic investigation of invention disclosure, patent checking, contract design, and revenue management.

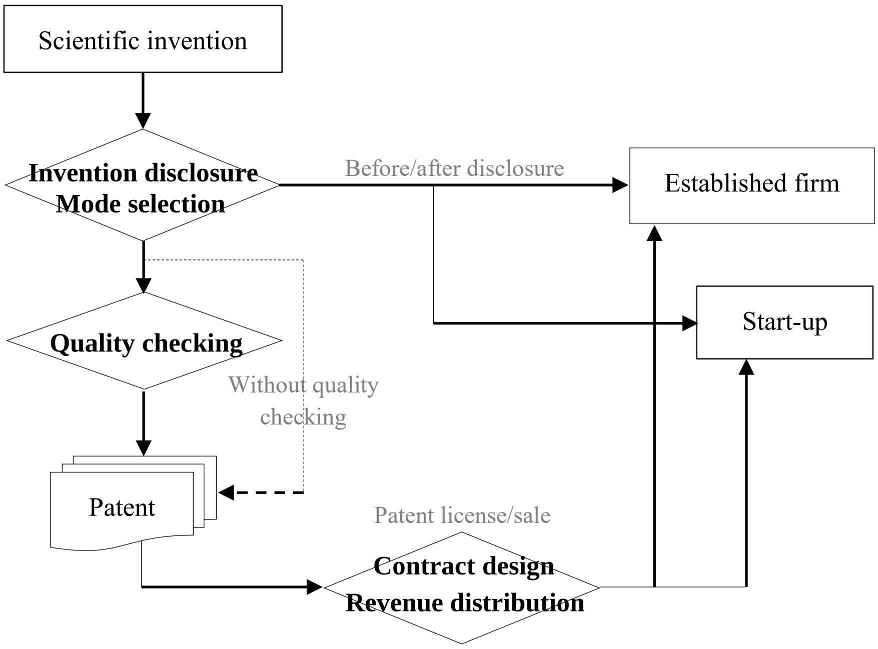

Figure 5.1 Process of university industry technology transfer

According to Figure 5.1, in the following sections this chapter would investigate the faculty invention disclosure, commercial mode selection, patent quality checking, contract design, and revenue management.

5.2 Investigation of faculty invention disclosure

5.2.1 Faculty invention disclosure problem

In a competition/collaboration environment, faculty who focus all their efforts on specific scientific problems are the ones developing unique approaches in their research fields. Competitors may be working on the same problems but not following the same research direction or approach. In this situation, the faculty's achievement in their individual fields far exceeds that of others (Jiang et al., 2012). As shown in Figure 5.2, I consider that there are three different scenarios in the process of invention disclosure. First, if faculty disclose their inventions publicly to universities through invention reports or publication systems, other competitors may find their potential value timely and follow the faculty's research. Thus, in this situation, the faculty may obtain a given rate of licensing revenue and increased reputation, but will have established a competitive environment (Clancy and Moschini, 2013). Second, if faculty disclose an invention to an interested firm, they can collaborate with the firm's researchers for further studies and receive 100% of the licensing revenue. Firm disclosure involves semi-open disclosure-oriented target objectives that are different from university disclosure (Thursby et al., 2009). In the last scenario, the faculty keep their inventions a secret, conducting further studies to improve the inventions' maturity and then waiting for the right opportunity to maximize their expected payoff. On the other hand, if universities or firms reject the invention, faculty continue their research and then disclose again at a later stage. Note that, in this study, I did not consider faculty-run or university-run start-ups: they have the same impact on invention disclosure in the theoretical model, even though they are also important channels of knowledge diffusion and technology transfer (Gregorio and Shane, 2003; Powers and McDougall, 2005).

Disclosing an invention is a complex process (Bekkers and Bodas-Freitas, 2008; Jensen et al., 2003). Because the faculty can estimate the value of the current research and the final invention before making decisions, the backward induction method is a more effective way to optimize the faculty's expected payoff. In this way, although invention development is a continuous process, the disclosure process can be translated into a stage decision procedure (for example, the early/middle/late stage). This translation brings faculty face to face with the same disclosure type (i.e. university disclosure, firm disclosure, and on-going study) at any disclosure stage. In addition, this study allows us to investigate a single- or multi-stage disclosure decision according to invention maturity. Based on this, unlike previous studies (e.g. Haeussler, Jiang, Thursby, and Thursby, 2014), I use a difference equation instead of a differentiability equation as the basis of stimulations.

In order to prove and supplement the theoretical results, this study simulates faculty's optimal disclosure stage and type by assigning multiple values to each parameter. 16,384 simulation cases are created and then a simple linear regression model is used since the theoretical results have estimated their monotonically increasing or decreasing relationship.

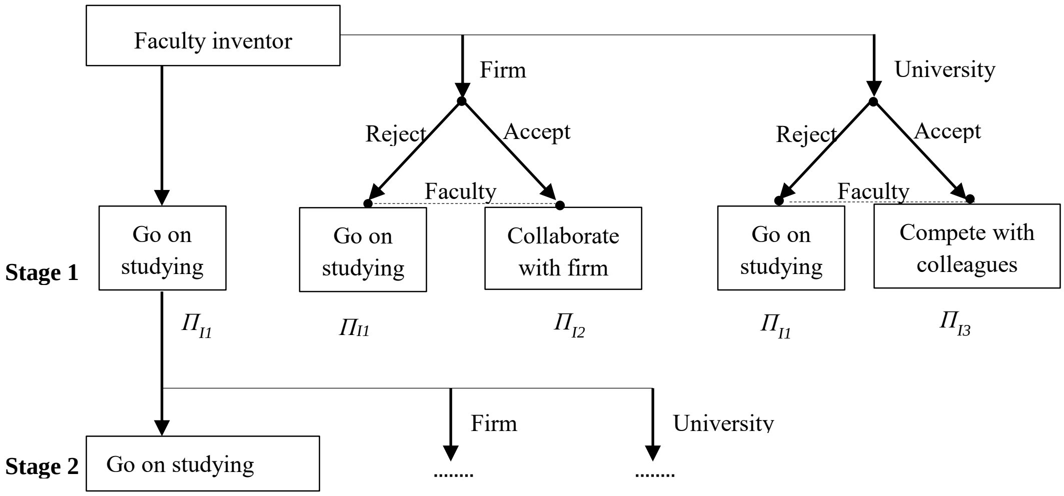

Figure 5.2 Process of faculty invention disclosure

5.2.2 Theoretical model

5.2.2.1 Basic mode

Initially, the whole invention as the faculty finishes will generate value q_iV, where V is the economic profit resulting from the whole invention development and q_i $(0 < q_i < 1)$ is a measure of the faculty's research capability, including research level, resources, experience, and social network in their fields. The higher q_i is, the higher the probability that the faculty can solve the given scientific problem. In this setting, I assume that the faculty has finished an initial invention with value rV $(0 < r < 1)$, where the variable r indicates the invention maturity and disclosure stage. This initial achievement meets the requirement of the patent application, while its reputational value is still less than that of the total invention. I consider r to be independent from the faculty capability q_i in order to allow each faculty to make their discoveries freely. If the faculty is the only one working on the research until completion, they will receive benefits resulting from their current achievement and further work $rV + (1 - r)q_iV$. The opportunity cost of continuing to study independently is the value of an alternative project K times their research capability q_i. It is strictly assumed that $V > K$, otherwise no faculty would put their effort into these projects. The effort they need to complete the remaining research work increases to the value of $1 - r$, then the opportunity cost of continuing to study is $(1 - r)q_i K$. Therefore, the net benefit of achieving the initial invention independently before the disclosure decision is: $[r + (1 - r)q_i]V - (1 - r)q_i K$.

For inventions in their initial stages, disclosing them to universities has both benefits and risks. The risk is that faculty disclosing an early invention obviously obtain less economic benefit since the value of the disclosed invention must be less than V. In addition, the disclosure of the initial invention creates a possible competitive environment for the faculty before they complete their research work. It allows other interested competitors to focus on the same research topics or follow their approach (Haeussler et al., 2014). More importantly, if the competitors have greater research capability, perhaps they gather the remaining value of $(1 - r)V$ and become the ultimate winner, while the faculty only obtain rV. I assume that there are n academic competitors with the same research capability q_c, which may be larger or smaller than q_i. The competitor size n also indicates the threat of entry. If the faculty works independently and competes with the other n competitors, the probability that they will win the remaining invention development is $\frac{q_i}{nq_c + q_i}$.

However, the main benefit of university disclosure is that the faculty can receive an initial reputational value $n\mu rV$, since their disclosure allows the entire research community to find out about their preliminary invention. I assume the initial reputational factor to be $\mu \in (0,1)$. Another benefit is that the faculty could receive a boost to their reputation by finishing the remaining research first. In this setting, I assume the rest of the possible benefit to be $(1 + bn)(1 - r)q_i V$, while the variable b indicates the effect of the additional reputation. The third benefit is that faculty could receive a rational economic return when their invention is successfully licensed to outside entities. I assume that the faculty's share rate stated in their university policies is α. Last but not least, when other researchers who have made similar achievements decide to disclose their inventions to their universities publicly first, this could decrease the innovative power of these competitors' follow-on inventions and may even prevent them from applying for related patents. University disclosure, as an important strategy, allows faculty to maintain competitiveness in their research field (Baker and Mezzetti, 2005). Therefore, in this scenario, the net benefit of faculty π_I^{I-U} in university disclosure is:

$$\pi_I^{I-U} = \alpha rV + n\mu rV + \frac{q_i}{q_i + nq_c}\left[(1+nb)(1-r)q_iV\right] - q_iK$$

As shown in Figure 5.2, if firm disclosure takes place and a firm accepts the preliminary inventions, first the faculty could receive a total 100% of the licensing revenue paid by the firm (Nizovtsev and Thursby, 2007). It is noted that detailed invention information in firm disclosure is not open to the public, since firms have to prevent their competitors from obtaining similar technologies or discoveries, thus in many cases exclusive licenses are used. For the remaining research work, the faculty needs to collaborate with the firm's R&D staff. I assume the probability of winning the rest of the project to be $(1-r)(1+q_f)q_i$. This indicates that firm involvement could speed up research progress, as more technology will be invested into that research. Collaboration between faculty and firm also changes the opportunity cost. First, the collaboration will reduce the overall cost, since it shortens the invention time cost. As in the research by Dechenaux et al. (2009, 2011) and Jiang et al. (2012), I also correlate the reduction of cost saving with the faculty's and firm's capabilities, indicated by $(1-r)(1-q_iq_f)$. Meanwhile, the collaboration cost is established, such as communication and coordination costs between faculty and firm since they have different capabilities. I then assume that this cost increases with the capability difference of $(1-r)(q_i-q_f)^2$. Collaboration cost is very common in the process of university technology transfer (Crama et al., 2008; Fuller, 2008). For example, the faculty has the preliminary invention and higher research capability, while the firm's strength is in its ability to invest financial capital. The benefit to faculty of cooperating with firms is purely economic; there is no benefit to their reputation since they cannot disclose their invention openly. However, firms prefer to reduce their technology investment while continuing to expect sufficient research output (Dechenaux et al., 2009; Hellmann, 2007). Thus, the net benefit of faculty in firm disclosure is:

$$\pi_I^{I-F} = rV + (1-r)(1+q_f)q_iV - \left[(1-r)(1-q_iq_f) + (1-r)(q_i - q_f)^2\right]q_iK$$

Given the preliminary invention, in each disclosure stage, the faculty faces similar choices of university disclosure, firm disclosure, or continuing to study in order to maximize their expected payoff. I assume that faculty will disclose their inventions to firms at the probability of q, while the probability of university disclosure is $1-q$. I also assume that the probability of invention disclosure (including university and firm disclosure) is p, while the probability that they will continue to study is $1-p$. Therefore, at disclosure stage r_t ($t \in \mathrm{N}^+$), the net benefit to faculty is:

$$\Pi_I(r_t) = p\left[q\pi_I^{I-F}(r_t) + (1-q)\pi_I^{I-U}(r_t)\right] + [1-p]\Pi_I(r_{t+1}) \tag{5.1}$$

This is a non-homogeneous linear difference equation. It is denoted as a new function related to the disclosure stage r_t, i.e. $F(r_t) = q\pi_I^{I-F}(r_t) + (1-q)\pi_I^{I-U}(r_t)$. Specifically, when $r_T = 1$ indicates that the faculty has completed the whole invention, they need not go on studying, I have $\Pi_I(r_T) = F(r_T)$. Therefore, I can calculate the expected payoff at each stage as:

$$\begin{cases} \Pi_I(r_t) = p\left[q\pi_I^{I-F}(r_t) + (1-q)\pi_I^{I-U}(r_t)\right] + [1-p]\Pi_I(r_{t+1}) \\ \Pi_I(r_T) = F(r_T) \end{cases} \tag{5.2}$$

This indicates that faculty first estimates the expected payoff of the whole invention development regardless of university or firm disclosure, and then backwardly calculates the payoff at each disclosure stage. It is noted that faculty's disclosure decision depends only on their current and future decisions, and not their past ones. This is the reason why I use the difference function rather than the differentiability function to optimize the faculty's payoff. After calculating the expected payoff in each stage, faculty can make a disclosure decision as to whether the benefit of their disclosure will be greater than that of further work on the invention. The maximization problem of the disclosure payoff is as below:

$$\max_{r_t} G(r_t) = \frac{1}{p}\left[\Pi_I(r_t) - \Pi_I(r_{t+1})\right] + \Pi_I(r_{t+1})$$

$$\text{S.t. } \Pi_I(r_t) - \Pi_I(r_{t+1}) > 0, \; 0 < r_t < r_{t+1} \le 1 \tag{5.3}$$

On the other hand, competitors' willingness to participate in faculty's research depends mainly on how much remaining work is left and the opportunity cost thereof. Specifically, competitors do not need to enter and compete with the original inventor if all invention development has been completed. Thus, competitor size decreases with invention maturity and disclosure stage. In addition, only part of the research direction or approach will be absorbed when competitors enter. I assume the absorption rate is s $(0 < s < 1)$. Therefore, competitors will expect a payoff as below:

$$\pi_C(n) = \frac{q_c}{q_i + nq_c}\left[bn(1-r_t)q_cV + (1-r_t)q_cV\right] - (1-sr_t)q_cK \tag{5.4}$$

If faculty disclose their inventions to universities, their original invention ideas, research approaches, and future directions will be revealed to their competitors. Equation (5.4) indicates that competitor size will be kept in a dynamic decay. Competitors will enter into competition until the benefit of entering is equal to or less than zero.

In this research, I consider that faculty's endogenous decision is disclosure stage and disclosure type. Combining Equations (5.2), (5.3) and (5.4) gives us the optimal disclosure stage r_t^*. Then, at a given stage, I calculate the payoff of university disclosure and firm disclosure respectively and then choose a specific disclosure type with more benefits. In the following section, this study will mainly analyse these theoretical solutions.

5.2.2.2 Model analysis

(1) Disclosure decision

In this section, in order to analyze the theoretical solutions, I first assume that faculty would choose invention disclosure in each stage with the same probability, i.e. p=0.5. In addition, I also assume that the probability that faculty will choose university or firm disclosure is the same, i.e. q=0.5. Therefore, Equation (5.2) can be rewritten as:

$$\begin{cases}\Pi_I(r_t)=0.5\left[0.5\pi_I^{I-F}(r_t)+0.5\pi_I^{I-U}(r_t)\right]+0.5\Pi_I(r_{t+1})\\ \Pi_I(r_T)=F(1)\end{cases}$$

They are denoted as $M=\frac{(1+nb)q_i^2V}{q_i+nq_c}$, $H=(1+q_f)q_iV-\left[(1-q_iq_f)+(q_i-q_f)^2\right]q_iK$, $r_t=\frac{t}{T}$ and $Z=\alpha V+n\mu V+V$. The variable M indicates the expected payoff of the remaining invention in university disclosure. The variable H indicates the expected payoff of the remaining invention in firm disclosure. The variable Z indicates the expected payoff of the total invention development. Therefore, $rZ-M-H$ reflects the value gap between the preliminary invention and the remaining research. This gives us

$$\Pi_I(r_t)=\left(\frac{1}{2}\right)^{t+1}Z+\frac{1}{2}\left[(Z-M-H)r_t+Z-q_iK\right] \tag{5.5}$$

Meanwhile, when faculty decide to disclose their inventions to universities or firms, their expected payoff is equal to $0.5\pi_I^{I-F}(r_t)+0.5\pi_I^{I-U}(r_t)$, denoted by $F(r_t)$. Then I have

$$F(r_t)=\frac{1}{2}\left[r_tZ+(1-r_t)(M+H)-q_iK\right]$$

First, if $Z<M+H$, $\Pi_I(r_t)$ and $F(r_t)$ are all the monotonic decreasing functions of r_t, this indicates that faculty may obtain the maximum expected payoff in the early stages. In this case, I have to compare the value of $\Pi_I(r_t)$ and $F(r_t)$ to see whether the disclosure payoff is larger than the total expected payoff in a given stage.

$$\Delta=F(r_t)-\Pi_I(r_t)=\frac{1}{2}(M+H-Z)-\left(\frac{1}{2}\right)^{t+1}Z$$

If the disclosure stage r_t satisfies $t>\frac{\ln Z-\ln(M+H-Z)}{\ln 2}=r_t^*$, then I have $\Delta>0$. Therefore, if I consider that faculty disclose their inventions only once to a university or firm, their optimal disclosure stage is r_t^*. In this case ($p = q = 0.5$), it also indicates that in stage r_t^* the disclosure payoff is equal to the expected payoff of continuing to study.

Second, if $Z > M + H$, the value of Δ is less than zero. This indicates that the enhanced reputation resulting from university disclosure and the cost saving resulting from collaboration with the firm are all less than the benefit from the faculty's finished work. Meanwhile, the marginal effect of changes in r_t on $F(r_t)$ is always greater than zero, which means $F(r_t)$ is an increasing function. Therefore, faculty disclose the invention after completing all the related research work ($r_t^* = r_T$). After obtaining r_t^*, faculty can compare the benefits of university and firm disclosure and choose the best type.

(2) Influence of faculty share of licensing revenue

An increase in faculty's share of licensing revenue α would definitely increase the value of Z. When $Z(\alpha) \leq M + H$, in order to find the effect of variable α on disclosure stage, I have

$$\frac{\partial r_t^*}{\partial \alpha} = \frac{1}{\ln 2}\left[\frac{V}{Z} + \frac{V}{M + H - Z}\right] > 0 .$$

This indicates that the impact of increasing α could effectively increase r_t^*. A higher inventor share rate could increase the expected payoff of university disclosure (Friedman and Silberman, 2003; Thursby et al., 2009). This effect would encourage faculty to disclose their inventions at a later stage, since more economic benefits resulting from the remaining research are created then than in the earlier stages. When α makes $Z(\alpha) > M + H$, the faculty intend to disclose a more mature invention to the university or firm at a later stage, thus an increase in α has little influence on faculty's optimal disclosure time. There exists a minimum $\alpha^* = M + H - (n\mu + 1)V$. In summary, the marginal effect of changes in α plays positive role in disclosure stage.

From the perspective of universities, if they want faculty to disclose their inventions at an earlier stage to enhance information sharing and invention diffusion, they should give faculty a lower share of licensing revenues. However, if they want faculty to disclose more mature technology at a later stage to increase the probability of university technology transfer, the faculty share rate should satisfy $\alpha > \alpha^*$. I also denote that

$$\Delta\pi = \pi_I^{I-U} - \pi_I^{I-F} = r_t\left(\alpha V + n\mu V - V\right) + \left(1-r_t\right)\left(M - H\right) - q_i K$$

Which means $\frac{\partial \Delta\pi}{\partial \alpha} = r_t V > 0$. This indicates that the impact of increasing α can effectively encourage faculty to choose university disclosure.

In summary, I obtain the policy implication that increasing α could encourage faculty to disclose more mature technology to universities when $\alpha \leq \alpha^*$. In contrast, if $\alpha > \alpha^*$, the only role of increasing α is to promote university disclosure. For basic research, information sharing and diffusion should be encouraged so that a lower faculty share rate is appropriate, while for applied research a higher faculty share rate should be used to promote invention development.

(3) Influence of threat of entry

If faculty disclose their inventions to universities, threats of entry occur. In this section, I consider the threat of entry to be the total number of potential competitors focusing on the same research field. In order to evaluate the influence of threat of entry, first I have

$$\frac{\partial \pi_c}{\partial n} = \frac{\left(bq_i - q_c\right)\left(1-r_t\right)}{(q_i + nq_c)^2} q_c^2 V \tag{5.6}$$

In Equation (5.6), variable b reflects the marginal effect of the additional reputation resulting from the remaining research work. Meanwhile, the influence of n on $F(r_t)$ is:

$$\frac{\partial F\left(r_t\right)}{\partial n} = \frac{1}{2}\left[r_t \mu V + \frac{\left(1-r_t\right)\left(bq_i - q_c\right)q_i^2 V}{(q_i + nq_c)^2}\right] \tag{5.7}$$

Therefore, Equations (5.6) and (5.7) clearly show that the influence of threat of entry on faculty's and competitors' benefits (i.e. π_c, $F(r_t)$) depends on the value of $bq_i - q_c$:

(1) When $bq_i \leq q_c$, $\frac{\partial \pi_c}{\partial n} \leq 0$. If research popularity is less than a competitor's comparative advantage, the threat of entry, which is the number of competitors, has a negative impact on each competitor's expected payoff. In the real world, late competitors must decide whether they want to enter into the faculty's research field, especially when there is strong competition. In this case, I consider that competitors might enter until the entering benefit is equal to zero. Thus, if I denote n^* as the real amount of entry that satisfies $\pi_c(n^*) = 0$,

$$n^* = \frac{(1-sr_i)q_iK - (1-r_i)q_cV}{(1-r_i)bq_cV - (1-sr_i)q_cK} \tag{5.8}$$

Equation (5.8) reflects the maximum number of potential competitors.

From the faculty perspective, the influence of competitor size n on $F(r_t)$ is uncertain. If $n \geq \frac{q_i}{q_c}\left[\sqrt{\frac{(1-r_t)(q_c-bq_i)}{r_t\mu}} - 1\right] = \underline{n}$, $\frac{\partial F}{\partial n} \geq 0$, or else $\frac{\partial F}{\partial n} < 0$. This indicates that F is a concave function of competitor size n. The positive impact of n on F occurs only when there are enough entries to bring additional reputation. On the other hand, considering the influence of r_t on n^* and $\underline{n}$, I have $\frac{\partial n^*}{\partial r_t} < 0$ and $\frac{\partial \underline{n}}{\partial r_t} < 0$, which indicates that competitor size decreases with disclosure stage.

If $n^* \geq \underline{n}$, and competitor size is $n \in [0, \underline{n}]$, $\frac{\partial F}{\partial n} \leq 0$, $\frac{\partial \pi_c}{\partial n} \leq 0$. The marginal effect of n on F is less than zero. In this case, faculty's possible additional reputation is less than the real effect of competition, so the increasing threat of entry encourages them to keep their inventions as technology secrets. In contrast, once competitor size is larger than $\underline{n}$ but smaller than n^*, i.e. $n \in (\underline{n}, n^*]$, $\frac{\partial F}{\partial n} > 0$, $\frac{\partial \pi_c}{\partial n} \leq 0$, faculty improve their reputation over and above that of the competition, so an increase in n would also increase F. Therefore, at a given disclosure stage, faculty disclose their invention only when entry size is over $\underline{n}$.

If $n^* < \underline{n}$, I always have $\frac{\partial F}{\partial n} \leq 0$, $\frac{\partial \pi_c}{\partial n} \leq 0$. In this case, possible improvement to faculty's reputation is always less than that of the competition, so increasing competitor size poses a threat to both faculty and existing competitors. Thus, in order to remain competitive, faculty disclose their inventions at a later stage, or choose firm disclosure at an early stage.

(2) When $bq_i > q_c$, I always have $\frac{\partial F}{\partial n} \geq 0$, $\frac{\partial \pi_c}{\partial n} > 0$. For a popular research field, if faculty disclose their inventions to their universities, their payoff and that of all their competitors' increases with competitor size, since an enhanced reputation will result from the remaining research work. In this case, all researchers focusing on the same research topic will benefit from this competition. The threat of entry encourages faculty to disclose their inventions to their universities in a timely manner in the early stages. Further, considering the impact of n on $\Delta\pi$, I have $\frac{\partial \Delta\pi}{\partial n} = r_t \mu V + M' > 0$. This suggests that a larger competitor size also increases university disclosure in this case.

5.2.2.3 Model extension

Above section suggests that there is only one opportunity for faculty to make a disclosure decision. However, in reality, they can disclose their invention more than once at different disclosure stages. For instance, they could first disclose their innovative conceptual idea to their university in the early stages in order to enhance their academic reputation; later, they disclose the more mature invention to interested firms. In this section, I develop several theoretical models that allow faculty to disclose their invention twice. Initially, if universities or firms reject the invention at the first disclosure, faculty may opt to disclose again after further studies. In this scenario, faculty's payoff on the first disclosure is zero. In addition, when the university (firm) accepts the invention at an early stage, faculty can continue working on their research independently, and then disclose their further research findings to the university (firm) or firm (university).

（1）When the first disclosure has been accepted/rejected

For a popular research problem, it is possible for faculty to create more than one paper or patent. When a university or firm has accepted (or rejected) a faculty member's early invention, they may go on working on their research alone and produce further research findings. In this scenario, I assume that faculty would prefer to maximize their benefit through disclosing their invention twice. For instance, faculty disclose their invention to universities through internal reports or publications to establish their academic reputation in the early stage, and then apply patents with universities' permission to obtain economic benefit in the later stages. In addition, their two disclosure decisions have a close relationship, as the content of the second disclosure has to be markedly different from that of the first. Therefore, when the university or firm has accepted (or rejected) the faculty's invention at the first disclosure, the faculty's optimization problem is given as:

$$\max_{r_i < r_j \leq 1} \left\{ \max_{r_i} F\left(r_i\right) + F\left(r_j\right) \right\}$$

For this maximization problem, faculty's first disclosure decisions are based on the global optimum perspective, while their second decisions are more local ones.

(2) Multi-stage disclosure decision from the global perspective

In above sections, faculty make their decisions according to current situations and future payoff, and may not completely adopt a global perspective. If faculty have a disclosure plan before completing their research work, they may divide their total invention into two or more parts and then disclose these to external parties one by one. In this scenario, though each of their disclosure decisions may not be a global solution, the total benefit of all the invention disclosures will be the greatest. Therefore, faculty's optimal invention disclosure is:

$$\max_{r_i, r_j} \left\{ F\left(r_i\right) + F\left(r_j\right) \right\}$$

In this case, one should make sure that faculty's payoff for a single disclosure is less than that for a multi-stage disclosure. In addition, multi-stage invention disclosure enables faculty to obtain both economic and non-economic benefits.

(3) Multi-stage independent disclosure decisions

Looking at the above optimal theoretical models, I finally consider faculty's decisions, namely university or firm disclosure, to be independent from each other. Therefore, I cannot use function F to represent the expected payoff of the invention disclosure. Specifically, faculty perhaps obtains maximum reputation benefit in the early stages and maximum economic benefit at a later stage. It thus appears that there exists a stage gap for invention disclosure. Faculty's optimization problem with regard to invention disclosure is therefore:

$$\max\left\{\max_{r_i}\left\{\pi_I^{I-U}\right\},\max_{r_j}\left\{\pi_I^{I-F}\right\}\right\}$$

In this theoretical model, faculty should first calculate the optimal disclosure stage for university or firm disclosure, and then compare their payoffs with a specific disclosure type at the optimal disclosure stage.

5.2.3 Simulation results

5.2.3.1 Simulation set-up

In order to simulate faculty's disclosure decision, each parameter has multiple values, and 16,384 cases are examined. First, all cases are divided into four scenarios according to the research capability of faculty, competitor, and firm. Scenario one (S1:$q_i < min\{q_c, q_f\}$) is that the faculty's research capability is less than that of competitors and firms. The second and third scenarios are that S2:$q_f \leq q_i \leq q_c$ or S3: $q_c \leq q_i \leq q_f$, in which the faculty's research capability lies between that of competitors and firms. The fourth scenario is the situation (S4: $q_i > \max\{q_c, q_f\}$) in which the faculty is more capable than either competitors or firms. In this study, simulation parameters are μ, b, q_i, q_f, q_c, and $k = \frac{K}{V}$. The technology absorptivity rate s is 0.85. All other parameters vary over (0, 1).

5.2.3.2 Optimal disclosure stage

Table 5.1 shows the faculty's optimal disclosure stage in four scenarios. Specifically, in S1, the faculty would like to disclose their invention to their university at a late stage, while its proportion in the area (0.8-1.0) is 92.83%. However, few inventions (0.61%) are disclosed to universities or firms at this early stage. In S2, when the faculty's research capability is better than that of the firm but less than that of their competitors, the optimal disclosure stage is distributed more evenly in the area (0.0-0.8), and the probability of disclosing at the late stage (0.8-1.0) eventually decreases to 85.24%. With an increase in the faculty's research capability in S3, the faculty discloses their invention either in the early stage (12.95%) or at the late stage (55.65%). Finally, when faculty have the best research capability, as in S4, I found a similar phenomenon in that the proportion of invention disclosure at each stage was greater than five percent.

Table 5.1 Optimal disclosure stage under the four scenarios

r	S1: $q_i < min\{q_c, q_f\}$	S2: $q_f \le q_i \le q_c$	S3: $q_c \le q_i \le q_f$	S4: $q_i > \max\{q_c, q_f\}$
0.0~0.2	0.61%	1.34%	12.95%	9.64%
0.2~0.3	0.98%	1.19%	7.29%	5.36%
0.3~0.4	0.86%	1.19%	4.61%	5.89%
0.4~0.5	0.61%	2.53%	4.91%	6.43%
0.5~0.6	1.35%	2.68%	5.51%	6.43%
0.6~0.7	1.41%	2.23%	4.61%	6.43%
0.7~0.8	1.35%	3.42%	4.46%	7.32%
0.8~1.0	92.83%	85.42%	55.65%	52.50%
Cases	6528	2688	2688	4480

In order to evaluate the factors influencing the optimal disclosure stage, parameter r, which indicates the invention maturity and disclosure stage, is considered a dependent variable. Other parameters are independent variables (i.e. μ, b, q_i, q_f, q_c, and k). A linear regression model is employed to correlate the optimal disclosure stage with several independent variables. Table 5.2 shows empirical results under the four scenarios.

(1) Effects of μ and b

If faculty disclose their invention to a university, they can obtain credits and recognition from their peers. The effect of reputation depends on two factors, μ and b. The initial aspect of reputation results from the faculty's preliminary work. As shown in Table 5.2, an increase in the reputational factor μ is weakly positively related to the value of r (significant at 10% in S2, and 1% in S3 and S4). Ceteris paribus, the larger μ indicates that the more significant the finished work, the more impact it produces. Thus, it can motivate faculty to disclose more mature technology.

Inventions are disclosed to universities as public knowledge attracts other competitors to complete the remaining research work in order to gain additional reputation. When faculty's research capability is less than that of their competitors, in most cases, they will be losers in these competitions even though they are the original inventors. Therefore, in S1 and S2, the value of additional reputation had little impact on the optimal disclosure stage. On the other hand, if faculty's research capability is better than that of their competitors (as in S3 and S4), the additional reputation resulting from the remaining research work, which is indicated by variable b, has a negative impact on disclosure stage r. This encourages faculty to disclose their early inventions and leaves most of their research work to be completed in a competitive environment in order to gain additional reputation from their competitors. In summary, variables μ and b have an opposite influence on faculty's optimal disclosure stage, depending on the relationship between initial and additional reputation.

(2) Effects of q_i, q_f and q_c

Faculty's research capability is negatively related to their optimal disclosure stage in all four scenarios, S1, S2, S3, and S4. An increase in q_i raises the probability that faculty first completes the remaining research work, but reduces the comparative competiveness of their competitors. Thus, increasing one unit of q_i could rapidly decrease the disclosure stage 1.38 times in S3 or 0.72 times in S4 at the 1% significance level. Comparing S1, S2, S3 and S4, the significance of increasing q_i also depends on the position of the faculty's research capability in their research communities. When a faculty member's research capability is consistently at a lower level, their optimal strategy is to keep their inventions a secret until the whole invention has been developed independently. Thus, the negative impact of q_i in S1 and S2 is less significant than that in S3 and S4. Lastly, when faculty's research capability is less than that of firms, they can disclose their invention to and collaborate with firms in order to speed up their remaining research work. In this scenario, faculty do not need to worry about competition from their competitors, so they can disclose their inventions to firms at an earlier stage. As shown in Table 5.2, the impact of q_i is more significant in S1 and S3.

The marginal effect of changes in q_f in Table 5.2 is always negative, but its value fluctuates significantly across the four scenarios. All other parameters being equal, the larger value of q_f increases the likelihood of the firm becoming a potential collaborator. If faculty disclose their invention to and cooperate with the firm's R&D staff, they can complete all of the research work more quickly and successfully than their competitors can. However, holding q_i constant, collaboration cost depends on a firm's research capability q_f (see Equation 5.2). When $q_i \geq q_f$, increasing q_f can result in collaboration costs being reduced more rapidly, and this encourages faculty to disclose their inventions to firms in the earlier stages in order to seek collaboration. When $q_i < q_f$, any increase in q_f raises collaboration costs because of the increasing capability gap. Thus, in S1 and S3, the variable q_f plays a weaker role in faculty's optimal disclosure stage than in S2 and S4.

The marginal effect of changes in q_c in Table 5.2 is always positive, but it is only significant in S3 and S4 (significance at the 1% level). An increase in q_c enhances the probability that competitors will first complete the remaining research works successfully. When $q_i < q_c$, faculty discloses fewer inventions to universities, so the correlation coefficient of variable q_c is close to zero in S1 and S2. Meanwhile, $q_i \geq q_c$ reflects that faculty are more capable than their competitors. In this scenario, an increase in q_c indicates that the competitiveness gap between faculty and their competitors is narrower, which drives faculty to disclose more mature inventions in order to avoid direct competition in the early stages.

In summary, collaboration with firms could encourage faculty to disclose their inventions at an earlier stage, while competition makes them more inclined to disclose more mature inventions at a later stage. The optimal disclosure stage depends on faculty's capability position in their community.

(3) Effect of k

The effect of k is negative in all four scenarios. The greater the value of k, the higher the opportunity cost, which can also be considered as an entry cost. Facing competition from potential competitors, if the entry cost is very low, faculty will not disclose their inventions to universities until they have completed all the research work. In addition, in S1 and S2, the faculty's research capability is less than that of their competitors, so even higher entry costs will not prevent competitors from entering into the faculty's research field. In S3 and S4, faculty have the competitive advantage of entry cost and research capability in participating in research competitions. Thus, an increase in entry cost will rapidly affect the disclosure stage (significant at the 1% level).

Table 5.2 Impact of each parameter under the four scenarios

	S1: $q_i < min\{q_c, q_f\}$	**S2:** $q_f \le q_i \le q_c$	**S3:** $q_c \le q_i \le q_f$	**S4:** $q_i > max\{q_c, q_f\}$
μ	0.029	0.071^{*}	0.140^{***}	0.168^{***}
b	-0.017	-0.048	-0.188^{***}	-0.330^{***}
q_i	-0.380^{***}	-0.157^{***}	-1.380^{***}	-0.728^{***}
q_f	-0.012^{**}	-0.520^{***}	-0.145^{***}	-0.940^{***}
q_c	0.001	0.01	0.197^{***}	0.263^{***}
k	-0.042^{**}	-0.125^{***}	-0.193^{***}	-0.470^{***}
R^2	0.360	0.486	0.765	0.765
Cases	6528	2688	2688	4480

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

5.2.3.3 University disclosure and firm disclosure

Table 5.3 shows the proportion of university and firm disclosure in the four scenarios. Specifically, university disclosure has the highest proportion in S1 (0.67%, 96.94%) and S2 (1.93%, 93.75%), and mainly occurs in the late stage (0.5, 1). However, the proportion of firm disclosure is less than 5% in these two scenarios. In S3 and S4, the two types of invention disclosure are evenly distributed. Table 5.3 shows that university disclosure decreases to less than 80%, while firm disclosure increases to more than 15%.

Disclosing inventions to universities can result in receiving credits and enhanced reputation. However, due to the possible competition and weaker competitiveness in S1 and S2, faculty's optimal disclosure strategy is to disclose more mature inventions to universities in the late stage to obtain initial but not additional reputation. This is why most faculty prefer to disclose inventions to universities under area (0.5, 1) in Table 3. In S3 and S4, though competing with other competitors, faculty with greater research capability have the confidence to complete the remaining research work first, so the proportion of university disclosure in the early stage increases.

Disclosing inventions to firms means seeking collaboration and results in more economic benefits. When $q_i \geq q_c$, the proportion of firm disclosure in S3 and S4 becomes greater in the early stages (0, 0.5). This indicates that faculty prefer to disclose early inventions to firms in order to gain research support and speed up the remaining research work. In addition, Table 5.3 shows that the firms with the highest research capability could attract the largest proportion of invention disclosure in S3.

Table 5.3 Proportion of university and firm disclosure under the four scenarios

Type	Disclosure stage	S1: $q_i < min\{q_c, q_f\}$	S2: $q_f \leq q_i \leq q_c$	S3: $q_c \leq q_i \leq q_f$	S4: $q_i > \max\{q_c, q_f\}$
University disclosure	0<r≤0.5	0.67%	1.93%	8.48%	7.77%
	0.5<r≤1	96.94%	93.75%	70.24%	76.70%
Firm disclosure	0<r≤0.5	0.43%	3.27%	20.39%	14.82%
	0.5<r≤1	1.96%	1.04%	0.93%	0.71%
Cases	16,384	6,528	2,688	2,688	4,480

In order to examine the influence of each exogenous parameter on university disclosure and firm disclosure, I code these two types of disclosure (university disclosure=1 and firm disclosure=0) and employ a simple linear regression model to forecast faculty's disclosure strategy. As shown in Table 5.3, university disclosure has the highest proportion in all four scenarios (over 90% in S1 and S2, over 70% in S3 and S4). In order to reduce its dominant influence on the regression model, I randomly choose 150 samples from each group – university disclosure and firm disclosure – in S1, S3, and S4. Specifically, in S2 I only choose 100 samples from each group since the sample size for firm disclosure is 117.

First, Table 5.4 shows that parameter μ has a positive effect on university disclosure at the 1% level of significance in S2, S3 and S4. The most attractive benefit of university disclosure is peer reputation. Thus, increasing μ greatly encourages faculty to choose university disclosure. As for the effect of parameter b, compared with their significant negative effect on disclosure stage in Table 5.2, they have little influence on disclosure type in any of the four scenarios. I estimate the possible reason to be that disclosure type is a dichotomous variable, indicating enhanced reputation occurs only after invention disclosure.

Second, Table 5.4 shows that q_i and q_f are all negatively related to university disclosure at the significance levels of 1 or 5%. The results show that an increase in q_i makes faculty prefer collaborating with firms over competing with their competitors. I find that greater research capabilities allow faculty to focus on the success rate of their invention and economic profit, but not the reputation of their competitors. In particular, when $q_i > q_c$, this negative effect on university disclosure becomes more significant. On the other hand, increasing q_f also encourages faculty to choose firm disclosure. Established firms with greater research capability, such as experienced R&D staff and advanced research labs, have a significant advantage in terms of attracting faculty's collaboration, since these assets are helpful in enabling faculty to complete their remaining research work quickly and successfully. It is noted that the effect of q_f is more significant in S2 and S4 ($q_i > q_f$) because increasing q_f also reduces collaboration cost.

Lastly, parameter k, which indicates the entry cost, is positively related to university disclosure in S1 (0.561, significant at the 1% level), while in other scenarios, it has little influence. Greater entry costs can effectively prevent other competitors from entering into faculty's research field, so it can encourage them to choose university disclosure, especially when their own research capability stays at bottom relative to their research community.

Table 5.4 Effect of each parameter under the four scenarios

	S1: $q_i < min\{q_c, q_f\}$	**S2:** $q_f \le q_i \le q_c$	**S3:** $q_c \le q_i \le q_f$	**S4:** $q_i > \max\{q_c, q_f\}$
μ	0.418	1.267^{***}	1.051^{***}	1.305^{***}
b	-0.213	-0.033	-0.001	0.001
q_i	-1.663^{***}	-0.339^{**}	-2.043^{***}	-0.766^{***}
q_f	-0.098	-1.756^{***}	-0.394^{**}	-1.757^{***}

q_c	0.026	-0.050	0.031	0.105
k	0.561***	-0.009	-0.261	0.488
R^2	0.817	0.816	0.674	0.714
Cases	300	200	300	300

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

5.2.3.4 Simulation of multi-stage disclosure

There are five disclosure strategies for multi-stage disclosure, as shown in Table 5.5. I assume that faculty have one or two opportunities to disclose their invention, especially when their first disclosure is at an early stage. When faculty first disclose an invention to their university in order to enhance their reputation, it is possible to choose firm disclosure again in order to gain economic benefit. Meanwhile, if firm disclosure is the first choice, faculty also have the opportunity to disclose their mature invention to their university with the firm's approval, or to firms again, in the later stages.

Table 5.5 Five types of invention disclosure in multi-stage disclosure

Disclosure strategies	First invention disclosure	Second invention disclosure
D_U_U	University	University
D_U_F	University	Firm
D_F_U	Firm	University
D_F_F	Firm	Firm
D_DN	University or firm	/

As shown in Table 5.6, the strategy of D_U_U is the most common across the four scenarios (all over 50%), which is also in line with the results in Table 5.3. This result shows that enhancing reputation is faculty's main objective in university disclosure. The strategy of D_DN ranks second, representing over 20% of approaches used in the four scenarios. In this strategy, faculty disclose their completed invention and have no opportunity for further disclosure. The third strategy is D_U_F, whose proportion reaches 10.27% in S3. In this scenario, faculty disclose their early stage inventions to universities to obtain an enhanced reputation, and then disclose the more mature inventions to firms to seek their collaboration and economic profit. In the D_U_F strategy, faculty might complete their entire invention first in spite of the competition. Table 5.6 also shows that few inventions are disclosed again after firm disclosure is chosen the first time.

Table 5.6 Proportion of multi-stage disclosure under the four scenarios

Disclosure strategy	S1: $q_i < min\{q_c, q_f\}$	S2: $q_f \le q_i \le q_c$	S3: $q_c \le q_i \le q_f$	S4: $q_i > \max\{q_c, q_f\}$
D_U_U	73.41%	71.58%	57.89%	57.50%
D_U_F	1.65%	3.57%	10.27%	9.20%
D_F_U	0.00%	0.00%	0.15%	0.18%
D_F_F	0.00%	0.00%	0.30%	0.00%
D_DN	24.95%	24.85%	29.02%	31.72%
Cases	6528	2688	2688	4480

In order to examine the marginal effect of each parameter on faculty's disclosure strategy, I denote the variable TIME to reflect whether the invention is disclosed once (code "0") or twice (code "1"). Then I divide the faculty's disclosure into two groups. In Group 1, TIME is equal to zero, and in Group 2, TIME is equal to one. I continue to use simple linear regression for the analyses. As shown in Table 5.6, D_U_U dominates the whole group in each scenario, representing over 70% of strategies in S1 and S2 and over 50% in S3 and S4. Therefore, similar to the sample selection approach used in above section, I randomly choose 150 samples from each group under the four scenarios.

First, Table 5.7 shows that parameter μ, which indicates more initial reputation, is negatively related to multi-stage disclosure in S2 (significant at the 10% level) but has little influence in other scenarios. Higher μ suggests that faculty continue further research (see Table 2) and then disclose to their university at a later stage (see Table 5.4). For the marginal effect of changes in parameter b, however, an increase in b always encourages faculty to disclose more than once (significant at the 1% level), since an enhanced reputation only occurs in university disclosure and increases with competitor size.

Second, parameter q_i has a negative influence on multi-stage disclosure, significant at the level of 1% in S3 and 5% in S4. Faculty with higher research capability prefer firm disclosure (see Table 5.4) and rarely disclose again to universities or firms. Once such faculty have disclosed their invention to and collaborated with a firm, they will need to negotiate their upcoming disclosure strategy with the firm and obtain their approval. In the real world, firms rarely agree to faculty disclosing an invention again in order to protect their commercial interests and competitiveness. Table 5.7 also shows that an increase in competitor capability will encourage faculty to disclose an invention twice in S3 and S4 (significant at the 1% level). When $q_i \geq q_c$, in spite of facing increasing competition from other competitors, faculty disclose their early invention to their university in order to enhance their reputation, and then disclose the completed invention to their university again, or to a firm. Based on the simulated cases, when q_c is equal to 0.6 or 0.7, faculty disclose their invention to the university at the 0.1 stage first, and then disclose again to the university or a firm at the 0.9 stage.

Finally, Table 5.7 shows that entry cost always has a negative impact on multi-stage disclosure. For any given scenario, higher entry costs prevent competitors from entering into faculty's research field, which reduces the competition. In addition, higher entry costs also lead to a lower optimal disclosure stage. Therefore, increasing entry costs give faculty more opportunities to disclose their invention twice.

Table 5.7 Effect of parameters in multi-stage disclosure under the four scenarios

	S1: $q_i < min\{q_c, q_f\}$	**S2:** $q_f \leq q_i \leq q_c$	**S3:** $q_c \leq q_i \leq q_f$	**S4:** $q_i > max\{q_c, q_f\}$
μ	0.233	-0.490*	-0.158	-0.277
b	6.272***	5.740***	3.820***	3.190***
q_i	-0.001	-0.112	-0.453***	-0.321**
q_f	-0.013	-0.016	-0.243	-0.158
q_c	0.070	0.011	0.687***	0.581***
k	5.888***	6.674***	6.233***	6.258***
R^2	0.793	0.809	0.609	0.562
Cases	300	300	300	300

* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

5.2.4 Model discussion

5.2.4.1 Reputation and Competition vs. Economic Benefit and Collaboration

In this chapter, I found that economic benefit and reputation, competition and collaboration, are determinant factors to faculty's disclosure decisions. University disclosure enhances reputation and causes possible competition, and firm disclosure provides economic benefit and collaboration.

The current scientific reward system is "winner-Take-All". In university disclosure, one of the most important motivators is reputation, which encourages faculty to be the first to create early inventions and occupy an area of academic territory from the beginning (Baker and Mezzetti, 2005; Haeussler et al., 2014). Enhanced reputation is also quite attractive if faculty can complete the remaining research work. Besides reputation, competition always follows university disclosure, making it a double-edged sword. On the one hand, competition resulting from university disclosure allows other competitors to be the ultimate winners if they have greater research capability (especially in S1 and S2); this makes faculty postpone their disclosure. On the other hand, effective competition also increases initial and additional reputation because of more competitors entering the game (especially in S3 and S4). Therefore, compared with previous studies (e.g. Jiang et al., 2012; Siegel et al., 2003b; Thursby et al., 2002), I provide more detailed evidence that the effect of initial reputation encourages faculty to choose university disclosure in the early stages; however, the effect of additional reputation and competition depends mainly on faculty's capability position within their research community.

In firm disclosure, university faculty obtain more economic benefit since their share of licensing revenues is equal to one. Consistent with existing research (e.g. Aghion and Tirole, 1994; Macho-Stadler and Perez-Castrillo, 2010; Thursby et al., 2009), increasing faculty's share of licensing revenues has the effect of decreasing the proportion of firm disclosure. In addition, this study adds to the understanding that postponing faculty's disclosure stage will generate more economic benefit in the later stages. The collaboration also encourages faculty to choose firm disclosure in the early stages since the lesser competition and more powerful research capability offered. Collaboration cost depends mainly on the capability gap.

From the policy perspective, in order to improve the timely disclosure of basic research, university administration should enhance faculty's initial reputation, such as increasing invention awards and providing effective competition. However, for applied research, disclosing more mature inventions in the later stages is beneficial to university-industry technology transfer. The economic incentive, through increasing faculty's share of licensing revenue, is a fair and appropriate way to ensure that such late disclosure takes place.

5.2.4.2 Balancing the right disclosure stage and type

This study focuses on the question of when and which disclosure strategy should be adopted. Initially, the simulation results suggest that faculty disclose mature technology to universities but early technology to firms (Tables 5.1 and 5.3). Disclosing mature inventions to universities can result in enhanced reputation among peers, since a significant academic contribution has been made (also tested by George, Jain, and Maltarich, 2005). In addition, competitor size, which represents the threat of entry, decreases with invention maturity. In order to maintain competiveness, faculty with lower research capability have to conceal their inventions by postponing their disclosure. This result seems different from claims in previous research that most faculty inventions remain at the conceptual model or lab scale stage (e.g. Jensen et al, 2003; Owen-Smith and Powell, 2001; Thursby et al., 2002). The explanation is that the disclosure type in this study includes publications, inventions and patent applications. In the real world, it is also conceived that the optimal disclosure stage is different for basic and applied research (Haeussler et al., 2014).

However, for faculty who do not care about reputation, disclosing early inventions to firms is an effective alternative, since it enables larger economic benefit to be obtained, as well as closer collaboration with firms and less competition (Nizovtsev and Thursby, 2007). As shown in Table 5.3, in the group of firm disclosure, more inventions are disclosed in the early stages. Specifically, when the research capability of the firm (faculty) is catching up with that of the faculty (firm), firm disclosure is a better choice for faculty since collaboration cost is reduced. In this scenario, the shortened capability gap indicates that both faculty and firm are intended to put the required effort into technology transfer without any moral hazard (Gans and Murray, 2014; Siegel et al., 2003a,b).

Last but not least, in the real world, faculty normally want to obtain both reputation and economic benefit, so the decision to disclose an invention more than once, at different stages of maturity, is essential. Generally, faculty may disclose an invention to their university twice to further enhance their reputation, or they can disclose first to their university for the sake of peer recognition and second to a firm for economic benefit. However, once faculty have chosen firm disclosure, they cannot disclose again to their university or firm since the firm has to prevent its competitors from having access to its invention. Further, it is clear that multi-stage disclosure depends on faculty's decision-making mode, such as unplanned multi-stage disclosure, planned multi-stage disclosure, or multi-stage independent disclosure.

5.3 Investigation of commercial mode selection[19]

5.3.1 Process of university-industry technology transfer

Harmon et al. (1997) and Zaltman et al. (1973) defined the process of university technology transfer as a linear flow including the preparing stage and the licensing stage. Since these studies, further research has expanded this simple conceptual model into more complex ones including invention disclosure, invention quality evaluation, patent application, license executed, license contract design, and licensing revenue management (e.g. Rogers et al., 2001; Shane, 2005; Siegel et al., 2003b). Therefore, among the three stakeholders, the faculty who creates inventions, the TTO who manages the technology transfer, and the licensee who brings university-invented patents to market, all make vital contributions to the success of UITT.

Figure 5.3 presents the whole process of UITT. I find that this more general technology transfer flow could reflect a more comprehensive process of the action set of all the stakeholders. The process is presumed to start with an academic invention. Before disclosing the invention to the TTO, the faculty would like to search for potential technology buyers independently, bypassing the TTO's monitoring, because that way they can keep 100 per cent of their licensing revenue, rather than 30 per cent or so as stipulated by the university.

[19] The Section 5.3 has been accepted by journal of "Science and Public Policy" in Jan, 2015.

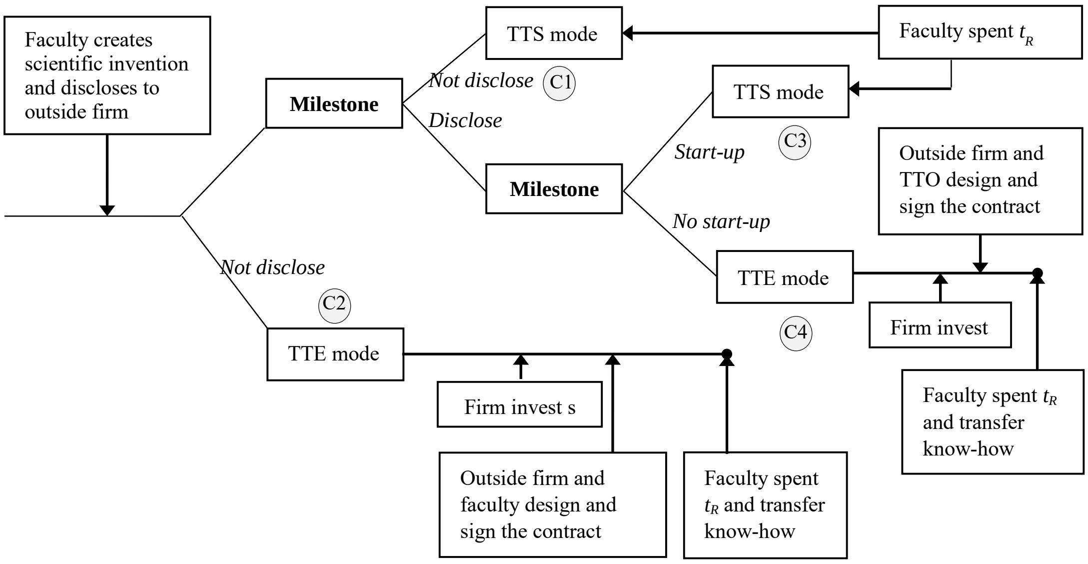

Figure 5.3 University-industry technology transfer from faculty to firm

Once the faculty invention is accepted, the firm R&D staff and faculty inventor would work together to market the invention immediately, since the successful UITT needs both the faculty effort and the firm investment (Aghion and Tirole, 1994; Dechenaux et al., 2011). The next stage of this process is based on the assumption that the firm may reject the faculty invention, perhaps due to possible legal issues, lack of trust, or low commercial value. Faculty will then have to decide between disclosing to their TTO (university assignment) and establishing a new start-up. If the faculty chooses the latter one, extra financial support (i.e. entrepreneurship capital) is needed. On the other hand, when the faculty discloses their inventions to the TTO, it can also be used to establish a new start-up, in which the faculty will act as principal or director. When the TTO applies and licenses the patent, faculty and firm have to decide on their effort and investment. Meanwhile, the TTO and firm (or start-up) will negotiate together to formulate the license contract.

Another perspective of UITT involves the distribution of licensing revenue and relevant activities of the faculty. The faculty's shared profit has two significant influences across the process of UITT: (1) an impact on the faculty's invention disclosure. According to the value of the faculty's sharing ratio stated in published university policies, the faculty can choose the preferred assignment (i.e. university assignment or non-university assignment); and (2) an impact of the faculty effort towards successful UITT. The reasonable share of licensing revenue should fully reflect on the faculty's marginal contribution. This could entice faculty to put more effort into UITT (Crama et al., 2008; Jensen et al., 2003).

5.3.2 Theoretical model

5.3.2.1 Model setup

Consider a university-based invention that will be transferred from a faculty or TTO to a firm. There are two types of commercialization mode classified by the licensee (i.e. established firm or start-up). When the faculty invention is transferred to an established firm (called the TTE mode), the faculty effort as well as the firm investment is needed to determine transfer success. On the other hand, only faculty needs to make necessary contribution, such as spending time on researching and putting in financial capital, when the specific invention is transferred to a start-up (called the TTS mode) in which the faculty is a principal and shareholder.

Many studies illustrate that university faculty mainly focuses on basic research that most of their inventions just stay at conceptual model or laboratory phase (Jensen and Thursby, 2001; Thursby and Kemp, 2002). Invention requires faculty's tacit knowledge (know-how) and further development, such as technology test and pilot run, before it can be commercialized. Therefore, I assume in TTE mode commercial knowledge transfer from inventor to licensee requires effective faculty-firm collaboration to remove barriers. The faculty effort and firm investment will determine the success rate of technology transfer (Siegel et al., 2003b). Meanwhile, in TTS mode, only faculty participates and invests in commercialization to develop their start-ups independently. In addition, I assume that faculty and firm play equal influence since their marginal contribution to the success of UITT is equal (Aghion and Tirole, 1994; Crespi et al., 2006).

In this study, the probability of successful technology transfer is given by $p(t_R, s)$, where t_R is the faculty effort and s is the firm investment. This function is partly borrowed from Dechenaux et al. (2009, 2011), but unlike them, in order to present the equivalently substitutive relationship between faculty effort and firm investment, I give a more specific functional form. I assume that,

$$p(t_R, s) = \begin{cases} p_1 = 1 - p_0 e^{-at_R - bs}, \text{ andTTE} \\ p_2 = 1 - p_0 e^{-at_R}, \text{ andTTS} \end{cases} \tag{5.9}$$

The probability $p(t_R, s)$ is an increasing function of both t_R and s, where the parameter $a \in [0,1]$ measures the importance of faculty effort to the success of UITT, while $b \in [0,1]$ measures the role of firm investment. In TTE mode, when a (or b) is equal to zero, the probability of successful UITT will depend solely on firm investment (or faculty effort). In TTS mode, a similar rule could also apply. In addition, for the given faculty effort, the success rate of UITT is larger when an established firm is involved.

The TTO owns and can exclusively license the faculty's invention to a specific firm. I assume that the TTO is of an economic orientation and will maximize its utility given by $U_T = (1 - \alpha)R - K$, where $(1 - \alpha)$ is the licensing share profit that is accrued to the TTO, where R is the licensing revenue, and K is the TTO's total search cost.

For university faculty, their participation in UITT is motivated by licensing income as well as other non-economic factors, such as entrepreneurship, reputation or research funding (Baldine and Grimald, 2005; Littunen, 2000; Thursby and Thursby, 2011). Thus, if faculty discloses their inventions to the TTO, I assume their utility function includes two parts: (1) an economic benefit in the form of a sharing ratio of licensing revenue, and (2) a noneconomic benefit when disclosing inventions to the TTO. The faculty's utility is given by $U_R = \alpha R - A_0 e^{t_R} + A_1 e^{-\gamma T}$, where α is the faculty's share of licensing revenue, $A_0 e^{t_R}$ measures faculty's time cost spent on the UITT, the parameter p is the probability of invention disclosure, and $A_1 e^{-\gamma T}$ measures the faculty's total discounted benefits until retirement as a result of invention disclosure, e.g. academic reward, peer reputation, or the title of professorship. The variable γ is the average interest rate, and T is the length of time from the year of invention disclosure to the faculty's retirement year. A_0 and A_1 are the impacts of time cost and interest rate respectively. If faculty chooses non-university assignment, their utility is $U_R = R - A_0 e^{t_R}$ since they can keep 100 percent of the licensing revenue.

The TTO offers the firm an exclusive license contract that specifies a particular type of payment. In this study, I take the royalty payment as an example, denoting the patent license contract by $O = (m, r)$. The payment term m is the upfront fee paid immediately when the firm accepts the license contract. The payment term r is the royalty fee per unit, which is a continuation payment since it is positively related to the yield of new product x. And then $R = m + rx$. Since the firm is economic driven, and its expected utility is given by the net profit. I assume the firm profit from selling the new product is equal to π, and that C_t is its total production cost. Thus, with the successful technology transfer, the expected utility of the established firm is given by $U_F = p_1(\pi - rx) - m - C_t$. Clearly, if the firm attempts to commercialize the university-based invention, the optimal level of investment should be set firstly.

5.3.2.2 Stage 1: UITT based on faculty-established firm

In this stage, once creating an invention, faculty has to make a decision whether to disclose the invention to the TTO or to an established firm directly. If the faculty chooses TTE mode first, meanwhile, for an established firm, this method of obtaining a faculty invention has a lower licensing price and transaction cost, but faces possible legal issues concerning intellectual property. Thus, when an established firm receives the invention information, they have to decide whether to buy the invention directly from the faculty or indirectly from the TTO. The utility of established firm is given by

$$U_{F11} = p_1(\pi_{11} - rx) - m - C_t - (1 - p)C_p$$

Where C_p measures the possible cost of fines due to IP legal issues and has a negative effect on the utility of established firm, while the invention disclosure rate p plays positive effect. Meanwhile, the faculty's utility is given by

$$U_{R11} = (1 - p + \alpha p)(p_1 rx + m) - A_0 e^{t_R} + pA_1 e^{-\gamma T}$$

The condition of accepting inventions is that the firm can earn positive economic profit.

Therefore, the maximum licensing price is $R_{\max} =$

$\left[(\pi_{11}+m)p_1-m-C_t-(1-p)C_p\right]/p_1$. The faculty then makes the optimal invention disclosure rate according to the given licensing price that

$$p^* = \left[(2-\alpha)C_p-(1-\alpha)(\pi_{11}p_1-C_t)+A_1e^{-\gamma T}\right]/2(1-\alpha)\,C_p.$$

At this stage, the faculty has two choices: disclosing the invention to the TTO or licensing the invention to an established firm independently bypassing the TTO's monitoring. From the above equation, the invention disclosure rate significantly increases with the faculty's share of licensing revenue. Specifically, when $p^* > 0.5$, the variable α should meet the requirement that: $\alpha \geq 1-\frac{C_p+A_1e^{-\gamma T}}{\pi_{11}p_1-C_t}=\alpha^*$. This indicates that only if the faculty's share of licensing revenue is larger than the lower boundary α^* does the faculty have enough incentive to disclose the invention to the TTO. Further, the faculty's willingness of invention disclosure depends on the noneconomic benefit and parameters related to the firm. The higher the noneconomic benefit, the smaller the boundary of faculty share profit.

Proposition 5.1 (GM): The probability of successful UITT plays negative role on the invention disclosure rate, but positive role on the licensing price.

Proposition 5.1 shows that faculty prefer to keep inventions that are easy to market, rather than disclose them to the TTO. However, for inventions that are difficult to commercialize, such as basic research or conceptual innovations, faculty first disclose them and prefer to transfer them to established firms. This theoretical result is in line with the empirical conclusion of Thursby et al. (2009) which the faculty discloses applied inventions with higher success rate to non-university assignment. On the other hand, for a given faculty invention, if it is easy to transfer and commercialize, firms do not need to invest much further research funding for technology development. Thus, the licensing price of an invention increases with the success rate of UITT.

Proposition 5.2 (GM): The faculty's share of licensing revenue is positively related to the invention disclosure rate and licensing price.

From policy perspective, the faculty's share of licensing revenue is one of the most important policies for TTO and faculty. A higher faculty's share of licensing revenue significantly increases faculty's expected utility, which automatically pushes up the invention disclosure rate. Many studies (e.g. Crespi et al., 2006; Thursby et al., 2009) have also tested this proposition. Meanwhile, due to an increase in invention disclosure rate, the interested firm has to negotiate with the TTO, which has higher bargaining power, and this increases the licensing price directly. In addition, the higher faculty's share of licensing revenue will possibly indirectly increases the licensing price because the TTO attempts to maximize its profit by passing on the increasing faculty's share to licensee.

Proposition 5.3 (GM): The invention disclosure rate is positively related to the noneconomic benefit.

Proposition 5.3 indicates that future noneconomic benefit, such as professorship and peer reputation, has significantly positive impacts on faculty's willingness to disclose inventions to the TTO. Siegel's (2003a) research also demonstrates that disclosing a patent is an effective way to get professor tenure and develop personal academic position. In addition, noneconomic benefit is positively related to work time. This is especially true for younger researchers as they have no motivation to adopt speculative behaviour. The more patents a faculty has disclosed, the richer their future benefits will be.

5.3.2.3 Stage 2: UITT based on faculty-TTO-firm

If the established firm rejects the invention, the faculty has three choices: (1) disclosing it to the TTO and taking part in UITT involving an established firm, (2) establishing a start-up with invention disclosure, and (3) establishing a start-up without invention disclosure. In this stage, the process of UITT possibly involves three stakeholders, i.e. faculty, TTO, and firm. I assume that the TTO offers a take-it-or-leave-it license contract to the firm. In order to simplify the model, I consider the invention disclosure rate p in this stage as a dichotomous variable when the faculty discloses the invention to the TTO (coded as "1"), and does not disclose the invention (coded as "0"). In order to analyse each commercialization mode (i.e. TTE or TTS mode), this section will develop different theoretical models respectively based on the three choices in the following section.

(1) TTE mode (Transfer technology to established firm)

In TTE mode, when the faculty discloses the invention to the TTO, the TTO will first provide a license contract with (m, r) to the firm and restate α as the faculty's share of licensing revenue. If the firm rejects the license contract, the bargaining game is over and the TTO will continue to search for another potential licensee. If the firm accepts the license contract, it has to pay the upfront fee m immediately and invests s for further technology development; it must also pay a royalty fee r per unit when manufacturing patent-based product. At the same time, the faculty should put effort t_R into UITT.

In this commercialization mode, the firm's expected utility is given by $U_{F21}(s) = p_1(\pi_{21} - rx_{21}) - s - m - C_t$, the faculty's expected utility is given by $U_{R21}(t_R) = \alpha(rp_1x_{21} + m) - A_0e^{t_R} + A_1e^{-\gamma T}$, and the TTO's expected utility is given by $U_{T21}(m, r) = (1 - \alpha)(rp_1x_{21} + m) - K$. The TTO's objective is to maximize its utility, so it is always motivated to participate and operate the process of UITT. For established firm and faculty, their pre-condition for taking part in UITT is that: $U_{F21} > 0$, $U_{R21} > \alpha m + A_1e^{-rT}$. I consider that the success rate of UITT depends on t_R and s in TTE mode, and that the faculty makes an effort t_R only after the established firm has invested s. Therefore, in order to solve this game model, I employ the backward induction method.

First, the optimal faculty effort t_R^{21} follows the equation that $U'_{R21}(t_R) = 0$, and then I have $t_R^{21} = \frac{1}{a+1}\mathrm{Ln}\left(\frac{ap_0\alpha rx_{21}e^{-bs}}{A_0}\right)$, which also meets the requirement $U_{R21}(t_R^{21}) > m + A_1e^{-\gamma T}$. Thus, it can be found that the influence of firm investment s on faculty effort depends on faculty characteristics A_0, as well as product yield x_{21}. A larger yield will raise the faculty's expected utility because royalty payments are used. After estimating the faculty effort, the optimal firm investment s^{21} can be calculated by the theoretical model $\max U_{F21} = p_1(\pi - rx_{21}) - s - m - C_t$. Then the optimal firm investment is $s^{21} = \frac{a+1}{b}\ln\frac{bp_0(\pi - rx_{21})}{a+1} + \frac{a}{b}\ln\frac{A_0}{ap_0\alpha rx_{21}}$. Considering s^{21}, I know that the optimal faculty effort is $t_R^{21} = \ln\frac{(a+1)a\alpha rx_{21}}{A_0b(\pi - rx_{21})}$.

Successful UITT needs cooperation from the faculty and the firm (Siegel et al., 2003a). When their information and action set are perfectly information symmetrical, the "lazy behaviour" of any of players will lead to moral hazard and unsuccessful technology transfer because an incomplete license contract has to be fulfilled. For example, when there is little expected future profit of UITT in TTE mode, it is easy for the faculty to move his attention to other research projects, resulting in the moral hazard of the faculty. Once the firm observes this moral hazard, little investment will be input, and then the faculty will put less effort into the UITT as a result. This self-reaction chain finally leads to the failure of the UITT. In particular, when t_R (or s) is equal to zero, the firm investment (or faculty effort) will drop to zero as well. This is termed a "No-cooperation Nash Equilibrium" in TTE mode.

In order to control the moral hazard, the TTO, acting as the intermediary between faculty and established firm, has to design a reasonable license contract and faculty's share rate to make sure that both sides make a satisfactory effort (or investment). Especially, giving the faculty further profit, not limited to the faculty's share of royalty fees as described in this study, but including equity share rate, milestone payment, and annual payment. Another issue is that if the TTO wishes to keep a fixed organizational profit, the higher licensing price increases the marginal cost of established firm, which is also not beneficial for the successful UITT. Therefore, although the non-cooperation equilibrium does not exist, and stable equilibrium with positive t_R and s always exists, it is crucial for the TTO to balance its economic orientation and the social welfare.

For the given faculty effort and firm investment, the optimization model of TTO is as follows,

$$\max_{\alpha,r} U_{T21} = (1-\alpha)\left[p_1\big(t_R(\alpha,r), s(\alpha,r)\big) r x_{21} + m\right] - K$$

$$\text{S.T. } t_R = t_R^{21}, s = s^{21}, \alpha > 0, r > 0$$

Proposition 5.4 (GM): In TTE mode, there has:

(1) The faculty's share of licensing revenue is positively related to the faculty effort, and,

(2) The influence of royalty fee per unit on faculty effort, firm investment and the success

rate of technology transfer will all depend on a particular point: when $r \leq \frac{ab\pi}{(a+1)x} = r_0$, they all increase with royalty fee per unit; however, when $r > r_0$, the opposite trend occurs.

In the supplementary proofs, Proposition 5.4 shows that in TTE mode, although an increase in faculty's share of licensing revenue will decrease TTO's economic profit, it significantly encourages the faculty to put more effort, and then indirectly increases firm investment. Thus, a higher faculty share rate could remit all stakeholders' moral hazard and increase the success rate of UITT. Specifically, moral hazard will vanish from the UITT process when α is equal to one. Considering Propositions 5.2 and 5.4, they indicate that increasing the faculty's share of licensing revenue has two important roles: promoting the invention disclosure and increasing the faculty effort. From the policy perspective, ceteris paribus, i.e. setting a higher faculty share of licensing revenue is an effective way of promoting the university technology spillovers with TTO involvement.

When royalty fee per unit is smaller than the particular point r_0, an increase in royalty fees by TTO could encourage faculty to make more contribution to UITT as a result of higher future expected profit, and could also offset the firm's losses because of a higher success rate. However, when the royalty fee per unit is larger than r_0, increasing royalty fees would rapidly reduce the product yield due to the decreasing profit margin, thereby reducing the total licensing revenue as well. In addition, if the firm is risk-averse, higher royalty fees also decrease its investment. Therefore, the TTO has to design an optimal license contract in which the maximum royalty fee per unit is r_0.

Proposition 5.5 (GM): When the royalty fee per unit is smaller than r_0, the optimal license contract $(\alpha(t_R^{21}, s^{21}), \min\{r(t_R^{21}, s^{21}), r^0\})$ will be obtained in order to maximize the TTO's utility.

As detailed in the supplementary proofs, the royalty fee has a negative effect on product marginal profit, over-priced patents ($r > r_0$) will damage all stakeholders' utility. Proposition 5.5 suggests that the royalty fee per unit should be at an appropriate level, and its optimal value is regarded as the function of faculty effort, firm investment, and yield.

Combining Proposition 5.4 and 5.5, they indicate that increasing faculty's share of licensing revenue or royalty fee (less than r_0) has the same incentive effect of promoting the UITT. For the TTO and university policy makers, they have to coordinate these two incentive conduits through setting the value of α, r and m. In the real word, in a specific university license contract, the proportion of royalty payment always keep at a reasonable level, in most instances, less than 50 per cent of the total licensing price (Crama et al., 2008).

(2) TTS mode (Transfer technology to start-up)

The faculty, through entrepreneurship capital or financial support (e.g. angel investment, venture capital), can establish a new start-up independently before/after invention disclosure to the TTO. In this commercialization mode, the TTO just record the invention as an achievement without any search services provided. In TTS mode, the faculty and their own start-up have the same economic target and less conflict of interest. However, there is a possible adverse selection behaviour in that faculty do not intend to disclose high commercial value inventions to the TTO before establishing the new start-up. In this mode, first, for a given faculty's share of licensing revenue α stated in the university policies, if the faculty does not disclose the invention, it is game over. If the faculty discloses the invention, then the TTO provides patent license contract $O(m, r)$. Second, when the faculty rejects the contract, the venture is over, unless the faculty makes the decision as to whether it is worthwhile establishing the new start-up or not.

In TTS mode, I recognize that the faculty will definitely take part in UITT since they could be one of the principals or directors of the new start-up. And the success rate of technology transfer only depends on faculty efforts while $p_2 = 1 - p_0 e^{-at_R}$. Thus, the expected utility of faculty in TTS mode is as below,

$$\begin{gathered} U_{R22} = p[\alpha(p_2 r x_{22} + m) + \sigma(p_2 \pi_{22} - r x_{22} - m - C_t) + A_1 e^{-\gamma T}] \\ + \sigma(1-p)(p_2 \pi_{22} - C_t) - A_0 e^{t_R} \end{gathered}$$

The variable p ($p = 0$ or 1) describes the faculty's invention disclosure. The variable σ measures the faculty's initial entrepreneurship capital for establishing the new start-up. Thus, the optimal faculty effort is equal to $t_R^{22} = \frac{1}{2}\text{Ln}\left(\frac{pa\alpha r x_{22} p_0 + \sigma a \pi_{22} p_0}{A_0}\right)$ $(p = 0 \text{ or } 1)$ when $U'_{R22}(t_R) = 0$. Meanwhile, the sufficient but unnecessary condition that the faculty discloses the invention to the TTO is $t_R > \frac{1}{a}\text{Ln}\left(\frac{a\alpha r x_{22} p_0}{A_1 e^{-\gamma T} - (\sigma - \alpha)(r x_{22} + m)}\right) = t_R^0$, where t_R^0 is a particular point of faculty effort. Therefore, I can conclude the following propositions.

Proposition 5.6 (GM): In TTS mode, the relationship among the faculty effort, the faculty's share of licensing revenue and the royalty fee per unit is as follows.
(1) When $t_R \in [0, t_R^0)$ and $A_1 e^{-\gamma T} - (\sigma - \alpha)(r x_{22} + m) > 0$, the faculty will not disclose invention to the TTO, and the optimal faculty effort is $t_R^* = \min\{t_R^0, t_R^{22}(p = 0)\}$,
(2) When $t_R \in [t_R^0, +\infty)$ and $A_1 e^{-\gamma T} - (\sigma - \alpha)(r x_{22} + m) > 0$, the faculty discloses invention to the TTO, and the optimal faculty effort is $t_R^* = \max\{t_R^0, t_R^{22}(p = 1)\}$, and,
(3) When $A_1 e^{-\gamma T} - (\sigma - \alpha)(r x_{22} + m) < 0$, the faculty optimal effort is $t_R^* = t_R^{22}$.

In the supplementary proofs, Proposition 5.6 has two implications: first, disclosing inventions to the TTO should meet external requirement (i.e. the noneconomic benefit is larger than the added benefit resulting from bypassing the TTO's monitoring), and internal requirement (i.e. the faculty can provide effort which is larger than t_R^0); second, when the noneconomic benefit becomes less, the influence of t_R^0 will disappear. For the faculty with less initial entrepreneurship capital, two possible reasons will cause the adverse selection behaviour: (1) the faculty would like to keep 100 per cent of the economic profit; and (2) the faculty does not have enough time to take part in UITT.

According to the result of Proposition 5.6, from the policy perspective, the TTO should enhance its invention reporting system that requires all faculties to disclose all their inventions. In addition, the university and government should provide enough financial support for faculty entrepreneurial activities since there exists a substitute relationship between invention disclosure rate and initial entrepreneurship capital.

When the faculty discloses the invention to the TTO, the optimization model of TTO is as follows,

$$\max_{\alpha,r} U_{T22} = (1-\alpha)\left[p_2\left(t_R(\alpha,r)\right)rx_{22} + m\right]$$

$$\text{S.T. } t_R = t_R^*(\alpha,r), \alpha > 0, r > 0$$

Proposition 5.7 (GM): In TTS mode, the TTO's utility is a concave function, and has a maximum value at the boundary point. The optimal faculty share profit is $\max\left\{\alpha(t_R^*), \sigma - \frac{A_1e^{-\gamma T}}{rx_{22}+m}\right\}$, and the optimal royalty fee per unit is $r(\alpha^*)$.

As highlighted in the supplementary proofs, compared with the TTE mode, the result of Proposition 5.7 shows that the TTO's optimal strategy of licensing revenue distribution relates not only to the faculty's effort, but also to the initial entrepreneurship capital and noneconomic benefits. Then its licensing strategy mainly depends on the revenue management. Proposition 5.7 also indicates that licensing price increases with the faculty's share of licensing revenue. Therefore, in TTS mode, the TTO cannot increase the faculty share quickly in order to keep the royalty fees at an acceptable level, which could protect faculty entrepreneurship and save their expenditure.

(3) Invention disclosure and commercialization mode selection

a) Invention disclosure decision

As shown in Figure 5.3, the faculty has to make a disclosure decision after considering the influence of the faculty's share of licensing revenue, initial entrepreneurship capital and time cost. The precondition of invention disclosure is given by,

$$A_1e^{-rT} + \alpha(p_2rx_{22} + m) + \sigma(p_2\pi_2 - rx_{22} - m - C_t) > \sigma(p_2\pi_2 - C_t)$$

Thus, the sufficient but unnecessary condition of invention disclosure is $\sigma \le \min\{\alpha p_2\}$ and $t_R > t_R^0$. This indicates that only when faculty's initial entrepreneurship capital is less than the minimum expected return rate, and they have enough time to participate in UITT, will they disclose their inventions to the TTO.

b) Commercialization mode selection (TTE or TTS)

Once the faculty discloses the university-based invention to the TTO, the invention ownership is shifted to the university administration according to the “Bayh-Dole Acts” and university employment contract. However, the faculty as inventor still plays a significant role in commercialization mode selection due to their irreplaceable role. Therefore, only after faculty chooses the TTE mode, will the TTO continue to search for potential interested firms.

The expected utility gap of faculty is given by

$$\Omega = U_{R21} - U_{R22} = \alpha r(p_1 x_{21} - p_2 x_{22}) - \sigma(p_2 \pi_{22} - r x_{22} - m - C_t)$$

It shows whether the faculty establishes the new start-up ($\Omega < 0$) depends on the TTO’s royalty fees. Specifically, when $r > \frac{\sigma(p_2\pi_{22} - m - C_t)}{\alpha(p_1 x_{21} - p_2 x_{22} + x_{22})}$, the new start-up based on the faculty invention has less advantage as a result of smaller marginal profit, thus transferring the specific invention to an established firm is a better choice. The results also indicate that high initial entrepreneurship capital promotes the emerging of start-up before/after the invention disclosure. It is noted that an important difference is that faculty who establishes start-up without invention disclosure normally has more sufficient entrepreneurship capital than those who discloses patents and then establishes start-ups.

In order to promote the university knowledge spillovers and bring university-based invention to market, the TTO is always motivated to facilitate UITT development. The expected utility gap of the TTO is given by,

$$\Psi = r(1-\alpha)(p_1 x_{21} - p_2 x_{22}) - K$$

When the firm investment meets $s \geq -\frac{1}{b}\mathrm{Ln}[\frac{x_2}{x_1} - \frac{e^{at_R}}{x_1}\left(\frac{K}{p_0 r(1-\alpha)} - \frac{x_1 - x_2}{p_0}\right)] = s_0$, Ψ is larger than zero, indicating that the TTO will choose TTE mode. In the real word, if the established firm wants to get a specific invention license, an effective way is to send a signal that its further investment is larger($s \geq s_0$), or to inject research funding to participate in university R&D activities.

Proposition 5.8 (GM): The precondition of the TTE and TTS modes before/after invention disclosure in the whole process of transferring university invention from the faculty to the firm is shown in Table 5.8.

Table 5.8 Precondition of TTE and TTS mode in UITT

	Decision	Conditions of mode selections	Index
Before invention disclosure	TTS mode	$\sigma \geq \max\left\{\alpha p_{min}, \frac{p_1(rx+m)-A_0 e^{t_R}}{p_2\pi_2-C_t}\right\}$ or $t_R \leq t_R^0$	C1
	TTE mode	$\alpha \leq 1-\frac{C_p+A_1 e^{-\gamma T}}{\pi_{11}p_1-C_t}$, $\sigma \leq \frac{p_1(rx+m)-A_0 e^{t_R}}{p_2\pi_2-C_t}$	C2
After invention disclosure	TTS mode	$r \leq \frac{\sigma(p_2\pi_{22}-m-C_t)}{\alpha(p_1x_{21}-p_2x_{22}+x_{22})}$, $\sigma \leq \alpha p_{min}$ and $t_R \geq t_R^0$	C3
	TTE mode	$s \geq -\frac{1}{b}\mathrm{Ln}[\frac{x_2}{x_1}-\frac{e^{at_R}}{x_1}\left(\frac{K}{p_0 r(1-\alpha)}-\frac{x_1-x_2}{p_0}\right)]$	C4

Proposition 5.8 gives the precondition of each commercialization mode showing in Figure 5.3. Development of TTS mode mainly depends on the faculty's initial entrepreneurship capital, research time and royalty fee per unit. Especially, the difference in "C1" and "C3" indicates higher licensing fees would drive the faculty to choose TTS mode without invention disclosure, which adds to the understanding of the relationship between licensing price and invention disclosure decision. The faculty's share of licensing revenue plays a crucial impact in the mode selection between "C2" and "C3". Compared with the other three conditions, "C4" indicates that the faculty would disclose invention and collaborate with the established firm only if firm investment is sufficient (larger than s_0).

5.3.3 Research design

In the context of theoretical analysis, it shows that invention disclosure rate mainly depends on economic and non-economic factors. Specifically, according to Proposition 5.1, the likelihood of faculty disclosing an invention to the TTO decreases with the commercial value and the ease with which it can be transferred. In addition, Proposition 5.2 illustrates that the faculty's share of licensing revenue is positively related to invention disclosure rate and licensing price. Finally, Proposition 5.3 provides an explanation that the motivation for invention disclosure comes partly from the non-economic benefit provided (e.g. professor title, peer reputation or academic reward). Meanwhile, it is also reasonable to infer that younger faculty has higher disclosure desire even though they have fewer inventions than older faculty.

In order to re-examine the above propositions through empirical evidence, I established a special dataset based on 35 top patent-application Chinese universities. This section presents the data source and descriptive statistics, followed by consideration of the influencing factors, i.e. licensing price, the faculty's share of royalty/equity revenue, professorship, and faculty age.

5.3.3.1 Dependent and independent variables

In this study, I correlated the faculty decision of invention disclosure to patent claims, university policies and non-economic factors. The dependent variable "invention disclosure" is a dichotomous variable when faculty discloses the invention to the TTO (coded as "1") or not (coded as "0") in a given university in a given year. In addition, "average invention disclosure rate" as an alternative dependent variable was employed to examine the influence of licensing price at university level.

In order to measure the invention value, the variables "patent claim" and "average licensing price" (Thousand RMB) are considered as two of the most representative indicators (Ho et al., 2013; Thursby et al., 2009). Thus, in this section, I use the number of patent claims as measures of invention value that is also the approach employed in Thursby's research. Meanwhile, I use the average licensing price to indicate the invention's real commercial value.

In order to find out the relationship between the faculty's share of licensing revenue and invention disclosure rate, I examined the faculty's share of royalties and equity fee, respectively. The faculty whose technologies are licensed by the TTO could receive royalty revenues based on a specific rate stated in public policies. The royalty rate may be a fixed sum, or perhaps a decreasing function of total licensing fees. Under most circumstances, the faculty's share of royalties is affected by the yield of new products, thus the faculty cannot be sure of the exact share of royalties that they will receive. Therefore, like Gregorio and

Shane (2003), I used the "minimum faculty's share of royalty" as an independent variable. Meanwhile, I also used the "minimum faculty's share of equity" to re-examine the influence of universities policy of revenue management.

In order to measure the influence of non-economic factors, first I used a static indicator variable "faculty position" to control the impact of professorship in every year. Next, I used the "length of time as professor" as an alternative measure. This variable is equal to patent application year minus the year when the faculty got the professor title. By doing this, I can find differences in invention disclosure with different faculty academic position. Meanwhile, I use the variable of "length of remaining work time" to examine the influence of faculty age. Table 5.9 presents the summary statistics for all variables included in this section.

Table 5.9 Descriptive statistics for all independent variables

Variable	No. Obs.	Mean	Std. Dev.	Minimum	Maximum
Average invention disclosure rate	350.000	0.868	0.777	0.590	1.000
Average license price (thousand RMB)	350.000	289.860	482.361	0.000	4575.000
Patent assignment	18435.000	0.868	0.338	0.000	1.000
Patent claim	18435.000	5.117	6.328	1.000	106.000
Minimum inventor share of royalty	18435.000	0.356	0.183	0.200	0.800
Minimum inventor share of equity	18435.000	0.309	0.136	0.200	0.700
Faculty position (professorship)	18435.000	0.890	0.338	0.000	1.000
Length of time as professor	18435.000	6.027	5.271	-10.000*	57.000
Length of remaining work time	18435.000	14.342	6.660	-27.000**	34.000

* The value of this variable is the time gap between patent application year and the year when faculty awards professorship. ** In this section, I recognize faculty's retirement age is 60 years old, the negative length of rest work time means faculty still works as a professor in university after retirement.

5.3.3.2 Empirical model and analysis approach

To examine the relative impact on invention disclosure, I developed two separate regression models while treating the disclosure decision as the function of licensing price, patent claims and the faculty's share of licensing revenues. First, in order to explore the relationship between disclosure rate and licensing price, the average licensing price per patent and average disclosure rate of the 35 Chinese universities during the period from 2002 to 2012 were collated, and the linear regression model was employed. Second, I investigated the influence of the faculty's share of licensing revenue on the individual's decision, for a given invention disclosure. In most circumstances, two types of faculty share rate are considered in relation to the random yield or licensing price, so I used the "minimum faculty's share of royalty/equity" instead of other unobservable data. Finally, I considered the role of non-economic factors, such as professorship and the length of the remaining work time on invention disclosure.

For the analysis approach, two types of analysis method were used in this section due to the characteristic of dependent variable. From the perspective of the university organization level, simple linear regression was employed to explore the correlation between average disclosure rate and patent licensing price since only one independent variable was considered. Meanwhile, in most previous studies, the binary logistic regression model was considered as the most appropriate technique for dichotomous value variables (Fini et al., 2010; Fuller, 2008; Thursby et al., 2009). Therefore, in this study, the binary logistic regression model was used to find the correlation between the invention disclosure and the faculty's share of licensing revenue, between invention disclosure and noneconomic profit, since the faculty's decision of invention disclosure at individual level is a dichotomous variable.

5.3.4 Empirical result

5.3.4.1 Impact of economic factors from university/faculty level

Table 5.10 presents clearly the impact of economic factors on invention disclosure from university/faculty level. In this table, "Average licensing price" and "Patent claim" are used as a pair of alternative variable examining the influence of invention value from a different perspective. "Minimum faculty's share of equity" is also adopted to re-examine the influence of faculty's share of royalty for robust test. In summary, the results illustrate that invention value and university policies all have significant impacts on invention disclosure decisions.

First, as shown in Table 5.10, “Average licensing price per patent” is negatively related to invention disclosure at the significance level of 10 percent. It shows that an invention with higher commercial value is less likely to be disclosed to the TTO by faculty and partly proves the theoretical result of Proposition 5.8. This result is in line with previous studies’ results (e.g. Jensen et al., 2003; Markman et al., 2007). However, I find “Patent claim” plays a weak positive influence on faculty’s disclosure decision at the significance level of 1 percent. Considering the opposing influence of these two variables, I reckon that an invention disclosed to the TTO by faculties normally developed from their basic research, which could be authorized to have more claims to establish a wider technology scope. In addition, when faculty chooses non-university assignment, they have to negotiate with assignees on the issue of protection scope, in order to ensure that their future studies will not infringe the assignees’ licenses and reserve the right to apply for related patents.

At the individual faculty level, the findings suggest two sets of university policies - faculty’s share of royalty and equity appear to influence invention disclosure significantly, proving Propositions 5.2 and 5.4. The coefficients on the minimum faculty’s share of royalty/equity are positively significant at 1 percent level. These imply that increasing faculty’s share of royalty/equity per unit leads to invention disclosure increases of 0.384 and 1.262 respectively. Table 5.10 also suggests that equity payment has a stronger impact since it plays little influence on the marginal profit of new products. However, as shown in Propositions 5.4, 5.6 and 5.8, the optimal royalty fee per unit partly depends on the yield of new products and firm profit.

Table 5.10 Regression of faculty invention disclosure rate

Variable	**University level**		**Faculty level**	
	Coef.	**95% Conf. Interval**	**Coef.**	**95% Conf. Interval**
Average price per patent	-1.478^{*}	[-2.990, 0.033]		
Patent claim			0.038^{***}	[0.028, 0.047]
Minimum inventor share of royalty			0.384^{***}	[0.225, 0.543]
Minimum inventor share of equity			1.262^{***}	[0.797, 1.728]
No. Obs.		350		18435

*** Level of significance: 1%. ** Level of significance: 5%. * Level of significance: 10%.

5.3.4.2 Impact of noneconomic factors

To examine the role of non-economic factors, the influence of faculty academic position (i.e. professor, associate professor or lecturer and length of time as professor) and the length of remaining work time were tested in Table 5.11. First, though the coefficient of faculty academic position is negative (-0.036), it has little bearing on invention disclosure decision. When employing the “Length of time as professor” as an alternative measure, its coefficient (0.028) is weakly positive at the significance level of 1 percent. This result implies that faculty’s invention disclosure decision increases slightly with their professor tenure. This empirical evidence also proves Propositions 5.4 and 5.6 that professor could provide more efforts for the UITT because of their richer research experience.

In addition, Table 5.11 suggests the “Length of remaining work time” plays weakly positive on invention disclosure at the significance of 1 percent level. This variable represents the importance of further payoff because of invention disclosure (i.e. academic reward, peer reputation, even including professorship). The result indicates that younger faculty has more willingness to disclose inventions to the TTO than older ones, which also supports the conclusion stated in Proposition 5.3.

Table 5.11 Regression of non-economic factors

Variable	Coef.	95% Conf. Interval
Faculty position	-0.036	[-0.203, 0.130]
Length of time as professor	0.028^{***}	[0.016, 0,040]
Length of remaining work time	0.013^{***}	[0.006, 0.021]
No. Obs.	18435	

*** Level of significance: 1%. ** Level of significance: 5%. * Level of significance: 10%.

5.3.5 Model discussion

Despite the existing research on technology transfer and university entrepreneurship, invention disclosure and related specific commercialization mode need more attention in a more comprehensive UITT process from faculty to firm. The theoretical model has offered several propositions, given the pre-condition of commercialization mode selection and provided optimal solution (faculty’s share of licensing revenue and royalty fee per unit) for the TTO. The empirical evidence has demonstrated the influence of economic/non-economic factors, and proved some of the theoretical propositions. In order to discuss and generalize this research, this section provides more arguments based on these three reality questions.

(1) What is the optimal choice for a faculty: TTE mode or TTS mode?

In the overall process of UITT, the faculty has to make two important decisions: (1) whether to disclose the invention to the TTO; and, (2) whether or not to establish a start-up based on their own invention. Compared with previous theoretical studies (e.g. Aghion and Tirole, 1994; Crama et al., 2008; Dechenaux et al., 2009, 2011), this study has offered a more comprehensive understanding of the process of UITT. First, the faculty has two opportunities to choose the TTE or TTS mode before and after disclosing their invention. As shown in Proposition 5.8, if the faculty's share of licensing revenue stays at a considerably low level, the faculty would choose TTE mode directly without invention disclosure and contingent payment to their universities. Next, faculty would like to disclose their patent to the TTO if they have less entrepreneurship capital or required effort, rather than establish a faculty-run new start-up. In addition, once the invention ownership has been shifted to the TTO, the faculty's decision of commercialization mode selection depends on the licensing price. A higher licensing price is easy to hurt faculty entrepreneurship, as they are usually cash-constrained. Lastly, if faculty discloses invention and chooses TTE mode, they have to enter incomplete license contracts with their licensees. In order to avoid possible moral hazard, the TTO has to follow the solution provided by Propositions 5.5 and 5.7.

(2) How does the TTO set the right licensing price and manage the licensing revenue?

From the TTO perspective, the theoretical results indicate that the TTO could always set optimal faculty's share of licensing revenue and license contracts (See Propositions 5.5 and 5.7). Specifically, proved by previous studies (e.g. Crespi et al., 2006; Friedman et al., 2003; Siegel et al., 2003a, b), there is a widespread view that an increase in faculty's share of licensing revenue could increase faculty effort. However, similar effect for invention disclosure only holds up when ceteris paribus. Until now, few studies have paid attention to the mediating effect among faculty's share of licensing revenue, licensing price and invention disclosure decision. In this study, combining the theoretical results and empirical evidence, I find that an increase in the faculty's share of licensing revenue can directly improve invention disclosure (Proposition 5.2), which also leads to a higher licensing price, but decreases the invention disclosure rate (Table 5.10). Therefore, it is hard to define the favourable revenue policy for faculty in order to increase invention disclosure rate definitely.

In the TTE mode, the optimal royalty fee per unit mainly depends on faculty's effort and firm investment (Proposition 5.5), while in the TTS mode, it only relates to the faculty's share of licensing revenue (Proposition 5.7). Therefore, at the stage of commercialization mode selection with the involvement of the TTO, the TTO could affect faculty's entrepreneurship willingness through setting different levels of licensing price. When the royalty fee per unit or firm investment cannot meet the requirements showing in Table 5.8, there is an area of disagreement about mode selection. The final commercialization mode (TTE or TTS mode) will depend on the negotiation result between the faculty and TTO. In this scenario, the TTO needs more power to act as an intermediary agent.

(3) What is the influence of professorship and faculty age?

In this research, non-economic impact factors, namely professorship, length of time as professor and length of remaining work time, have significant influence on invention disclosure. First, even though many studies of faculty invention disclosure have shown that disclosing and assigning patents to the TTO is one of the most effective ways to achieve the rank of professor (Jason and Walter, 2001; Siegel et al., 2003b). I add to the understanding that experienced professor is more likely to disclose inventions to the TTO since they can be provided with more required effort. As for the influence of faculty age, younger faculty prefers to choose invention disclosure. It is because the opportunity cost of breaking those rules is more severe than their further payoff in the long term. Therefore, younger faculty is more willing to follow their employment contracts and observe their university invention reporting systems. Combining these two findings, I can infer that older professor is more reluctant to disclose inventions to the TTO. This is a significant implication, suggesting that the TTO should pay more attention to older professors' invention disclosure behaviour in order to safeguard the university's interest.

5.4 Investigation of patent checking on faculty behaviour

5.4.1 The effect of patent checking on faculty behaviour

In the process of university-industry technology transfer, the TTO, as the intermediary organization between faculty inventor and enterprise, has two significant roles including checking the quality of faculty patents and licensing patents to enterprises. In this part, I attempt to analyse how a TTO's patent evaluation strategy may affect faculty's willingness to disclose inventions to the university. The TTO receives inventions from faculty inventors and then must decide whether to check their quality. Checking the invention quality and only licensing high-value patents to enterprises could establish a better reputation and allow the TTO to sell patent at a higher price. Siegel et al. (2003b) pointed out that the university TTO has to do the patent evaluation by checking the faculty invention's commercial value and choosing the appropriate way to protect faculty's idea after interviewing faculty inventors, TTO staff and enterprises. Macho-Stadler et al. (1996) also tested this opinion and found that the TTO's patent checking strategy was influenced by long-term and short-term profit of patent licensing revenue. Patent evaluation is beneficial to a TTO's reputation and long-term interest.

However, faculty inventors disclose their patents to the TTO only when they believe their patent can be licensed to enterprises successfully at a reasonable price. If their inventions are shelved by the TTO because of reasonable or unreasonable reasons, it will decrease their willingness to continue to disclose inventions in the future. From this point of view, patent checking means some of inventions they disclosed have a low probability of being patented and licensed to enterprises. Because of this, university faculty inventors may disclose fewer inventions to the university TTOs (Humberstone, 2009; Thursby et al., 2002).

This section attempts to solve three key research questions: First, under what conditions will a TTO select and check faculty patent effectively? Second, what is the influence on faculty invention disclosure when the TTO checks the patent quality? And, third, how does the TTO decide the matched patent licensing strategy. The answers to these questions will be beneficial in identifying whether a TTO should evaluate an invention before patent application since Chinese universities always apply for patents before conducting an evaluation.

In this section, a theoretical model related to faculty invention disclosure, TTO patent checking and licensing was generated. Each faculty inventor has only one invention in one period and must decide whether to disclose the invention to TTO or establish start-up based on this invention. Once faculty discloses an invention, the TTO must make a decision whether to check its quality and license the invention to an outside enterprise or just shelve the invention. It is noted that the licensees also have no information about the invention's true value until the patent is put into use. That means they must rely on the TTO's judgement about invention quality. This assumption is also in line with Macho-Stadler et al. (1996).

Once the licensees accept the invention, they have to pay the licensing fee and invest the adoption fee continually. In this stage, there are two possible scenarios. First, if low value inventions have a greater value than adoption cost, there is no need for the TTO to check each invention's quality. In this situation, there is an extra payment because invention checking cannot compensate the loss of shelved inventions.

Second, if the low value invention has a lower profit than the adoption cost, the TTO should check the quality of faculty invention and only license those with high value. In this scenario, the TTO has two licensing strategies to deal with checked and unchecked inventions. First, the TTO can only license checked inventions with high value. This strategy leads to the outcome that high value inventions are checked but low value inventions will not be checked and will be shelved. It decreases the faculty willingness of invention disclosure. Second, the TTO could only shelve the low value patent if it is discovered in the checking process. In this situation, all checked inventions with high value will be licensed to enterprises and part or all unchecked faculty inventions also have opportunity to be brought into the technology market. This increases the expected value of disclosure and leads to a greater level of disclosure.

If the TTO decides to check the quality of the faculty invention, there exist two significant factors. The first factor is the checking rate which depends on TTO's checking cost. The other factor is the checking standard which is a critical value point. In many previous studies, such as Humberstone (2009), the average value of the faculty invention was based on the historical record as the checking standard. Through invention checking, any invention with a higher than average value will be held, and the rest will be shelved.

From an efficiency perspective, the TTO's invention checking process has two advantages. First, for a given level of faculty invention disclosure, it can avoid licensing low value inventions and improve the success rate per invention that is disclosed to university. Second, university faculty may want to make more high value inventions after observing the success of licensed inventions. A good example is that the TTO cannot license any invention to an enterprise if the average value is less than the adoption cost. In this scenario, the faculty will not disclose any invention from an economic standpoint. In contrast, if the TTO checks the quality of faculty inventions, it will increase the expected payoff of disclosure invention, and it also indirectly lead to an increase in faculty invention disclosure. Further, because the checking activities require a lot of time and human resources, it is impossible for the TTO staff to check each invention case by case. The alternative way is randomly choosing part of faculty inventions and then checking their quality. Thus, the TTO's checking decisions also decrease with the checking costs.

The following section will focus on when the TTO should check the quality of faculty disclosed inventions, what proportion of faculty invention will be chosen to check their quality, and which licensing strategy should be adopted to maximize the TTO's profit. The next section also analyses the effect of checking policy on faculty's invention disclosure. More specifically, its negative effect would decrease the number of disclosed inventions because faculty would be afraid that their invention may be shelved rather than licensed. Shelving reduces the expected value of disclosing inventions to the TTO. On the other hand, if the TTO does not check the invention quality, this also may lead to a bad performance of invention licensing and a possible decline in the number of disclosed inventions since low value inventions occupy the main technology market.

5.4.2 Model set and assumption

In this section I model a traditional process of university industry technology transfer involving a faculty, a TTO, and an enterprise where the patent commercialization is conducted by the TTO who receives inventions from academic faculty and licenses patents to enterprises. The specific process is modelled based on the following economic assumption:

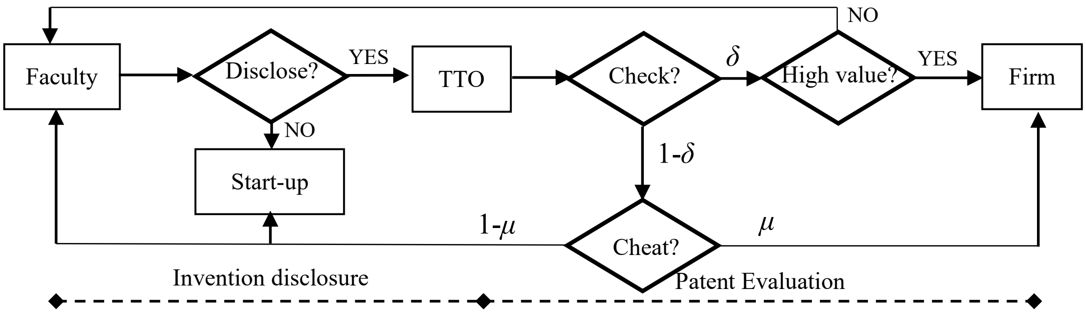

Figure 5.4 Process of invention disclosure and evaluation

As shown in Figure 5.4, initially, the academic faculty have two choices when they create inventions: disclosing to the university TTO or establishing a start-up which is based on their technology. In the beginning, all stakeholders do not know the true commercial value of faculty invention because almost all faculty patents are still at a proof of concept stage. I assume the true value of the invention v randomly distributed in the range $v \in [0, V]$, and its expected value is v_E. As a common knowledge to all stakeholders, the variable v obeys a specific distribution where distribution function is $F(v)$ and probability density function (PDF) is $f(v)$. Hence, in this section the invention with a business value higher than v_E could be defined as a high value invention, while the rest are low value inventions. The invention disclosure rate of academic faculty is p. At this stage, the academic faculty must decide whether to disclose inventions to the TTO in the hope that it can be licensed or to establish a start-up. I assume in this stage the faculty cannot both disclose invention to the

TTO and develop a start-up at the same time although the faculty could first disclose inventions and then undertake their commercial plan. There exists a significant difference in revenue creating before versus after invention disclosure. The faculty can obtain all business profits when they develop a start-up before disclosing the invention to the TTO.

I do not consider the influence of publication value for the following reasons. First, the publication shows the invention's scientific value which is a long term value and is not correlated to the business value (short term value). An academic invention could have low business value but high scientific value (Stokes, 1997). For example, Light-Emitting Diode (LED) technology was created in 1962, but was not developed and used on a large scale until the 1990s. Thus, faculty's choices heavily depend on their personal preference rather than rational economic analysis. Second, for a given invention, applying a patent and licensing to a potential invention usually takes several years, while publishing a research paper takes less than one year. It is hard to compare the total profit of each choice for the academic faculty. Therefore, in this section, I only make a comparison between disclosing inventions and then licensing it to established firms and developing a start-up directly to transfer the technology.

Finally, if the academic faculty disclosed their inventions, they would receive the non-economic profit K which follows the uniform distribution $K \sim U[0, A]$. For example, disclosing inventions is much beneficial for the faculty to establish his reputation in peer group, obtain tenure, or potential research funding. However, if the faculty establish a start-up but bypass TTO's control, they may catch a punishment cost c_P.

After receiving series faculty inventions disclosed by the academic faculty, the TTO can have the commercial quality knowledge only when they check the quality one by one. This assumption is different with the research of Hoppe and Ozdenoren (2005) who believe the technology manager and experts can identify all inventions' quality in one time. In this stage, the TTO firstly decide the checking rate δ ($\delta \in [0,1]$) that how many faculty inventions will be checked. The checking cost is denoted by $C(\delta)$ for $C(0) = 0$. I also assume that $C'|_\delta \geq 0$ and $C''|_\delta \geq 0$ that means the checking cost increases with the checking rate, as well as its marginal rate.

In the last stage, the TTO decides how to license inventions to the enterprise. To license an invention, the TTO usually makes a take-it-or-leave-it offer to the potential licensee. The licensee may accept the offer, pay for the licensing fee and input the adoption fee c_F, or reject the offer. I assume c_F is independent with the business value and the same across the outside licensee and faculty's start-up. The TTO also must decide how to deal with the rest unchecked invention:

Strategy 1 (**S1**): Only licensing the checked invention that has high commercial value;
Strategy 2 (**S2**): Only shelving the checked invention that has low commercial value.

If the TTO choose S2, they must decide the licensing rate μ ($\mu \in [0, 1-\delta]$) that how many unchecked invention could be brought into technology market. Specially, μ is equal to zero means the TTO choose S1. During this stage, the aim of quality checking is to shelve the low value invention. If the TTO choose S2 and licensing an unchecked invention with low value unfortunately, the S2 will be considered as TTO's cheating strategy since their patent checking does not working effectively.

When the given invention was licensed successfully, the enterprise has to pay the license fee to the TTO. In this section, I assume the equity is used as the payment way where the equity rate is β ($0 < \beta < 1$). Meanwhile, the TTO must share a proportion of licensing revenue with the faculty. I also assume the inventor share rate of licensing fee is s ($0 < s < 1$).

5.4.3 Model development

5.4.3.1 Basic model (without invention checking)

When the patent checking is not conducted, all stakeholders, including the academic faculty, the TTO, and the enterprise all have no idea about the true commercial value. They make related decisions according to the expected value based on the previous data. The expected payoff to the faculty from disclosing their invention to the TTO is $\pi_I^N = s\beta v_E + K$. When the faculty choose to establish a start-up, their economic revenue will depend on invention's true commercial value v rather than the expected value, while the total cost including the adoption cost and punishment cost. Hence the payoff from start-up is $\tilde{\pi}_I^N = v - c_F - c_P$.

The expected payoff to the TTO without checking activities is $\pi_{TTO}^{N} = (1-s)\beta v_E p$. Finally, the expected payoff to the enterprise is $\pi_F^N = (1-\beta)v_E - c_F$.

The successful university technology transfer requires all stakeholders' payoff is greater than zero. Because a take-it-or-leave-it offer is used in this process, the critical point of equity rate is equal to $\beta^N = 1 - c_F v_E^{-1}$. At this point, the TTO can receive the maximum profit while the licensee's profit is zero. Besides, the condition that the faculty disclose their inventions to the TTO is $\tilde{\pi}_I^N < \pi_I^N$. Therefore, if the TTO does not check the invention quality, the probability that the faculty disclose their invention is p^N,

$$p^N = \int_{(1-s)(v_E-c_F)-c_P}^{A} \frac{1}{A} dK = \frac{A-v+s(v_E-c_F)+c_F+c_P}{A} \tag{5.10}$$

In this scenario, the invention disclosure increases with the expected value, the adoption cost and the punishment cost, but decrease with the true business value. It is inferred that this probability has the same distribution with the invention value. That means its distribution function is $F(p^N)$ and PDF function is $f(\mathrm{p}^{\mathrm{N}})$.

5.4.3.2 University technology transfer with invention checking

When the invention checking is conducted, it can help the TTO to establish a trustable reputation that only license high value invention and bring up the license price, it also possible reduce the possibility that licenses a low value invention to an enterprise. In this section, I assume the faculty and the licensee only understand the invention has been checked, but how many inventions will be checked and which licensing strategy will be adopted is TTO's private information. Therefore, in the condition of invention checking, the faculty and the licensee would like to believe the S1 is adopted when only high value invention licensing is observed, but without any doubt that the TTO employs the S2 and by chance all unchecked invention also have high commercial value. On the other hand, once the faculty and the licensee observed the low value invention is licensed, they can make sure the TTO does not adopt the S1.

In this section I firstly definite the efficiency of invention checking. Its main function is to maximize TTO's profit and minimize the number of low valued inventions if the low value invention is less than the adoption cost. Hence I definite the efficient licensing is as below:

Definition: The TTO's licensing strategy is efficient in a given invention disclosure if

1. All high value inventions disclosed to the TTO are licensed;
2. Low value inventions disclosed to the TTO are shelved.

(1) The expected value of invention less than the adoption cost

In this section, if the TTO licenses this type invention to the enterprise, all stakeholders would possibly receive a negative net economic profit. Hence, shelving the low value is a must requirement for the TTO to improve its efficiency. The university technology transfer is a game process which is full of interest conflict, so an adverse induction method is employed. Firstly the commercial value of invention that licensed successfully would be distributed between the TTO and the licensee through the equity payment, hence the optimal equity rate is $\beta^R = 1 - {}^{c_F}/_{v}$ $(v \in (v_E, V])$. And then the inventor share of licensing rate δ $(\delta \in [0,1])$ is decided by the TTO. Thus, in the period of $[t, t + dt]$, the number of high value invention licensed to the enterprise is equal to $\int_{v_E}^{V} f(v)\delta p \mathrm{d}v \mathrm{d}t$.

Firstly, if the TTO choose the strategy of S1, it cannot be driven out the technology market by the enterprise since it only licenses the checked invention that has the high business value. Hence, the total economic profit in the whole period is,

$$\Pi_{TTO}^{R}(\delta) = \int_{0}^{+\infty} \int_{v_E}^{V} f(v)\,[(1-s)(v-c_F)\delta p - C(\delta p)]\mathrm{dvdt} \tag{5.11}$$

Denoted $M = \int_{v_E}^{V} v f(v)\mathrm{d}v$, $N = \int_{v_E}^{V} f(v)\mathrm{d}v$, since the $\Pi_{TTO}^{R}(\delta)$ is the concave function of δ, the optimal invention checking rate δ^R satisfied the condition $\frac{\partial \pi_{TTO}^{R}}{\partial \delta^R} = 0$, that is,

$$C'(\delta^R p)N = p(1-s)(M - c_F N) \tag{5.12}$$

As shown in Equation (5.12), the optimal invention checking rate δ^R decreases with the inventor share rate s and the adoption cost c_F. Higher inventors share rate and the adoption cost would encourage the faculty to disclosure more inventions to the TTO, so the checking rate becomes smaller due to the increasing checking cost.

In the strategy S1, the TTO has shelved all the checked invention with low value and all the unchecked inventions although not all unchecked inventions have low commercial value. Therefore, the S1 significantly reduces the probability that invention being checked and licensed to the enterprise, makes a decline in invention disclosure. The S1 also wastes part of high value invention in the unchecked group. Because of these disadvantages, when the expected value is less than the adoption cost, the TTO has the motivation to adopt the S2 although its long term interest may has a bad influence. One possible practice is that the TTO randomly selects a given proportion of inventions disclosed by the faculty according to the optimal checking rate δ^R and checks their quality. And then all the high value inventions are brought into technology market firstly, while all the low value inventions are shelved directly. In the end, in order to make good use of all high value invention and maximize TTO's profit, the TTO could market part or all the rest inventions and mark that their quality has not been checked.

In this case, because the expected value is less than the adoption cost, this study assume that if the enterprise pays high price for a low value invention, the TTO will be driven out the technology market because if its cheating behaviour. At the beginning, the faculty and the enterprise all believe the TTO adopt the S1, the optimal equity rate is β^R, the expected profit of high value invention is $\int_{v_E}^{V} f(v)(1-\mathrm{s})(v-c_F)\delta p \mathrm{d}v$. Since the TTO may license the unchecked inventions to the enterprise, their expected profit is $(1-s)\beta^R \mu p v_E$ ($\mu \in [0, 1-\delta]$). Thus, TTO's expected profit in unit time is,

$$\pi_{TTO}^{C}(\delta,\mu) = \int_{v_E}^{V} f(v)\left[(1-\mathrm{s})\left(\frac{v-c_F}{v}\right)(\delta p v + \mu p v_E) - C(\delta p)\right]\mathrm{d}v \tag{5.13}$$

So, until the TTO is driven out of technology market, its total discount profit is,

$$\Pi_{TTO}^{C}(\delta,\mu) = \int_0^T e^{-rt}\pi_{TTO}^{C}(\delta,\mu)\mathrm{d}t \tag{5.14}$$

In Equation (5.14), the variable r is the expected market interest rate. The variable T is time point when the enterprise firstly receives a low value invention, and it is negative with the variable μ (that is $T'(\mu) < 0$). Specially, when μ is equal to zero the variable T tends to infinity since all low quality inventions have been shelved and the TTO is in the technology licensing market forever.

When $v_E < c_F$, from TTO's perspective, its final target is to maximize its own economic profit, so it can be translated into the following model:

$$\max \Pi_{TTO}^{C}(\delta,\mu) \ \left(\delta \in [0,1] \text{ , } \mu \in [0,1-\delta]\right)$$

The Equation (5.14) is also the concave function of the variable δ and μ. If the TTO adopts the S2 that only shelving the low value inventions that have been checked, then the optimal checking rate δ and the optimal licensing rate of unchecked invention μ must satisfy the following equations:

$$\frac{\partial \Pi_{TTO}^{C}}{\partial \delta^{C}} = (1-s)(pM - c_F pN) - C'(\delta p)N = 0 \tag{5.15}$$

$$\frac{\partial \Pi_{TTO}^{C}}{\partial \mu^{C}} = e^{-rT}T'\pi_{TTO}^{C} + \frac{(1-e^{-rT})pv_E}{r}(1-s)(N - c_F Z) = 0 \tag{5.16}$$

In Equation (5.15), the variable Z is donated as $Z = \int_{v_E}^{V} f(v)v^{-1}\mathrm{d}v$. Combing the Equation (5.12) and (5.15), it shows that the rate of licensing unchecked invention has no any impact on the optimal checking rate, that is $\delta^R = \delta^C$. Meanwhile, the optimal rate of licensing unchecked invention μ^C has the close relationship with the checking rate and interest rate in Equation (5.16). It demonstrates that the best checking strategy does not independent with the licensing strategy. For the TTO, it should firstly make the optimal invention checking rate and then choose the related licensing strategy.

Proposition 5.9 (GM): When the expected value of invention is less than the adoption cost, choosing S2 cannot play any impact on the optimal invention checking rate; iff the expected interest rate is less than the critical point $\hat{r}$ ($r \le \hat{r}$), the TTO would not license any unchecked invention. The point is as following:

$$\frac{\hat{r}}{1-e^{\hat{r}T}}=\frac{pv_E(1-s)(N-c_FZ)}{T'[(1-s)(\delta pM+\mu pv_EN-\delta pc_FN-\mu pv_Ec_FZ)-CN]} \tag{5.17}$$

Proposition 5.9 implies that adopting S2 depends on the long term and short term interest. When the expected interest rate is less that the critical point, an increase in the probability of high future profit will occur, and faculty's willingness of choose the S2 would decrease. In contrast, if there is an increase in the expected interest rate, the TTO would like to license unchecked inventions to maximize its short term profit even though it may be driven out the technology licensing market. Further, the Equation (5.17) shows that the critical point $\hat{r}$ is negatively related to the expected value but positively related to the adoption cost. The higher value of invention could reduce TTO's economic risk of licensing unchecked inventions, and can bear the lower interest rate. With an increase in the adoption cost, TTO's licensing revenue would shrink and the critical point of interest rate would rise quickly, hence the TTO would not choose the S2.

(2) The expected value of invention larger than the adoption cost

In this case, even though the TTO does check the invention quality, it can get the positive profit from the technology licensing. Hence, it needs to investigate the expected profit gap $\Delta\pi_{TTO}$ with invention checking and without invention checking.

$$\Delta\pi_{TTO}=\pi_{TTO}^{R}-\pi_{TTO}^{N}=p(1-s)[\delta(M-c_FN)-(v_E-c_F)]-C(\delta p)N \tag{5.18}$$

Iff the value $\Delta\pi_{TTO}$ is greater than zero ($\Delta\pi_{TTO}>0$), the TTO has the motivation to check the quality of invention disclosed by faculty inventor. Hence, according to the Equation (5.18), two scenarios should be discussed one by one.

a) When the expected value satisfies the inequation ($v_E \geq c_F+\delta(M-c_FN)$), then $\pi_{TTO}^{R} \leq \pi_{TTO}^{N}$. In this scenario, the TTO will not check the invention quality in order to maximize its economic profit, and all invention disclosed by to the TTO would be brought into market. In fact, the condition ($v_E \geq c_F$) could make sure all stakeholders have a positive net profit. Considering the checking cost, only when the expected value is greater than $\delta(M-c_FN)$ of the adoption cost, the TTO will not check the invention quality. And,

b) When the expected value satisfies the inequation ($c_F \leq v_E \leq c_F + \delta(M - c_F N)$), whether the TTO check the invention quality depends on the relationship between the checking cost and the inventor share of licensing revenue. When the expected value is greater than the adoption cost ($v_E \geq c_F$), TTO's checking behaviour could improve the quality effectively but its economic profit may become less. On the other hand, if the inventor share of licensing revenue is smaller, the TTO also would like to check the invention quality. In this situation, the low share rate and strict invention checking would decrease the faculty willingness of disclosing inventions to the TTO.

If the TTO decide to check the invention quality, similar with the Section 5.4.3.1, which licensing strategy will be implemented needs to be investigated. If all the inventions licensed by the TTO have the high commercial value by chance, the faculty and the potential licensee cannot make sure whether the TTO adopts the S1 or S2. However, once the low value invention is licensed by the TTO, it is hard for the faculty and the enterprise to believe the TTO adopts the S1. The difference in this scenario is that the TTO will not be driven out the technology licensing market as a result of its cheating behaviour since the expected value is greater than the adoption cost. Instead, the enterprise will pay the licensing fee according to the expect value v_E, the equity rate decreases to β^N, while the licensing revenue also decrease to π_{TTO}^N. Hence, in the whole period TTO's total discount revenue $\widetilde{\Pi}_{TTO}^C$ is,

$$\widetilde{\Pi}_{TTO}^C(\delta,\mu) = \int_0^T e^{-rt}\,\pi_{TTO}^C \mathrm{d}t + \int_T^{+\infty} e^{-rt}\,\pi_{TTO}^N \mathrm{d}t \tag{5.19}$$

When $v_E \geq c_F$, in order to maximize the value of $\widetilde{\Pi}_{TTO}^C(\delta,\mu)$, TTO's decision model is

$$\max \widetilde{\Pi}_{TTO}^C(\delta,\mu)\ \big(\delta \in [0,1],\ \ \mu \in [0,1-\delta]\big)$$

Because the $\widetilde{\Pi}_{TTO}^C(\delta,\mu)$ is the concave function about the variable of δ and μ, the optimal $\tilde{\delta}^C$ and $\tilde{\mu}^C$ satisfy the following equations:

$$\frac{\partial \widetilde{\Pi}_{TTO}^C}{\partial \tilde{\delta}^C} = (1-s)(pM - c_F pN) - C'(\delta p)N = 0 \tag{5.20}$$

$$\frac{\partial \widetilde{\Pi}_{TTO}^C}{\partial \tilde{\mu}^C} = e^{-rT}T'\big(\pi_{TTO}^C - \pi_{TTO}^N\big) + \frac{(1-e^{-rT})pv_E}{r}(1-s)(N - c_F Z) = 0 \tag{5.21}$$

Combining the Equation (5.12), (5.15), and (5.20), when $v_E \geq c_F$, these three equations show that the optimal checking rate is independent with TTO's strategy.

Proposition 5.10 (GM): When the expected value is greater than the adoption cost, whether the TTO adopts the S2 has no influence on the optimal invention checking rate. When the expected interest rate is lower than the critical point $\tilde{r}$, the TTO will not choose the S2. Iff $\pi_{TTO}^{R} > \pi_{TTO}^{N}$ and $r \leq \tilde{r}$, TTO's optimal strategy is the S1 that only licenses high-value invention which has passed the checking process. The critical point $\tilde{r}$ satisfies that,

$$\frac{\tilde{r}}{1-e^{\tilde{r}T}} = \frac{pv_E(1-s)(N-c_F Z)}{T'[(1-s)(\delta pM+\mu pv_E N-\delta pc_F N-\mu pv_E c_F Z-pv_E-pc_F)-CN]} \tag{5.22}$$

Combining the Equation (5.17) and (5.22), it is clear that the value $\hat{r}$ is significant larger than that of $\tilde{r}$. It implies that the higher interest rate will increase the probability of adopting the S2, which is in line with the result shown in section 5.2.3.1.

Proposition 5.11 (GM): Because of the influence from the interest rate and the expected value, the TTO has to match the optimal checking strategy and licensing choice as following.

Table 5.12 Checking and licensing strategy varies with the interest rate and expected value

Interest rate	$\boldsymbol{v_E \in [0, c_F)}$	$\boldsymbol{v_E \in \left[c_F, c_F + \delta(M - c_F N)\right)}$	$\boldsymbol{v_E \in [c_F + \delta(M - c_F N), V]}$
$\hat{r} \leq r < 1$	Check, $\mu = \hat{\mu}^C$	Check, $\mu = \tilde{\mu}^C$	No check
$\tilde{r} \leq r < \hat{r}$	Check, $\mu = 0$	Check, $\mu = \tilde{\mu}^C$	No check
$0 \leq r < \tilde{r}$	Check, $\mu = 0$	Check, $\mu = 0$	No check

Note: Check/no check means the TTO checks the invention quality which is disclosed by the university faculty. $\mu = 0$ means the TTO chooses the S1 that only licenses the high value invention that has been checked, while $\mu = \hat{\mu}^C$ ($\tilde{\mu}^C$) means the TTO chooses the S2 and would brought a proportion of unchecked invention into technology licensing market.

Proposition 5.11 suggests that the TTO should check the invention quality when the expected value is significant low. Further, TTO's long term profit as a result of adopting cheating strategy and the probability of adopting the S2 increase with the expected value. When the expected value is very high, the TTO would have no need to check the invention quality.

5.4.4 The effect of invention checking on faculty disclosure

TTO's checking and licensing strategy has significant influence on faculty invention disclosure. First, for the high value invention, TTO's checking behaviour would decrease the probability of licensing to the enterprise. Second, this behaviour also may prevent the faculty to disclose low value invention. The following section will discuss the effect of invention checking on the faculty invention disclosure.

5.4.4.1 When $v_E < c_F + c_P$

(1) When $v \geq c_F + c_P$ and $v_E < c_F + c_P$, the probability that the faculty invention disclosed to the TTO gets a chance to be checked is δ. And the checking result that the invention is consider as the high value technology is $N^{-1}\delta \int_{v_E}^{v} vf(v)dv$ ($v \in [v_E, V]$). If the faculty does not observe TTO's cheating behaviour, they believe the TTO chooses the S1. Denoted $P(v) = \frac{F(v)-F(v_E)}{1-F(v_E)}$, then under the invention checking the expected profit of the faculty is $\pi_I^R = \beta^R sv\delta P(v) + K$, $v \in [v_E, V]$. On the other hand, when the faculty commercializes their own technology through bypassing TTO's control, their expected profit is $\pi_I^S = v - c_F - c_P$ ($v \in [v_E, V]$). The condition that the faculty discloses their invention has to meet the requirement $\pi_I^S \leq \pi_I^R$, hence the probability of the faculty disclose the high business value invention is,

$$p^R = \int_{\left(1-\beta^R s\delta P(v)\right)v-c_F-c_P}^{A} \frac{1}{A}\mathrm{d}K$$

Combining the Equation (5.10), the effect of invention checking on the faculty disclosure can be described as the probability gap that $\Delta p_H = p^N - p^R$. Hence, if the TTO checks the invention quality, the number of invention disclosed by the faculty has a significant change like that,

$$\Delta P_H = \frac{ps}{A}\int_{c_F+c_P}^{V}\left(v_E - c_F - \beta^R v\delta P(v)\right)f(v)\mathrm{d}v.$$

(2) When $v < c_F + c_P$ and $v_E < c_F + c_P$, the faculty would receive a negative net profit if they intend to establish the start-up based on their invention. Thus, in this case they would like to disclose their invention to the TTO, and the number of low value invention shelved by the TTO is as below,

$$\Delta P_L = p\delta \int_0^{c_F+c_P} f(v)\mathrm{d}v.$$

5.4.4.2 When $v_E \geq c_F + c_P$

(1) When $v > v_E$ and $v_E \geq c_F + c_P$, because of TTO's checking behaviour, the number of high value invention disclosed by the faculty experiences the below change,

$$\Delta\tilde{P}_H = \frac{ps}{A}\int_{v_E}^{V} \left(v_E - c_F - \beta^R v\delta P(v)\right) f(v)\mathrm{d}v$$

(2) When $c_F + c_P < v \leq v_E$ and $v_E \geq c_F + c_P$, the invention is always considered as the low value technology even though it has a positive business value. If the faculty discloses this type invention, it is possible to be shelved by the TTO. In addition, the faculty also has no idea whether the TTO would adopt the cheating strategy. Thus, for this type invention, TTO's checking behaviour would decrease faculty's willingness of invention disclosure. The number of decline in the invention disclosure is as below,

$$\Delta\tilde{p}_M = p\int_{c_F+c_P}^{v_E} f(v)\,\mathrm{d}v$$

(3) When $v < c_F + c_P$, the net profit through establishing start-up is negative. In this case, the TTO has to check part of invention because of the increasing disclosure of low value invention. The number of invention shelved by the TTO is as below,

$$\Delta\tilde{p}_S = p\delta\int_0^{c_F+c_P} f(v)\,\mathrm{d}v$$

Therefore, under the condition $v_E \geq c_F + c_P$, if the TTO decides to check the invention quality, the total number of invention shelved is $\Delta\tilde{p}_L = \Delta\tilde{p}_M + \Delta\tilde{p}_S$.

Proposition 5.12 (GM): The inventor share of licensing revenue has no any impact on the optimal invention checking rate. Iff $v_E - c_F > \delta P(v)(v - c_F)$, the disclosure of high value invention increases with the inventor share rate.

Proposition 5.12 shows that the probability of high value invention being checked and licensed to the enterprise is at a fairly low level when the invention checking rate is very small. The increasing in the inventor share of licensing revenue would enlarge the gap in the high value invention disclosure before/after invention checking. Meanwhile, the increase in the checking rate would shelved many low value invention directly, and encourage the faculty to disclose their high value invention indirectly.

In summary, the invention disclosure is positively related to the inventor share rate, but negatively related to the invention checking rate. Increasing the inventor share rate would offset the positive role of TTO's checking behaviour, thus these two strategies cannot be employed at the same time by the TTO. A feasible way is that the TTO firstly checks and improve the invention quality strictly, then increase the inventor share of licensing revenue to promote the faculty to disclose their high value invention voluntary.

Proposition 5.13 (GM): If the TTO decide to check the invention quality, its effect on the faculty invention disclosure, including high value and low value invention, is as below.

Table 5.13 Relationship between invention disclosure and related variables under TTO's invention checking strategy

Parameter	$\boldsymbol{v_E < c_F}$		$\boldsymbol{v_E \geq c_F}$	
	$\Delta \boldsymbol{p_H}$	$\Delta \boldsymbol{p_L}$	$\Delta \tilde{\boldsymbol{p}}_{\boldsymbol{H}}$	$\Delta \tilde{\boldsymbol{p}}_{\boldsymbol{L}}$
c_F	$\Delta p'_H\|_{c_F} > 0$	$\Delta p'_L\|_{c_F} > 0$	$\Delta \tilde{p}'_H\|_{c_F} < 0$	$\Delta \tilde{p}'_L\|_{c_F} < 0$
c_P	$\Delta p'_H\|_{c_P} < 0$	$\Delta p'_L\|_{c_P} > 0$	/	$\Delta \tilde{p}'_L\|_{c_P} < 0$
v_E	$\Delta p'_H\|_{v_E} > 0$	/	$\Delta \tilde{p}'_H\|_{v_E} < 0$	$\Delta \tilde{p}'_L\|_{v_E} > 0$
δ	$\Delta p'_H\|_{\delta} < 0$	$\Delta p'_L\|_{\delta} > 0$	$\Delta \tilde{p}'_H\|_{\delta} < 0$	$\Delta \tilde{p}'_L\|_{\delta} > 0$

Proposition 5.13 shows that the effect of the expected value, the adoption cost and the punishment cost on the disclosure of high value invention and the number of shelved invention all depend on the relationship between the expected value and the adoption cost. An increase in the checking rate would decrease the disclosure of high value invention, but shelve more low-value invention.

5.5 Investigation into patent license contract

5.5.1 University technology transfer chain

The university technology transfer chain (UTTC) is a system of the university faculty inventor, the university technology transfer office, and the licensee's involvement in the process of transferring university-invented technologies for the purpose of furthering development and commercialization, and links value chains. In the UTTC (Figure 5.5), the faculty as the inventor creates inventions in the academic workplace, discloses inventions to TTO, puts in related effort, and receives a ratio of patent licensing revenue. In terms of TTO, it is instrumental in developing relations with faculty inventor and firm and reducing their double moral hazard. Thus, TTO is considered as an appropriate governance and incentive structure to coordinate faculty and firm to offer the matched effort and investment. For the firm, who brings university inventions into the market, has to invest funding, and pay the licensing fee required by the specific license contract.

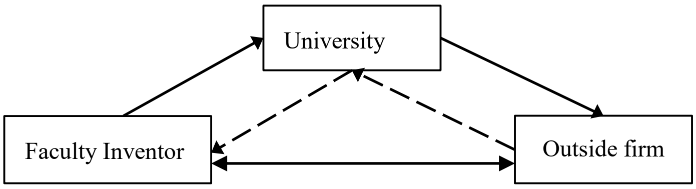

Figure 5.5 University technology transfer chain under TTO as the leader

In the process of UITT, TTO cannot write an ex-ante license contract that specifies faculty's unobservable effort and a firm's unverified investment, largely because the transfer of university inventions from faculty to firm is a dynamic process with double moral hazard. The traditional decentralized decision-making mode is based on the assumption that all participants, including the faculty, TTO, and firm are economic-driven, maximize their individual payoffs separately but care little about the social welfare of university technology transfer, which is the critical reason causing the mismatch between faculty's effort and a firm's investment in UITT. In addition, in the real world, majority of universities' TTOs are non-profit organizations. Their first responsibility is to reduce the double moral hazard and optimize the social welfare, and second is to maximize their own payoff. However, in the decentralized decision-making mode, it is impossible for TTO to judge whether faculty and firm have paid the matched effort and investment, and then design the optimal license contract and inventor share rate to control the double moral hazard and maximize the social welfare of UITT. Therefore, in this study, I introduce the concept of university technology transfer chain (UTTC), and seek to find an effective solution to improve these limitations of decentralized decision-making mode. I consider the TTO as the insider leader whose responsibility is to coordinate the activities of faculty and firm. In the context of UTTC, due to the fact that the individual best is not greater than collective optimum, I consider the performance of UTTC in centralized decision making as a benchmark, and attempt to use coordination of contract to remove the double moral hazard and achieve the benchmarking effect.

5.5.2 Theoretical model set

In order to investigate the double moral hazard in the process of UITT, this study develops a game model related to UTTC, involving one faculty inventor, one TTO, and a firm. I assume the faculty and firm are economic-driven. In terms of TTO, its first target is the optimization of social welfare, and the second target is its own payoff because of the licensing service provided.

It is widely viewed that a successful UITT needs the cooperation from faculty and firm because the university invention is still in the early development stage. In this section, the probability of successful UITT is given by $p(s_R, s_F)$, where s_R is faculty's effort, s_F is firm's investment. This function partly borrows from Dechenaux et al. (2009, 2011). However, unlike them, I consider faculty's effort and firm's investment play similar influence on the success rate of UITT because of their substitutive relations. So I relax the restriction of firm's fixed influence, assume the probability is also the exponential function related to firm's investment. I give a more specific functional form as below,

$$p(s_R, s_F) = 1 - p_0 e^{-as_R - bs_F}$$

The probability $p(s_R, s_F)$ is an increasing function of both s_R and s_F. When s_R (or s_F) is equal to zero, the probability will decrease rapidly and solely depend on firm investment (or faculty's effort). The parameter a measures the importance of faculty's effort to the successful UITT, while b measures the role of firm's investment. The parameter p_0 can be interpreted as a measure of the systemic risk in UITT. Only when p_0 is equal to one, then $p(0{,}0) = 0$. That is, unless the faculty and firm do not invest any inputs for technology transfer, in most cases the success rate of UITT does not go to zero. In terms of university inventions at the early development stage, they always have a high value of p_0, a and b.

The university TTO owns and can exclusively license university inventions to firm. I assume that the utility of TTO is $U_T = (1-\alpha)R - K$, where $1-\alpha$ is the licensing share profit that is accrued to university TTO, and R is its expected licensing revenue, and K is its search cost. For the university faculty, I assume their expected utility is $U_R = \alpha R - A_0 e^{t_R}$, where α is the inventor's share of licensing revenue, $A_0 e^{t_R}$ measures faculty's time-cost that spends on UITT, and A_0 is the influence of time-cost.

The university TTO offers the firm an exclusive license contract that specifies particular type of payment. In this section, I consider the commonly observed form of payment, i.e. royalties and equity, as the means of engaging faculty and firm's participation in the UTTC. I denote the patent license contract by $O = (m, r)$or θ. Payment term m is the upfront fee paid immediately once the firm signs the license contract. Payment term r is the royalty fee (per unit) which is a continuous licensing income. In this section, the firm's expected utility is closely related to the patent output revenue π and total production cost C_t. The total licensing fee is $R = m + rx$ (using royalties payment) or $R = \theta\pi$ (using equity payment). Therefore, with the successful UITT, firm's utility is given by $U_F = p(\pi - rx) - m - C_t$ or $U_F = p\theta\pi - m - C_t$.

5.5.3 Common patent license contracts

This section investigates normal patent license contract in the context of royalties and equity payment. The sum of all participants' payoff is considered as the social welfare of university technology transfer. I first study the activities of faculty and firm in the traditional decentralized decision-making mode, then, I look into the benchmark of UTTC in centralized decision-making without considering the revenue distribution between faculty and TTO, as well as between firm and TTO.

5.5.3.1 Decentralized decision-making mode

(1) Royalties payment

After accepting the university-invented technology, the TTO will first search and provides a specific license contract to potential firm. If the firm rejects the license contract, the bargaining game between the TTO and firm is over, and TTO goes on searching for another technology buyer. If not, the firm has to invest s_F for further development and pay the upfront fee m immediately. Meanwhile, the TTO assigns a ratio of licensing income to faculty inventor according to the inventor share ratio stated in university policies. Lastly, the faculty chooses the effort level s_R for the success of UITT. This bargaining game of university technology transfer is a dynamic process. Therefore, in this study, the backward induction method is employed to solve this issue where the sequential decision is faculty inventor→the firm→the university TTO.

In the decentralized decision-making mode with royalties payment, the firm's utility is $U_{Fd} = p_d(\pi - rx) - s_F - m - c_t x$, the utility of faculty is $U_{Rd} = \alpha(rp_d x + m) - A_R e^{s_R}$, and the university TTO's utility is $U_{Td} = (1-\alpha)(rp_d x + m) - K$, and the total social welfare is $U_{Sd}(\alpha, r) = U_{Fd} + U_{Rd} + U_{Td}$. To ensure the process can continue, I consider the initial condition that keeps faculty and firm voluntarily involved in UITT is $U_{Fd} > 0$, $U_{Rd} > \alpha m$. First, order $U'_{Rd}(s_R) = 0$, then faculty's effort is as below,

$$s_{Rd} = \frac{1}{a+1} Ln\left(\frac{\alpha rxape^{-bs_F}}{A_R}\right) \tag{5.23}$$

It is clearly seen that s_{Rd} meets the requirement that $U_{Rd}(s_{Rd}) > \alpha m$. Meanwhile, $U''_{Rd}(s_R) < 0$ indicates that U_{Rd} is a concave function and can get the maximum utility at s_{Rd}. After observing faculty's optimal effort level, firm's technology investment s_F is as follow,

$$s_{Fd} = \frac{a+1}{b} ln \frac{bp(\pi - rx)}{a+1} + \frac{a}{b} ln \frac{A_R}{\alpha rxap} \tag{5.24}$$

The condition that $U_{Fd}(s_{Fd}) > 0$ and $U''_{Fd}(s_F) < 0$ also suggests that s_{Fd} is firm's optimal investment. Thus, according to Equation (5.24), I have faculty's optimal effort,

$$s_{Rd} = ln \frac{(a+1)\alpha rxa}{A_R b(\pi - rx)} \tag{5.25}$$

(2) Equity payment

If the firm is cash-constrained and/or risk-averse, the equity payment is a common economical way of licensing academic inventions. In this scenario, the firm's utility is given by $U_{Fd} = (1-\theta)p_d\pi - s_F - c_t x$, the faculty's utility is $U_{Rd} = \alpha\theta p_d\pi - A_R e^{s_R}$, and TTO's utility is $U_{Td} = (1-\alpha)\theta p_d\pi - K$, and the social welfare of university technology transfer is $U_{Sd}(\alpha, \theta) = U_{Fd} + U_{Rd} + U_{Td}$. Similar to above section, first order $U'_{Rd}(s_R) = 0$, then,

$$s_{Rd} = \frac{1}{a+1} Ln\left(\frac{a\pi\alpha\theta p e^{-bs_F}}{A_R}\right) \tag{5.26}$$

Where s_{Rd} meets the requirement of $U_{Rd}(s_{Rd}) > 0$ and $U''_{Rd}(s_R) < 0$, it suggests that s_{Rd} is faculty inventor's optimal effort in decentralized decision-making with equity payment. I consider firm's optimal investment by denoting $U'_{Fd}(s_F) = 0$, then I have,

$$s_{Fd} = \frac{a+1}{b} ln\frac{(1-\theta)bp\pi}{a+1} + \frac{a}{b} ln\frac{A_R}{\alpha\theta\pi a p} \tag{5.27}$$

Where $U_{Fd}(s_{Fd}) > 0$ and $U''_{Fd}(s_F) < 0$ also indicates firm obtained its maximum payoff at the point of s_{Fd}. According to Equation (5.27), I have faculty's optimal effort as below,

$$s_{Rd} = ln\frac{(a+1)a\alpha\theta}{A_R b(1-\alpha\theta)} \tag{5.28}$$

In the process of university technology transfer, the TTO always has the motivation to facilitate the faculty and firm to put in effort and investment because it can obtain positive payoff from the UITT. Therefore, after estimating the given level of faculty's effort and firm's investment in the context of royalties and equity payment, TTO designs a satisfactory patent license contract and inventor share ratio to maximize the total social welfare (first target) and the organizational payoff (second target). Therefore, the utility function of TTO is given by,

$$U_{Td} = \max_{\alpha,\ \gamma\ or\ \theta} \{I(1-\alpha)(rp_d x + m) + (1-I)(1-\alpha)\theta p_d\pi\} - K$$

$$\text{S.T. } \max\{U_{Sd}(\alpha, r), U_{Sd}(\alpha, \theta)\}$$

$$s_R = s_{Rd},\ s_F = s_{Fd}, 0 < \alpha \le 1, r > 0, I = 0\ or\ 1$$

If $U_{Sd}(\alpha, r) \leq U_{Sd}(\alpha, \theta)$, $I = 0$, otherwise $I = 1$. It indicates that TTO first intends to maximize the social welfare of UITT, then optimize its own payoff.

Proposition 5.14 (GM): There exists optimal license contract for the TTO; when $I = 0$, the optimal equity rate is $\theta^* = 1 - \sqrt{\frac{1+a}{\pi b}}$, the optimal inventor share rate is $\alpha^* = \frac{(1-a)\sqrt{\pi b}+a\sqrt{1+a}}{(1+a)(\sqrt{\pi b}-\sqrt{1+a})}$; when $I = 1$, the optimal royalty fee is $r^* = \frac{1}{x}\left(\pi - \sqrt{\frac{\pi}{b}}\right)$, the optimal inventor share rate is $\alpha^* = \frac{1}{(1+a)(\sqrt{\pi b}-1)}$.

Please refer to Appendix 4 for details. In this section, I regard the probability of successful UITT depending on faculty's effort and firm's investment. Proposition 5.14 shows that there exists the only point $\{\alpha^*, \theta^*\}$ or $\{\alpha^*, r^*\}$ to maximize its own payoff. Another implication is that the optimal equality rate is related to the influence of faculty's effort and firm's investment, while the optimal royalty fee (per unit) has negative relationship with the product yield. Another significant implication is that the utility of TTO always decreases with the inventor's share of licensing revenue from 0 to 1, thus TTO cannot identify a specific value.

5.5.3.2 Centralized decision-making mode

In centralized decision-making mode, in order to maximize the total social welfare of UTTC, TTO as the leader of UTTC has the obligation and right to make faculty and firm to put in matched effort and investment. All participants in UTTC are jointly considered as an integration that could internalize the issue of revenue distribution. Thus, the total social welfare is given by,

$$U_{Sc}(s_R, s_F) = p_c\pi - A_R e^{s_R} - s_F - c_t x - K \tag{5.29}$$

It is clearly seen that U_{SC} is a concave function about s_R and s_F, since I have $U''_{Sc}(s_R) < 0$ and $U''_{Sc}(s_F) < 0$. Then I denote $U'_{Sc}(s_R) = 0$ and $U'_{Sc}(s_F) = 0$, and obtain faculty's optimal effort s_{Rc} and firm's optimal investment s_{Fc} as below,

$$s_{Rc} = ln\frac{(a+1)a}{A_R b} \tag{5.30}$$

$$s_{Fc} = \frac{a+1}{b} ln \frac{bp\pi}{a+1} + \frac{a}{b} ln \frac{A_R}{ap\pi} \tag{5.31}$$

In centralized decision making mode, the influence of inventor share ratio and license contract are internalized because the revenue distribution is an internal issue from the perspective of social welfare. As shown in Equations (5.30) and (5.31), faculty's effort and firm's investment are not related to the payment terms and inventor share ratio.

Proposition 5.15 (GM): The success rate of UITT and the total social welfare of UTTC in centralized decision making mode are greater than those in decentralized decision making mode; there exists mismatches of faculty's effort and firm's investment because of double moral hazard.

Proposition 5.15 demonstrates that there still exists room that for improvement for the activities of faculty and firm when the social welfare in centralized decision making mode is deemed as the benchmark. In addition, because of the substitutional relations between faculty's effort and firm's investment, the firm always has strong motivation to cut down investment once it observes faculty's high level of effort. Meanwhile, the faculty inventors also intend to shorten their input if they estimate a firm's decrease in investment funding. This kind of chain reaction easily makes faculty and firm invest insufficient or excessive and causes the double moral hazard.

Proposition 5.16 (GM): The single royalties or equity payment cannot solve the issue that makes faculty (or firm) input the same optimal effort level (or investment) in two types of decision mode.

Compared with decentralized decision-making mode, the centralized decision-making mode requires faculty and firm to offer more matched inputs, and generates an added profit for UITT. Then how to distribute effectively and fairly this additional profit between faculty inventor and firm is a key issue in the management of UTTC. Proposition 5.16 implies that the single royalties or equity payment lacks a supplementary means to redistribute the increased profit. Therefore, it cannot make faculty and firm input the effort and investment required in centralized decision making mode.

5.5.4 Coordination of patent license contracts

According to Proposition 5.16, the single royalties or equity payment cannot optimize the social welfare of UITT. Therefore, the TTO, as the coordinator and leader of UTTC, has to design a new scheme including license contract and inventor share ratio to achieve the performance of centralized decision making mode. In this section, I will employ portfolio contract with royalties and equity and side-payment self-enforcing contract to coordinate activities between faculty and firm.

5.5.4.1 Portfolio contract with royalties and revenue sharing

(1) When faculty's profit is smaller than that of firm

According to Equations (5.25) and (5.28), in this case, faculty's effort is smaller than that required in centralized decision making mode. Thus, in order to encourage faculty inventor to put in the matched effort, TTO uses the portfolio contract that transfer part of profit from firm to faculty through the secondary revenue distribution. It is worth noting that TTO is excluded from this secondary revenue distribution because it does not put in extra contribution to additional profit. I use the variable δ as the factor of revenue redistribution. Then, under the new decentralized decision-making with the revenue sharing factor δ, the firm's utility is $U_{Ft} = (1-\delta)[p_t(\pi - rx) - s_F] - m - c_t x$, the faculty's utility is $U_{Rt} = \delta[p_t(\pi - rx) - s_F] + \alpha(rp_t x + m) - A_R e^{s_R}$, and the TTO's utility is $U_{Tt} = (1-\alpha)(rp_t x + m) - K$.

I also use the backward induction method to solve this dynamic game model. First, denote $U'_{Rt}(s_R) = 0$, then I have,

$$s_{Rt1} = \frac{1}{a+1} Ln\left(\frac{[\alpha rx + (\pi - rx)\delta]ape^{-bs_F}}{A_R}\right) \tag{5.32}$$

In order to achieve the performance of centralized decision making mode, faculty's effort and firm's investment should meet the requirement that $s_{Ft} = s_{Fc}$ and $s_{Rt} = s_{Rc}$. Then, according to Equations (5.30) and (5.32), I have,

$$\delta = \frac{\pi - \alpha r x}{\pi - r x} \tag{5.33}$$

Lemma 5.1: In order to ensure faculty and firm voluntarily put in matched effort and investment, the new decentralized decision-making with revenue redistribution has to meet with the incentive compatibility constraint (ICC) as well as participant constraint (PC) as below:

ICC: The faculty and firm in the new decentralized decision-making with revenue redistribution all have high utility than those under previous decentralized decision-making with single royalties or equity payment, the total social welfare of UITT is equal to that under centralized decision-making mode;

PC: Faculty's effort and firm's investment in the new decentralized decision-making mode are equal to those in the centralized decision-making mode.

When TTO uses the portfolio contract with royalties and revenue sharing, firm's utility in new decentralized decision-making becomes negative because of $\delta \geq 1$. Therefore, according to Lemma 5.1, in this case the portfolio contract with royalties and revenue sharing as the secondary revenue distribution scheme does not meet with the ICC requirement. It cannot solve the issue that redistribute the added profit effectively and optimizes the social welfare of UITT.

(2) When faculty's profit is larger than that of firm

In this scenario, I assume the TTO use portfolio contract with royalties and revenue sharing to transfer part of profit from faculty to firm to promote firm to invest required research funding. In the new decentralized decision-making with revenue redistribution, the firm's utility is given by $U_{Ft} = (1-\delta)[\alpha(rp_t x + m) - A_R e^{s_R}] + p_t(\pi - rx) - s_F - m - c_t x$, the utility of faculty inventor is given by $U_{Rt} = \delta[\alpha(rp_t x + m) - A_R e^{s_R}]$, and utility of the university TTO is given by $U_{Tt} = (1-\alpha)(rp_t x + m) - K$. I also order $s_{Rt} = s_{Rc}$ and $s_{Ft} = s_{Fc}$ to meet the PC requirement, then I have,

$$\delta = 1 - \frac{(1+a)rx - a\pi}{(1+a)\alpha r x} \tag{5.34}$$

$$\alpha rx = \pi - rx \tag{5.35}$$

In order to meet the ICC requirement, compared with the previous decentralized decision making without any coordination, I have the following two inequalities:

$$U_{Rt}(s_{Rt}, s_{Ft}) \geq U_{Rd}(s_{Rd}, s_{Fd}),\ U_{Ft}(s_{Rt}, s_{Ft}) \geq U_{Fd}(s_{Rd}, s_{Fd})$$

The result shows that the factor of revenue redistribution δ must meet the following requirement,

$$\frac{\alpha(p_d rx+m)-A_R e^{s_{Rd}}}{\alpha(p_t rx+m)-A_R e^{s_{Rt}}} \leq \delta \leq 1 - \frac{(\pi-rx)(p_d-p_t)+s_{Ft}-s_{Fd}}{\alpha(p_t rx+m)-A_R e^{s_{Rt}}} \tag{5.36}$$

Proposition 5.17 (GM): The portfolio contract coordinates with royalties and revenue sharing coordinates the faculty and firm to put in the matched effort and investment, only when they obtain equal profit from technology transfer; the revenue transfer from faculty to firm depends on inventor share ratio, royalties, and faculty's importance.

Proposition 5.17 suggests a limitation of portfolio contract with royalties and revenue sharing. First, the portfolio contract does not work if faculty's profit is larger than that of the firm, since the firm is suffered from heavier operational risk in the process of UITT. In addition, Equation (5.34) presents that the revenue transfer from faculty to firm decreases with the inventor share ratio and faculty's importance, but increase with the royalty fee (per unit).

Proposition 5.18 (GM): The TTO could achieve its maximum profit at the boundary point.

For the university TTO, in order to coordinate the faculty and firm to put in the matched effort and investment, the portfolio contract and inventor share ratio should meet with the requirement that,

$$\frac{(\pi-rx)(p_d-p_t)+s_{Ft}-s_{Fd}}{\alpha(p_t rx+m)-A_R e^{s_{Rt}}} \leq \frac{(a+1)rx-a\pi}{(a+1)\alpha rx} \leq 1 - \frac{\alpha(p_d rx+m)-A_R e^{s_{Rd}}}{\alpha(p_t rx+m)-A_R e^{s_{Rt}}} \text{ and } \alpha rx = \pi - rx$$

On the other hand, TTO always has motivation to decrease the inventor share ratio but raise the royalty fee (per unit) after coordinating the faculty's effort and firm's investment, since

TTO's utility is strictly a monotonic function related to the inventor share ratio and royalties. Therefore, compared with previous decentralized decision making mode without any coordination, in this scenario, TTO always could achieve its maximum at the boundary point.

5.5.4.2 Side-payment self-enforcing contract

Because of the limitation of the portfolio contract shown in Proposition 5.17, in this section I consider to use another common coordination scheme of side-payment self-enforcing contract (SSEC) to coordinate the activities of faculty and firm from the perspective of UTTC.

I assume the function of SSEC is $T(s_R, s_F) = \sigma e^{s_R} + \omega s_F + k$, where the factor σ and ω measure the role of faculty's effort and firm's investment respectively, and k is a constant. Therefore, in the new decentralized decision making mode with SSEC, the firm's utility is given by $U_{Ft} = p_t(\pi - rx) - s_F - T(s_R, s_F) - m - c_t x$, then faculty inventor's utility is given by $U_{Rt} = \alpha(rp_t x + m) + T(s_R, s_F) - A_R e^{s_R}$, and TTO's utility is $U_{Tt} = (1 - \alpha)(rp_t x + m) - K$. The backward induction method is employed to solve this issue. First, I denote $U'_{Rt}(s_R) = 0$, and then I have,

$$s_{Rt2} = \frac{1}{a+1} Ln\left(\frac{\alpha rxape^{-bs_F}}{A_R - \sigma}\right) \tag{5.37}$$

The value of s_{Rt2} meets the inequalities that $U_{Rt}(s_{Rt2}) > \alpha m$ and $U''_{Rt}(s_{Rt2}) < 0$, thus faculty could maximize its utility at s_{Rt2}. After observed faculty's optimal effort, firm makes the matched optimal investment according to $U'_{Ft}(s_F) = 0$, then I have,

$$s_{Ft2} = \frac{a+1}{b} ln \frac{b(pM^{-1}(\pi - rx) + \sigma)}{(a+1)(1+\omega)} + \frac{1}{b} ln\, M \tag{5.38}$$

Where $M = \frac{\alpha rxap}{A_R - \sigma}$, s_{Ft2} meets the inequalities that $U_{Ft}(s_{Ft2}) > 0$ and $U''_{Ft}(s_{Ft2}) < 0$. Then for the given s_{Ft2}, I can calculate the faculty's effort as following,

$$s_{Rt2} = ln \frac{(a+1)(1+\omega)}{b(pM^{-1}(\pi - rx) + \sigma)} \tag{5.39}$$

The SSEC scheme in UTTC should meet the requirements of ICC and PC, according to Equations (5.30), (5.31), (5.38) and (5.39), I denote $s_{Ft2} = s_{Fc}$ and $s_{Rt2} = s_{Rc}$, then the factor σ and ω are as below,

$$\sigma = \frac{A_R(\pi - \alpha r x)}{\pi} \tag{5.40}$$

$$\omega = \frac{a(\pi - \alpha r x) - r x}{\pi} \tag{5.41}$$

In order to find the constant k, the utility gap of faculty inventor and firm is considered. In the new decentralized decision making with SSEC, the added profit of UTTC is given by,

$$\Delta U_S = U_{Sc}(s_{Rc}, s_{Fc}) - U_{Sd}(s_{Rd}, s_{Fd}) \tag{5.42}$$

On the other hand, the added profit of faculty inventor and firm are given by,

$$\Delta U_R = U_{Rc}(s_{Rc}, s_{Fc}) + (\sigma e^{s_{Rc}} + \omega s_{Fc}) + k - U_{Rd}(s_{Rd}, s_{Fd}) \tag{5.43}$$

$$\Delta U_F = U_{Fc}(s_{Rc}, s_{Fc}) - (\sigma e^{s_{Rc}} + \omega s_{Fc}) - k - U_{Fd}(s_{Rd}, s_{Fd}) \tag{5.44}$$

The bargaining game among the faculty, TTO and firm could be considered as a game repeated indefinitely since they have participated in the university technology transfer for many times. In this case, I use the Rubinstein bargaining game to study the revenue redistribution. Note φ_1 and φ_2 $(\varphi_1 + \varphi_2 = 1)$ as the discount factor measure the patience degree of faculty and firm respectively. The only sub-game perfect Nash equilibrium is $\left(\frac{1-\varphi_1}{1-\varphi_1\varphi_2}, \frac{\varphi_1-\varphi_1\varphi_2}{1-\varphi_1\varphi_2}\right)$. In this section, I use this Nash equilibrium rule to distribute the added profit of UTTC. I assume,

$$\Delta U_R = \frac{1-\varphi_1}{1-\varphi_1\varphi_2}\Delta U_S \tag{5.45}$$

$$\Delta U_F = \frac{\varphi_1-\varphi_1\varphi_2}{1-\varphi_1\varphi_2}\Delta U_S \tag{5.46}$$

Thus, according to Equations (5.40)-(5.46), I obtain the constant variable k as below,

$$k = \frac{1-\varphi_1}{1-\varphi_1\varphi_2}[U_{Fc} - (\sigma e^{s_{Rc}} + \omega s_{Fc}) - U_{Fd}] - \frac{\varphi_1-\varphi_1\varphi_2}{1-\varphi_1\varphi_2}[U_{Rc} + (\sigma e^{s_{Rc}} + \omega s_{Fc}) - U_{Rd}] \tag{5.47}$$

Then the SSEC function is $T(s_R, s_F) = \sigma e^{s_R} + \omega s_F + k$ where the value of σ, ω, and k is found in Equations (5.40), (5.41) and (5.47).

I denote $\tilde{\Delta} U_R = U_{Rc} + (\sigma e^{s_{Rc}} + \omega s_{Fc}) - U_{Rd}$ and $\tilde{\Delta} U_F = U_{Fc} - (\sigma e^{s_{Rc}} + \omega s_{Fc}) - U_{Fd}$. When faculty's utility is smaller than that of firm, in the new decentralized decision making with SSEC, the faculty has a negative added profit $\tilde{\Delta}\pi_R \leq 0$ because their effort results in over-investment, while firm has the positive added profit $\tilde{\Delta}\pi_F \geq 0$ because of higher success rate of UITT. In order to achieve the performance equal to that in centralized decision making, firm has to move to a positive side-payment for the faculty $k > 0$.

Proposition 5.19 (GM): In the side-payment self-enforcing contract, the faculty always obtains a positive added profit related to their effort; TTO maximizes its utility at the point $\{\min \alpha, \max r\}$.

Equation (5.40) presents that the profit transferred from firm to faculty is consistently positive because $\pi > \alpha r x$, it indicates that the faculty should be paid a positive salary based on their effort. On the other hand, Proposition 5.19 suggests that TTO always obtain its maximum utility at the boundary point, since the profit transfer $T(s_R, s_F)$ as the secondary revenue distribution scheme could coordinate faculty's effort and firm's investment in the whole area.

5.5.5 Numerical study

In order to investigate the efficiency of portfolio contract and side-payment self-enforcing contract, a series of numeric cases are used. I order $x = 100$, $\pi = 500$, $p_0 = 3$, $m = 10$, $c_t = 0.1$, $a = 1.5$, $b = 0.1$, $A_R = 11$, $\varphi_1 = \varphi_2 = 0.5$. I use the variable α and r to control the size of faculty's revenue $\alpha r x$ and firm's revenue $\pi - r x$.

As shown in Table 5.14, I consider the cases in the normally observed license contract. For the royalties payment at the given level of inventor share rate ($\alpha = 0.4$), the total social welfare of UITT is 360.12 in decentralized decision-making without any coordination, while 404.95 in centralized decision-making mode. It represents that the profit loss of the UITT reaches to 44.83 units because of unmatched inputs of faculty and firm. In addition, when

TTO increases the inventor share rate, the faculty puts in growing effort on UITT while the firm begins to reduce its investment rapidly, and the loss of social welfare increases to 69.43 units. However, for the equity payment, the social welfare increases with the inventor share ratio. It demonstrates that the inventor share ratio should be different with the types of license contract terms. Furthermore, Table 5.14 gives the information that there exists under-investment or over-investment for faculty's effort and firm's investment in decentralized decision-making compared with the matched inputs in centralized decision-making mode (See Proposition 5.16). In centralized decision-making, all participants' utility is larger than that in decentralized decision-making. This result indicates that there exists room for effective contract coordination to improve the performance of UTTC.

Table 5.14 Decentralized and centralized decision-making ($\boldsymbol{r = 3.5}$ or $\boldsymbol{\theta = 0.6}$)

Variables	**Decentralized decision-making**						**Centralized decision-making**		
	Royalties payment			**Equity payment**					
α	0.4	0.6	0.8	0.4	0.6	0.8	0.4	0.6	0.8
s_R	1.16	1.56	1.85	0.07	0.65	1.15		1.23	
s_F	11.54	5.46	1.14	21.05	14.96	10.65		22.55	
U_{SC}	360.12	348.71	335.52	293.43	327.45	352.10		404.95	
U_F	93.45	99.54	103.86	103.48	124.44	142.30		99.95	
U_R	85.67	128.50	171.33	68.87	113.37	160.92	99.50	168.00	236.50
U_T	181.00	120.67	60.33	121.07	89.64	48.88	205.50	137.00	68.50

Table 5.15 shows the improvement of UTTC through adopting the portfolio contract with royalties and revenue sharing. When the inventor share rate is 0.5 or 0.54, the portfolio contract cannot meet the requirement of ICC because the faculty obtains a lower utility ($U_{Rt} < U_{Rd}$). When the inventor share rate is larger than 0.54, the portfolio contract could play effective role in improving the performance of UTTC. It demonstrates that there is a limitation for the portfolio contract to coordinate faculty's effort and firm's investment (See Proposition 5.17) since it only works under some special conditions (see Inequation 5.36). In addition, when the value of inventor share ratio grows from 0.5 to 0.66, the utility of faculty inventor and firm increases slightly while TTO's utility drops sharply. Another important

phenomenon is that the benefit transferred from the faculty to firm make the participants put in the matched effort and investment automatically, and it is negatively related to the inventor share ratio, but positively related to the royalty fee (per unit).

Table 5.15 Portfolio contract with royalties and revenue sharing

Variables		Decentralized decision making				Portfolio contract with royalties and revenue sharing				
α	r	U_{Fd}	U_{Rd}	U_{Td}	U_{Sd}	U_{Ft}	U_{Rt}	U_{Tt}	U_{St}	δ
0.50	3.33	110.11	109.17	146.67	365.95	140.95	100.67	163.33	404.95	0.80
0.54	3.25	118.26	118.23	132.65	369.14	142.94	115.54	146.48	404.95	0.86
0.58	3.16	126.02	126.84	119.01	371.87	144.61	129.88	130.47	404.95	0.91
0.62	3.09	133.42	135.06	105.76	374.24	146.04	143.69	115.22	404.95	0.95
0.66	3.01	140.47	142.90	92.93	376.30	147.27	157.00	100.69	404.95	0.99

Table 5.16 shows that the improvement of UITT when the side-payment self-enforcing contract is employed as the coordination scheme. First, in this new coordination scheme, the faculty, firm and TTO could obtain a larger utility than that in decentralized decision-making without any coordination. The total social welfare of UITT is equal to that in centralized decision-making. Compared with the portfolio contract with royalties and revenue sharing, the side-payment self-enforcing contract works more effectively in the whole area related to the inventor share ratio and royalty fee (per unit). In addition, when the inventor share ratio increases from 0.4 to 1.0, faculty and firm's utility rises slightly while TTO's utility declines rapidly. Meanwhile, the profit transfer T from firm to faculty also decreases significantly with the inventor share ratio and the royalty fee (per unit). Specifically, the profit transfer drops down to negative value when these two factors are large enough. It suggests that the faculty has to transfer part of their profit to firm.

Table 5.16 The side-payment self-enforcing contract (SSEC)

		Centralized decision				Decentralized decision				SSEC			
α	r	U_{Fc}	U_{Rc}	U_{Tc}	U_{Sc}	U_{Fd}	U_{Rd}	U_{Td}	U_{Sd}	U_{Ft}	U_{Rt}	U_{Tt}	T
0.4	2	238.66	46.56	120.24	405.46	215.67	68.64	116.40	400.71	215.97	69.25	120.24	22.69
	3	143.46	84.64	177.36	405.46	131.07	89.44	164.40	384.91	133.60	94.50	177.36	9.85
	4	48.26	122.72	234.48	405.46	51.74	71.84	188.40	311.98	67.54	103.44	234.48	-19.28
0.6	2	238.66	86.64	80.16	405.46	221.34	102.96	77.60	401.90	221.68	103.63	80.16	16.99

	3	143.26	143.76	118.24	405.46	136.75	134.16	109.60	380.51	142.19	145.04	118.24	1.27
	4	48.26	200.88	156.32	405.46	57.41	107.76	125.60	290.77	85.40	163.74	156.32	-37.14
0.8	2	238.66	126.72	40.08	405.46	225.37	137.28	38.80	401.45	226.28	139.10	40.08	12.38
	3	143.46	202.88	59.12	405.46	140.78	178.88	54.80	374.46	149.67	196.67	59.12	-6.21
	4	48.26	279.04	78.16	405.46	61.44	143.68	62.80	267.92	102.17	225.13	78.16	-53.91
1.0	2	238.66	166.80	0	405.46	228.50	171.60	0	400.10	230.28	175.18	0	8.38
	3	143.26	262.00	0	405.46	143.90	223.60	0	367.50	156.56	248.91	0	-13.09
	4	48.26	357.20	0	405.46	64.56	179.60	0	244.17	118.33	287.13	0	-70.07

5.5.6 Model discussion

(1) Incomplete and complete contracts

The traditional patent license contract with royalties or equity payment is the incomplete contract, because the TTO cannot write any contract terms that govern faculty's unobservable effort and firm's unverifiable investment before transferring the university technology. Thus, in the process of UITT, it is easy for the faculty as well as firm to put the unmatched effort and investment, due to the unreasonable revenue distribution scheme among all participants. In this section, I introduce the concept of university technology transfer chain, and consider the achievement in centralized decision making as the benchmark, and explore the cases of complete contract by using the coordination contract. For the portfolio contract with royalties and revenue sharing, only when the inventor share ratio and royalty fee (per unit) follow the requirement that $\alpha r x = \pi - r x$, then the faculty puts in the optimal effort. Meanwhile, the faculty should transfer a rate δ of license income to firm to obtain its matched investment. In the scheme of side-payment self-enforcing contract, the profit transfer T, which could be positive or negative value, measures the contribution of faculty's effort and firm's investment to the success of UITT. By using the coordination contract with T, the faculty could obtain positive compensatory payment that reflects their time spent and tacit knowledge on UITT, but not only limited to the transfer of patent right.

(2) The role of university technology transfer office

Many studies have investigated the efficiency of TTO, and considered TTO as economic-driven (Anderson et al., 2007; Caldera and Debande, 2010; Chapple et al., 2005; Curi, Daeaio, and Lierena, 2012). Compared with these previous studies, I consider TTO's first target is to maximize the total social welfare of university technology transfer chain. As shown in Tables 5.14 and 5.16, although the match ($s_R = 1.23,\ s_F = 22.55$) in centralized decision-making could be considered as the benchmark because of the maximum profit of UTTC, the utility of faculty and/or firm is partially smaller than those in decentralized decision-making that does not follow the ICC requirement. It suggests that the centralized decision-making mode intensifies double moral hazard and the coordination of contract is needed to redistribute the stakeholders' profit. However, the traditional patent license contract with single payment term cannot achieve this goal (Proposition 5.16). In order to achieve the best performance ($U_{Sc} = 404.95$), adopting the portfolio contract with royalties and revenue sharing or side-payment self-enforcing contract to maximize the social welfare is the TTO's first role. In this study, I found that there are some limitations for portfolio contract because it could only solve the issue of revenue redistribution in some specific conditions (Inequality 14 and Table 5.15), while the side-payment self-enforcing contract could coordinate faculty's effort and firm's investment effectively (Table 5.16).

The second role of TTO is to distribute the license revenue R between faculty and TTO, the patent output π between firm and TTO. In the portfolio contract with royalties and revenue sharing, TTO has to make the matched inventor share ratio, royalty fee (per unit) and revenue sharing factor meets the requirements presented in Equations (5.34) and (5.35) and Inequality (5.36). It indicates that the feasible solution space is a linear space related to the inventor share ratio, and TTO obtains its maximum utility at the smallest boundary point $\{\min\{\alpha\}, r(\alpha), \theta(\alpha)\}$ (Proposition 5.18). However, in the side-payment self-enforcing contract, there is little limitation about the feasible solution space. After making the profit transfer T, TTO could maximize its own utility at the point $\{\min \alpha, \max r\}$ (Proposition 5.19).

(3) Portfolio contract vs. the side-payment self-enforcing contract

There are three differences between portfolio contract and side-payment self-enforcing contract: (1) the portfolio contract only could coordinate faculty's effort and firm's investment in a special feasible condition, while the side-payment self-enforcing contract works more effectively without any restrictions; (2) the portfolio contract mainly focuses on the distribution proportion of added profit, and redistributes the added profit in the final stage of UITT according to the product yield. Therefore, it is impossible for TTO to write an accurate revenue sharing factor between the faculty and firm because of uncertain product yield. In the side-payment self-enforcing contract, the profit transfer T depends on faculty's effort and firm's investment, and the absolute value of profit transfer is adopted. The faculty can get paid according to their time spent. So the TTO can easily write an ex-ante contract term that specifies the faculty's labour remuneration based on their time spent. And (3), the side-payment self-enforcing contract takes into account the patience degree which reflects the participants' negotiation power expressed by the Rubinstein bargaining factors. To conclude, I convince that the side-payment self-enforcing contract is a better coordination contract to optimize the social welfare of university technology transfer chain and all participants' utilities.

5.6 Summary

In this chapter, based on some strict but understandable theoretical assumption, I make clear how the faculty disclose their invention and choose preferred commercial mode in the competition/collaboration environment, what is the influence of patent quality checking in the process of UITT, and how to design contract and distribute licensing revenue between faculty, university, TTO, and industrial firms fairly. Table 5.17 summarizes all theoretical results.

Table 5.17 Summaries of all theoretical results

UITT process	Theoretical result
Invention disclosure	• Reputation and competition have opposite effects on university disclosure, whereas economic benefit and collaboration are positively related to firm disclosure. These four influencing factors have a close relationship with the disclosure stage. • The simulation results illustrate that initial and additional reputations have different impacts on the disclosure stage. An increase in the faculty's and the firm's capability promotes firm disclosure in the

	early stages, while the capability of the competitor has an opposite impact. However, entry cost relates negatively to the disclosure stage and to multi-stage disclosure.
Commercial mode selection	• The commercial mode selection depends on faculty's share if licensing revenue, faculty's initial capital and maximum effort, and interest rate. • Faculty's share of licensing revenue and non-economic benefit play positive impact on invention disclosure and faculty effort. • Increasing licensing price decrease invention disclosure rate and does not necessarily increase firm investment.
Quality checking	• Patent quality checking has negative relationship with invention disclosure, but it plays less influence on high-value patents. • The quality checking rate also negatively relate to faculty's share of licensing revenue and transferring cost. The policy of quality checking policy cannot implement with increasing faculty's share rate, and needs to match with university licensing strategies.
Contract design and revenue distribution	• The commonly observed license contract with single licensing item cannot reduce the double moral hazard of faculty inventor and firm. The portfolio contract with royalties and revenue sharing only works well in a specified feasible solution space. • The side-payment self-enforcing contract could effectively coordinate the inputs of faculty and firm, and the implementation Pareto is improved.

In this chapter, four mathematical models were built to investigate all stakeholders' action set in UITT from micro-level in order to understand faculty invention disclosure and provide instructive solutions to enhance the performance of UITT. Based on these theoretical results, I have the following research implications:

- Protect faculty original and mature scientific achievement and related economic benefit firstly, and then, build an open environment to encourage faculty share their research idea, approach, or inventions with peers, TTOs, and potential technology buyers.
- Promote faculty to disclose all inventions to university, meanwhile, respect faculty's choices of commercial mode, and provide necessary support.
- Check the quality of faculty disclosed invention (neither too strict nor too loose), match with university licensing strategies.

- Pay attention to moral hazard and adverse selection, and provide diversified license/sale contract including royalties, equity, milestone fee, annual fee, fixed fee, etc., according to various demands of technology buyer.

Regarding to the above research implication, I have a face-to-face interview with my classmate who is working in TTO of Tongji University. He said “I total agrees with these suggestion although some of them is hard to conduct, such as patent quality checking.” He explained that Chinese university still lack a patent quality standard, and most times the TTO staff have no authority and capacity to judge whether faculty’s invention is valuable to apply a patent. Regarding to faculty invention disclosure, the best strategy for university is paying attention to this phenomenon but do not try to prevent the non-university assignment.

All in all, combining the empirical and theoretical results, in the next chapter, this thesis would discuss all research findings, and the triangulation analysis would be employed to give more common research results.

Chapter 6 Discussion, Recommendations and Conclusion

To achieve the research aim, this study established three objectives and related research questions that are to be individually addressed. I carry out four independent analyses, namely, the interview survey with technology managers, the questionnaire survey for university faculty inventors, the game modelling of decision-making and the empirical study based on a unique patent dataset. This chapter summarises the findings and presents the triangulation of the results. Some common and important issues are also proposed for discussion and for use as bases in developing recommendations.

6.1 Response to each objective and its sub-objective

6.1.1 Response to overall objectives

Table 6.1 summarises how each of the objectives/sub-objectives and related research questions are addressed through the three independent analyses. Column 4 of the table presents the detailed answers to the questionnaires.

Table 6.1 Summary of research objectives, questions and responses

Objectives	Sub-objectives	Related research questions	Responses to research questions
(1) To establish an analytical framework for understanding faculty patent assignment, with specific consideration for non-university assignment	1. defining the concepts of UITT and faculty patent assignment	Q (a). How are UITT and faculty patent assignment defined in this research? Q (b). What types of faculty patent assignment systems exist in China's universities?	Objective (1) and its sub-objectives have been addressed in Chapter 2. Chapter 2 provided the detailed answer to Question (a), (b), (c), while Chapter 4 gave the answer to Question (d) through interviews.
	2. investigating the influencing factors of faculty patent assignment	Q (c). What are the influencing factors for faculty patent assignment, and how do these affect faculty decision-making as indicated in the literature review and interviews?	
	3. investigating UITT development in China	Q (d). How does UITT develop or progress in Chinese universities?	

(2) To clearly elucidate the reality that surrounds faculty patent assignment in Chinese universities	1. building a unique dataset and re-examining faculty patent assignment 2. examining influencing factors at the individual and organisational levels in China's universities	Q (e). How many faculty patents are assigned separately to universities and industrial firms, jointly to universities and firms or separately to individual faculty in Chinese universities? Q (f). What affects the decisions of faculty regarding assignment?	Objective (2) and its sub objectives have been successfully addressed in Chapter 4 through empirical study. 13.16% of faculty/patent pairs were not solely assigned to university. Chapter 4 provided the detailed answer to Question (f).
(3) To build theoretical game models of decision-making regarding invention disclosure	1. to investigate the optimal stage and type of invention disclosure for faculty 2. to examine the influence of university policies on faculty invention disclosure and UITT route selection 3. to examine the influence of patent evaluation on faculty invention disclosure and university licensing strategies 4. to design a contract that coordinates stakeholder decision-making with public interest	Q (g). How are optimal disclosure stage and type chosen in Chinese universities? Q (i). What is the relationship between faculty profit and invention disclosure? Q (j). How do revenue policies affect patent assignment and UITT route selection? Q (h). How does patent quality checking affect invention disclosure and licensing decisions? Q (k). How is stakeholder decision-making coordinated? Q (l). How do licensing contracts affect the decisions of faculty regarding invention disclosure?	Objective (3) and its sub objectives have been adequately addressed in Chapter 5. Chapter 5 gave answers to Question (g)-(l) based on simulation of decision-making process with four game models.
(4) To triangulate the research findings in this thesis	1. determining whether the theoretical game models are aligned with the other analyses 2. formulating policy recommendations	Q (m). Do the theoretical findings correspond with the interview and empirical results? Q (n). What improvements to the UITT process can Chinese universities and the	Objective (4) and its sub-objectives have been addresses through triangulation analysis. Chapter 6 answered the Question (m) and (n) adequately.

government implement?

6.1.2 Proof of propositions for Objective 2

Table 6.2 shows the tests on the propositions about Objective 2, which is addressed by the interviews and empirical study (Chapter 4). The overall evaluations are based on the interviewees' responses. The final column of the table provides illustrates the overall understanding of the issue at hand.

Table 6.2 Proof of propositions for Objective 2

To understand the real picture of faculty patent assignment based on the data set of 35 top patent applications of Chinese universities, by 1. To build a unique dataset and examine faculty patent assignment, and 2. To examine its influencing factors in individuals and organizations level			
Interviews with TTO directors and technology managers			
Proposition	**Related Question**	**Tests**	**Overall Result**
Proposition 4.1 (IS): The non-university assignment is common in China's universities.	Q (e) How many faculty patents are assigned separately to universities and industrial firms, jointly to universities and firms or separately to individual faculty in Chinese universities?	Proposition 4.1 (IS) is tested in section 4.2.2, Chapter 4.	**Supported**
Proposition 4.2 (IS): The university licensing revenue management has the significant impact on faculty decision-making of patent assignment.	Q (f) What affects the decisions of faculty regarding assignment?	Proposition 4.2 (IS) is tested in section 4.2.2, Chapter 4.	**Supported**
Proposition 4.3 (IS): China's current patent management system plays negative impact on the university assignment.		Proposition 4.3 (IS) is tested in section 4.2.2, Chapter 4.	**Supported**
Empirical study based on a unique dataset			
Proposition 4.1 (ES): The invention characteristics play significant role on faculty patent assignment.	Q (f) What affects the decisions of faculty regarding assignment?	Tested in section 4.5.1, 4.5.2 and 4.6.1, Chapter 4.	**Supported.** High quality patent is more likely assigned to non-university assignees.
Proposition 4.2 (ES): The more eminence of universities		Tested in section 4.5.1 and 4.5.2,	**Not supported** A positive

increases the likelihood of non-university assignment in China’s universities.		Chapter 4.	relationship with university assignment
Proposition 4.3 (ES): The higher inventor share of licensing revenue will enhance the university assignment.		Tested in section 4.5.1 and 4.5.2, Chapter 4.	**Supported**
Proposition 4.4 (ES): The inventor characteristics play significant role on faculty patent assignment.		Tested in section 4.5.1 and 4.5.2, Chapter 4.	**Supported**
Proposition 4.5 (ES): The university characteristics play significant role on faculty patent assignment.		Tested in section 4.5.1 and 4.5.2, Chapter 4.	**Partially supported**
Proposition 4.6 (ES): The university R&D input/output plays significant role on faculty patent assignment.		Tested in section 4.5.1 and 4.5.2, Chapter 4.	**Not supported** Weak impact om patent assignment.
Proposition 4.7 (ES): The faculty in high competitive city prefers non-university assignment.		Tested in section 4.5.1 and 4.5.2, Chapter 4.	**Not supported** Positive impact on university assignment

6.1.3 Response to Objective 3

Table 6.3 shows the tests on the propositions about Objective 3, which is addressed by the four theoretical game models (Chapter 5). The overall assessments of each proposition are confirmed.

Table 6.3 Proof of propositions for Objective 3

To simulate the decision-making through building a series of theoretical game models.

1. To investigate faculty’s optimal invention disclosure stage and type

2. To examine the influence of patent quality checking on faculty invention disclosure and licensing strategies,

3. To examine the influence of university policies on faculty invention disclosure and the UITT route selection, and

4. To design a coordination contracts that coordinate all stakeholders’ activities from public interest.

Theoretical game models: Commercial mode selection and faculty invention disclosure

Propositions	Related Questions	Tests	Overall Results
Proposition 5.1 (GM): The probability of successful UITT plays negative	Q (i) What is the relationship	Approved in section 5.3.2,	**Supported**

role on the invention disclosure rate, but positive role on the licensing price.	between faculty profit and invention disclosure?	Chapter 5.	
Proposition 5.2 (GM): The faculty's share of licensing revenue is positively related to the invention disclosure rate and licensing price.		Approved in section 5.3.2, Chapter 5.	**Supported**
Proposition 5.3 (GM): The invention disclosure rate is positively related to the noneconomic benefit.		Approved in section 5.3.2, Chapter 5.	**Supported**
Proposition 5.4 (GM): In TTE mode, there has: (1) The faculty's share of licensing revenue is positively related to the faculty effort, and, (2) The influence of royalty fee per unit on faculty effort, firm investment and the success rate of technology transfer will all depend on a particular point: when $r \le \frac{ab\pi}{(a+1)x} = r_0$, they all increase with royalty fee per unit; however, when $r > r_0$, the opposite trend occurs.	Q (j) How do revenue policies affect patent assignment and UITT route selection?	Approved in section 5.3.2, Chapter 5.	**Supported**
Proposition 5.5 (GM): When the royalty fee (per unit) is smaller than r_0, the optimal licensing contract $(\alpha(t_R^{21}, s^{21}), min\{r(t_R^{21}, s^{21}), r^0\})$ will be obtained in order to maximize the TTO's utility.		Approved in section 5.3.2, Chapter 5.	**Supported**
Proposition 5.6 (GM): In TTS mode, (1) When $t_R \in [0, t_R^0)$ and $A_1 e^{-\gamma T} - (\sigma - \alpha)(rx_{22} + m) > 0$, the faculty inventor will not disclose the invention to the TTO, and the optimal effort is $t_R^* = min\{t_R^0, t_R^{22}(p = 0)\}$, (2) When $t_R \in [t_R^0, +\infty)$ and $A_1 e^{-\gamma T} - (\sigma - \alpha)(rx_{22} + m) > 0$, the faculty inventor discloses the invention to the TTO, and the optimal effort is $t_R^* = max\{t_R^0, t_R^{22}(p = 1)\}$, and, (3) When $A_1 e^{-\gamma T} - (\sigma - \alpha)(rx_{22} + m) < 0$, the faculty inventor's optimal effort is $t_R^* = t_R^{22}$.		Approved in section 5.3.2, Chapter 5.	**Supported**
Proposition 5.7 (GM): In TTS mode, the TTO's utility is a concave function, and its maximum value is obtained at the boundary point. The optimal inventor share profit is $\max\left\{\alpha(t_R^*), \sigma - \frac{A_1 e^{-\gamma T}}{rx_{22}+m}\right\}$, and the optimal royalty fee per unit is $r(\alpha^*)$.		Approved in section 5.3.2, Chapter 5.	**Supported**
Theoretical game models: Influence of patent quality checking			

Proposition 5.9 (GM): When the expected value of invention is less than the adoption cost, choosing S2 cannot play any impact on the optimal invention checking rate; iff the expected interest rate is less than the critical point $\hat{r}$ ($r \leq \hat{r}$), the TTO would not license any unchecked invention.	Q (h) How does patent quality checking affect invention disclosure and licensing decisions?	Approved in section 5.4.3, Chapter 5.	**Supported**
Proposition 5.10 (GM): When the expected value is greater than the adoption cost, whether the TTO adopts the S2 has no influence on the optimal invention checking rate. When the expected interest rate is lower than the critical point $\tilde{r}$, the TTO will not choose the S2. Iff $\pi_{TTO}^{R} > \pi_{TTO}^{N}$ and $r \leq \tilde{r}$, TTO's optimal strategy is the S1 that only licenses high-value invention which has passed the checking process.		Approved in section 5.4.3, Chapter 5.	**Supported**
Proposition 5.11 (GM): As a result of the influence from the interest rate and the expected value, the TTO has to match the optimal checking strategy and licensing choice.		Approved in section 5.4.3, Chapter 5.	**Supported**
Proposition 5.12 (GM): The inventor share of licensing revenue has no any impact on the optimal invention checking rate. Iff $v_E - c_F > \delta P(v)(v - c_F)$, the disclosure of high value invention increases with the inventor share rate.		Approved in section 5.4.4, Chapter 5.	**Supported**
Proposition 5.13 (GM): If the TTO decide to check the invention quality, its effect on the faculty invention disclosure, including high value and low value invention.		Approved in section 5.4.4, Chapter 5.	**Supported**
Theoretical game models: Licensing contract design			
Proposition 5.14 (GM): There exists optimal license contract for the TTO; the optimal contract is $\{\theta^* = 1 - \sqrt{\frac{1+a}{\pi b}},\ \alpha^* = \frac{(1-a)\sqrt{\pi b}+a\sqrt{1+a}}{(1+a)(\sqrt{\pi b}-\sqrt{1+a})}\}$; or $\{r^* = \frac{1}{x}\left(\pi - \sqrt{\frac{\pi}{b}}\right),\ \alpha^* = \frac{1}{(1+a)(\sqrt{\pi b}-1)}\}$.	Q (k) How is stakeholder decision-making coordinated? Q (l) How do licensing contracts affect	Approved in section 5.5.3, Chapter 5.	**Supported**
Proposition 5.15 (GM): The success rate of UITT and the total social welfare of UTTC in centralized decision making mode are greater than those in decentralized	the decisions of faculty regarding invention	Approved in section 5.5.3, Chapter 5.	**Supported**

decision making mode; there exists mismatches of faculty's effort and firm's investment because of double moral hazard.	disclosure?		
Proposition 5.16 (GM): The single royalties or equity payment cannot solve the issue that makes faculty (or firm) input the same optimal effort level (or investment) in two types of decision mode.		Approved in section 5.5.3, Chapter 5.	**Supported**
Proposition 5.17 (GM): The portfolio contract coordinates with royalties and revenue sharing coordinates the faculty and firm to put in the matched effort and investment, only when they obtain equal profit from technology transfer; the revenue transfer from faculty to firm depends on inventor share ratio, royalties, and faculty's importance.		Approved in section 5.5.4, Chapter 5.	**Supported**
Proposition 5.18 (GM): The TTO could achieve its maximum profit at the boundary point.		Approved in section 5.5.4, Chapter 5.	**Supported**
Proposition 5.19 (GM): In the side-payment self-enforcing contract, the faculty always obtains a positive added profit related to their effort; TTO maximizes its utility at the point $\{\min \alpha, \max r\}$.		Approved in section 5.5.4, Chapter 5.	**Supported**

6.2 Triangulating the findings from the three research methods

This study establishes objectives, sub-objectives and related research questions for addressing. I conduct three independent analyses, namely, an interview with the directors and technology managers of selected Chinese universities, an empirical study based on a unique dataset and four theoretical game models (i.e. invention disclosure, patent checking, licensing revenue management and contract design models). Under each of these analyses are propositions to be validated. This section presents the triangulation of the research findings from the analyses. The triangulation is designed to identify commonalities in the results (Table 6.4).

Table 6.4 indicates that because numerous basic assumptions in theoretical game models are extracted from the interviews and empirical study, many of the propositions under the theoretical game models support the propositions falling under other research methods. A more interesting direction is to determine how real-world relationships are translated into mathematical models to obtain more details beyond a phenomenon. Propositions 4.1 (IS), 4.2 (IS) and 4.3 (IS) from the interviews are all supported by the empirical study and/or the four game models. Because Propositions 4.2 (ES), 4.6 (ES) and 4.7 (ES) from the empirical study are unsupported, they cannot be corroborated by the findings derived from the other analyses. The last column of Table 6.4 summarises my remarks related to these propositions.

Table 6.4 Triangulation of findings from three research methods

Propositions from interviews	Propositions from the empirical study	Propositions from four game models	Remarks
Proposition 4.1 (IS): For the faculty patent, the non-university assignment is common in China's universities.	13.16% of faculty /patent pairs are not solely assigned to university, and higher quality patent is more likely assigned to non-university assignees. **Tested**		The TTO should cope with this situation from aspect of patent quality checking, revenue manage and contract design.
Proposition 4.2 (IS): The university licensing revenue management has the significant impact on faculty's decision making about patent assignment. **Supported**	**Proposition 4.3 (ES):** The higher inventor share of royalty or equity will enhance the university assignment. **Supported**	**Proposition 5.2 (GM):** The inventor's share of licensing revenue is positively related to faculty's disclosure rate and licensing price. **Partially Supported**	The TTO should increase the inventor share rate but not damage the faculty entrepreneurship because of higher licensing fee.
Proposition 4.3 (IS): The current patent management system in universities plays negative impact on the faculty patent university assignment. **Supported**	**Proposition 4.5 (ES):** The university characteristics play significant role on faculty patent assignment. **Partially supported**	**Proposition 5.15 (GM):** There exist mismatches of faculty's effort and firm's investment because of double moral hazard. **Supported**	The government and university should make changes in invention ownership and organization structure.
	Proposition 4.1 (ES): The invention characteristics play significant role on faculty patent assignment. **Supported**	**Proposition 5.1 (GM):** The probability of successful UITT is negatively related to faculty's disclosure rate. **Supported**	The TTO should prevent the disclosure of low quality through quality checking.
	Proposition 4.4 (ES):	**Proposition 5.3 (GM):**	The TTO should

	The inventor characteristics play significant role on faculty patent assignment. **Supported**	The faculty's invention disclosure has a positive relationship with non-economic benefit. **Supported**	pay more attention to the influence of non-economic benefit of faculty decision-making.

6.3 Themes for discussion and recommendation

Through the comparative analyses and the triangulation of results, I found that some of the findings are supported by the different analyses conducted in this work. The three propositions from the interviews are validated by the empirical study, and the latter is validated by the theoretical game models. This section consolidates the issues that are common amongst all the analysis, with consideration for several themes: non-university patent assignment, incomplete information, patent quality checking, incentive policy packages and government intervention.

6.3.1 Non-university patent assignment

As previously discussed, non-university assignment is a prevalent practice in Chinese universities. To illustrate, 13.16% of faculty/patent pairs are not assigned solely to universities (5.28% are assigned to private firms, 5.73% are attributed to a university and a firm as joint assignees and 2.15% are assigned to faculty).

This phenomenon is due to three key factors. (1) As indicated in the empirical study, patent quality considerably influences faculty decision-making on assignment. Some Chinese faculty members would rather assign high-quality patents to non-university assignees than to universities—a practice that is regarded as inappropriate. (2) As determined from the questionnaire survey on Chinese faculty, this type of assignment stems from R&D cooperation between faculty and firms or from technology consulting arrangements. Under this situation, non-university assignment is legal and beneficial to UITT. (3) Finally, the issue of economic returns encourages non-university assignment. Disclosing inventions to non-university assignees earns inventors 100% of licensing benefits.

From the perspective of individual faculty, the principal factors that figure in faculty decision-making regarding patent assignment are invention and inventor characteristics and university licensing revenue management. In terms of an organisational viewpoint, university characteristics and city competitiveness are primary determinants of assignment-related decision-making.

6.3.2 Information asymmetry

Faculty, TTOs and firms are three major stakeholders in UITT. As a result of conflicts of interest amongst these stakeholders, information asymmetry occurs.

With respect to a faculty perspective, if faculty members do not disclose their inventions/patents at the beginning of the UITT process, a TTO will not determine how many patents have been assigned to non-university assignees. If faculty disclose patents to the TTO, patent quality counts as private information belonging to the faculty, with the TTO and firm having no knowledge of such information. This situation motivates faculty to disclose low-quality patents to TTOs for some non-economic benefits. When a licensing contract is signed, the effort that faculty commit to UITT cannot be measured and is unobservable by TTOs and firms. Therefore, TTOs should carefully verify patent quality and reasonably distribute licensing revenue to inventors to alleviate information asymmetry.

With regard to a TTO perspective, in most cases, TTOs have more information on faculty and potential technology demand than do other stakeholders because these agencies serve as links between patent creators and patent buyers. Another advantage of TTOs is that they can evaluate the commercial value of patents. This superiority in information enables a TTO to function as an intermediary. Furthermore, if a TTO decides to verify patent quality, the number of faculty patents for checking falls within the purview of the TTO as private information. This kind of information asymmetry improves the quality of disclosed inventions.

From a firm perspective, two kinds of private information arise. The first is a firm's actual purpose for buying faculty patents. A firm sometimes aims to establish patent pools to prevent other competitors from entering the field to which it belongs, thereby damaging universities' intention to initiate technology diffusion. The second type of private information is the fact that a firm's effort in advancing UITT cannot be estimated. A firm is motivated to maximise its individual payoffs by cutting costs; this tendency results from the fact that firms are economically driven. A case unique to China is that firms secure high-tech enterprise certification (approved by the government) by purchasing faculty patents.

6.3.3 Patent quality checking

Verifying patent quality effectively eliminates the problem posed by low-quality patents, although it sometimes negatively affects invention disclosure. Therefore, choosing a reasonable checking rate and an appropriate checking strategy is difficult for TTOs to accomplish.

If the expected value of a faculty invention is less than its adoption cost, a TTO is obligated to verify invention quality and exclude inferior creations from a university patent application list. More specifically, a TTO's primary task is to define a quality checking rate that is the decreasing function of inventor share rate and adoption cost. The second task of a TTO is determining a strategy for dealing with unchecked patents. This study indicates that TTOs cannot license unchecked patents if they significantly value their long-term profit. If the expected value of a faculty invention is larger than its adoption cost, verifying patent quality is unnecessary only when the checking cost is less than the added interest resulting from high-quality patent licensing. Similarly, for unchecked patents, a TTO's final decision depends on the interest rate, which reflects the short-term profit versus the long-term profit.

Considering the influence of patent quality, a TTO's decision on quality checking and licensing strategy depends mainly on the expected value of inventions and interest rates.

6.3.4 Incentive policy package

The inventor's share of licensing revenue stated in published university policies is the most critical factor for invention disclosure. First, increasing an inventor's share rate can encourage faculty to voluntarily disclose their inventions. Second, a high inventor share rate may raise licensing price, thereby negatively affecting product yield and reducing total licensing fees. Furthermore, a high inventor share rate negatively influences faculty entrepreneurship because it increases the cash expenses of faculty start-ups. In this case, faculty who want to establish their own start-ups are unwilling to disclose inventions. Therefore, if a TTO wants to improve invention disclosure by increasing the inventor's share of licensing revenue, it should be ready to relinquish part of licensing benefits.

The efficiency of increasing the inventor share rate for invention disclosure rests chiefly on patent quality, faculty's capital and faculty's free time. If patent quality is lower than the expected level, an increase in the inventor share rate cannot promote invention disclosure. The same trend is expected when a faculty's capital is insufficient. Finally, unless faculty have enough time to take part in UITT, increasing the inventor share rate cannot encourage faculty to disclose their inventions and exert more effort in advancing UITT.

The provision of non-economic benefits is another important incentive policy. In Chinese universities, faculty disclose inventions to their universities to secure professorship; the number of patent applications and authorisation are KPIs for faculty. Moreover, faculty adopt invention disclosure to establish peer reputation.

6.3.5 Government intervention

Chinese universities are public institutions without actual independent legal person status. They are controlled by central government agencies or local governments. The 'Patent Law' stipulates that patents resulting from government research funding belong to universities, and faculty patents are regarded as state-owned intangible assets. SAOs have the authority to implement final decisions regarding these issues. In this complex bureaucratic system, substantial uncertainty exists given that a university is required to obtain permission from its superiors. In many cases, this process takes more than half a year, especially when the patent transaction price is over RMB 8 million.

Because the Chinese government tends to protect employers' interests, faculty are denied the right to apply for and own patents. Related regulations also require faculty to disclose all service and non-service inventions to universities. If faculty can prove that their creations are non-service inventions, they can independently apply for patents. Nonetheless, providing evidence is difficult for faculty to accomplish, thus driving faculty to opt for the attribution of patents to non-university assignees. In this situation, faculty can own patents and earn 100% of licensing profits, although they will have to bear possible legal risks.

The central government, local governments and universities in China all encourage faculty to create an increasing number of inventions and financially support patent applications (i.e. paying for patent application fees, patent renewal fees, etc.). However, these institutions do not conduct genuine patent value assessment, thus creating an environment that encourages faculty to create low-quality inventions that pose no economic or non-economic risks.

To evolve into an innovation-driven country, Chinese governments provide research funding under the condition that faculty commit to completing a specific number of inventions. Innovative spirit amongst faculty is thus not a product of curiosity but of pressure arising from the obligation forced upon inventors. Producing low-quality inventions is easily accomplished in a short time; this approach is therefore an appealing means of satisfying government requirements for research projects.

6.4 Policy implications

The discussion in Section 6.3 highlighted the role of government, indicating the need for policy recommendations that improve faculty invention disclosure. This section summarises key policy suggestions.

6.4.1 Government perspective

As an authority that establishes regulatory agencies and policies, the government has more power than any other organisation or market in terms of improving internal decision-making, management practices and organisational structures. The government should adopt clearly defined policies and coherent policy measures to enhance faculty invention disclosure. With the research findings as bases, I craft recommended policies for the government.

(1) The government should eliminate approval agencies and endow universities independent rule over patent issues. This strategy may accelerate UITT and promote faculty invention disclosure.

(2) Inventors' rights should be protected by allowing faculty to own their original inventions or share ownership with universities. This measure can encourage the voluntary disclosure of high-quality inventions/patents.

(3) The government should provide strong incentives regulations. From economic perspective, the licensing revenue policies should be strictly implemented. The economic returns resulting from patent licensing should not be turned over to the state treasury and then refunded to universities. They should be directly distributed equally amongst faculty members, TTOs staff and universities.

(4) The university-run TTO should be non-profit organization.

(5) Faculty should be charged patent application fees and renewal fees by government because this may reduce the disclosure of and patent applications for low-quality inventions.

6.4.2 Market perspective

The government's policy mechanisms alone are ineffective because adhering to government regulations translates to high expenses. From a market perspective, all faculty patents should be commercialised. In some ways, market forces, in the form of economic incentives, can persuade faculty to disclose their inventions. On the basis of these observations, establishing a policy that leverages market forces is proposed.

(1) A value interval should be created for the inventor's share of licensing revenue (neither too low nor too high), and faculty should be allowed to negotiate with universities to enable them to protect their economic interests. These measures may motivate faculty with high-quality patents to share high licensing revenue.

(2) A market-oriented patent quality checking and related services should be established, standardised and implemented to gain the trust of faculty members.

(3) Demand from the technology market should be stimulated. Universities and faculties should be encouraged to apply for patents in accordance with market demand and potential commercial value, rather than on the basis of academic value.

6.5 Limitations and future research

Section 1.8 of this thesis presents the limitations of this study. In this section, additional limitations and future research directions are discussed in detail. The highlight of this study is its comprehensive analyses from different perspectives and different research methods: four theoretical game models, empirical research based on a unique dataset, interviews with the TTO directors and questionnaire administration to faculty.

Although a constant goal is to ensure excellence in the analyses, certain potential drawbacks remain. First, the empirical study focuses only on faculty patent assignment in relation to the top 35 applications from Chinese universities. More than 2,000 universities are not covered by this sample. As a result of insurmountable difficulties in data collection, this study cannot provide overwhelming evidence that non-university assignment stems from consulting arrangements. In addition, if the faculty inventions are assigned to their family members or other guanxi categories with different names, for example to firms where faculty had some ownership or otherwise could benefit from the IP without submitting to the state, these forms of invention assignment are extremely difficult to assess and track. In the future, a possible improvement is studying these forms case by case.

The validity of the four theoretical game models, which are characterised by numerous mathematical equations and inequations, is open to debate because of what may be excessively stringent assumptions. Finally, with regard to the discussion of results, additional questionnaires should have been administered to enable an accurate evaluation of the research implications put forward in this thesis. However, invention disclosure may be a highly sensitive topic for university faculty. Only a few of the questionnaires were returned, prompting me to concentrate on the data from the face-to-face interviews. Overcoming these problems would necessitate more time in taking account of each potential weakness.

This study provides a wide platform from which to launch further research. It has established a conceptual framework for investigating faculty patent assignment and comprehensive UITT. In the future, the influence of technology demand on invention disclosure should be considered. Meanwhile, because this work has introduced the university technology transfer chain into UITT, another potential research direction is developing strategies for coordinating and optimising all stakeholders' practices from the perspective of technology transfer chain management.

6.6 Conclusion

This thesis has explored faculty invention disclosure and patent assignment in mainland China. It provides a sufficiently reviewed body of literature, including that on UITT and faculty patent assignment and the influencing factors for invention disclosure. It has comprehensively analysed China's faculty invention disclosure from the perspectives of faculty, universities, TTOs and the government. The four key research methods used are interviews, a questionnaire survey, an empirical study and four theoretical game models. The interviews with TTO directors provided an introduction to faculty invention disclosure in Chinese universities. The questionnaire administered to the faculty confirm the details in the introduction and expands the information on influencing factors. The empirical study provided rich data on the overall picture of patent assignment in the Chinese universities from which the top 35 applications originated. This study also verified the influencing factors. The four theoretical game models were used to simulate the decision-making process from the perspectives of invention disclosure, quality checking, licensing revenue management and contract design. Triangulation analysis was adopted to combine the findings. It also advanced the formulation of policy recommendations.

The overall research findings include both empirical and theoretical results. These findings are expected to aid the understanding of faculty invention disclosure and patent assignment in the UITT process. They are also anticipated to be beneficial to policymakers in terms of improving their knowledge regarding how licensing revenue should be distributed and how licensing contracts should be designed. Delineating these strategies can enhance faculty invention disclosure rates and ensure the success of university technology transfer.

Appendices

Appendix A: The questionnaire with TTO in Chinese universities

Dear Mr/Miss

I am CHANG Xuhua, a dual joint-PhD student in Tongji University and The Hong Kong Polytechnic University. Now an interesting research related to technology transfer office in China's universities was conducted for my PhD research work. Due to your rich experience of university technology transfer, please let me sincerely invite you to take part in our survey.

Two part of questionnaire include in this survey: a brief introduction about your technology transfer office is as the first part, and then your opinion on some special questions will be collected in the second part. I promise that what I have collect from you will only be used for our research, anything about your personal information will be protect safely. If you would like to participate in our research, please answer the following 18 questions and email to cumtcxh2008@ or 1290 before June 10th, 2014.

Many thanks for your attention.

PART 1 Brief Introduction about Technology Transfer Office (TTO)

(Please choose the right answer and click the option button)

1.1 How do you think the ability of TTO on patenting cultivating and technology development? (Single Option)

○ Minimum ○ Lesser ○ Average ○ Strong ○ Stronger

1.2 When did the TTO set up in your university?

1.3 How many staff in your TTO (Including staff in center, branch center and technology transfer platform established by local government).

1.4 How old average age of staffs in your TTO? (Single option)

○ 20-30 ○ 31-35 ○ 36-40

○ 41-45 ○ 46-50 ○ Over 50

1.5 What is the degree distribution in your TTO?

☐ Social, Undergraduate ☐ Social Master ☐ Social, PhD

☐ Technical, Undergraduate ☐ Tehnical, Master ☐ Technical, PhD

☐ Medical, Undergraduate ☐ Medical, Master ☐ Medicl, PhD

1.6 How much average salary in your TTO? (Single option)

○Under 50, 000 RMB (Including) ○ 6,000~100.000 RMB

○ 110,000~150,000 RMB ○ 160,000~200,00 RMB

○ 210,000~250,000 RMB ○ Over 260,000 RMB

1.7 How many patents (proportion) was licensed in nearly 5 years in your TTO?

- Collaboration________________________
- Simple license________________________
- Exclusive license_____________________
- Start-up enterprise____________________
- Sole license__________________________
- Others______________________________

1.8 How much patents licensing revenue (proportion) in nearly 5 years in your TTO?

- Full payment______________________
- Royalties payment ___________________
- Annual fee________________________
- Share option payment ________________
- Equity payment ___________________
- Others ______________________________

1.9 How many times do carry out duty-invention disclose and valuation training in your TTO every year?

○ 0 time ○ 1 time ○ 2 times

○ 3 times ○ 4 times ○ Over 5 times (Including)

PART 2: Your Opinion on University-Industry Technology Transfer (UITT)?

2.1 What do you think is the most important outputting of your TTO?

☐ Number of license ☐ License revenue

☐ Number of R&D contract ☐ Revenue of R&D contract

☐ number of incubating enterprises ☐ Number of faculty disclosure

If you have other ideas, please add____

2.2 What is the independence of your TTO with university administration?

○ Minimum ○ Lesser ○ Average ○ Strong ○ Stronger

2.3 Do you think what influences the efficiency of TTO?

☐Value of faculty patents is lo ☐Faculty do not want to participate UITT

☐Approval process is unreasonable ☐Local government policy is unreasonable

☐Enterprises' technology demand is small ☐Others

2.4 Do you think what aspects should improve immediately in your TTO?

☐Low salary

☐Lack of trust between faculty and UITT staff

☐Complex management on intangible assets

☐UITT staff with low professional

If you have other ideas, please add____

2.5 Do you think what is the vital for success of UITT?

☐Enterprise's investment willingness ☐Faculty inventors' participation in UITT

☐The bridge role of university TTO ☐Attention from center and local government

If you have any idea, please add____

2.6 Do you think why enterprises buy technology from university?

☐Need a special technology owned by university ☐Build patents pool

☐Investment based on university technology ☐Apply for new high-tech enterprise

If you have any idea, please add____

2.7 Do you think your working performance rely on your social network?

○ Never ○ Little ○ Average ○ Strong ○ Stronger

2.8 Do you think faculty's description could influence your patent evaluation?

○ Never ○ Little ○ Average ○ Strong ○ Stronger

2.9 In your daily work, which department do you take most time to communicate every month?

○ Faculty inventor ○ Enterprise

○ University administration ○ Local government

Now, you have finished all questions, thank you for your participation. For this research, I would like to share with you, if you are interesting it.

○ Give feedback ○ No feedback

Appendix B: Data collection and screening method

Figure B.1 gives details about data collection in this study. First, I collected all professors' individual information from their CVs in websites on three research fields in the 35 Chinese universities in our sample. The individual information includes date of birth, gender, research field, work experience, the date when they acquired the title of professor, and their experience of administrative position. Note that in this study I classify research field according to the titles of the university departments (e.g. schools of mechanical engineering, schools of telecommunications, or schools of life science).

Second, I collected patent documents from the CNKI database by faculty names, and then matched faculty names with first-inventor names. To ensure that the sample included only patents with faculty who were truly employed by universities on the dates of their patent applications, a screening method was adopted that aimed at eliminating inventors who were not true faculty inventors: (1) in our dataset, faculty with no patents were eliminated. In order to avoid name repetition in two or more universities, I excluded patent/faculty pairs if the faculty names appeared in different universities but in the same city; (2) I excluded patent/faculty pairs if name repetition occurred in two or more departments, regardless of whether the faculty had a part-time job in another department; (3) when a faculty name appeared in both the university and an external enterprise, and the first four figures of the zip code in the patent document was not the same as that of the university, the patent/faculty pair was excluded. Finally, (4) for a given faculty inventor, I checked every one of his/her patents according to the patent classification code. I excluded those patents that were significantly different from others. In the end, 18,435 faculty/patent pairs were created in our tailor-made dataset.

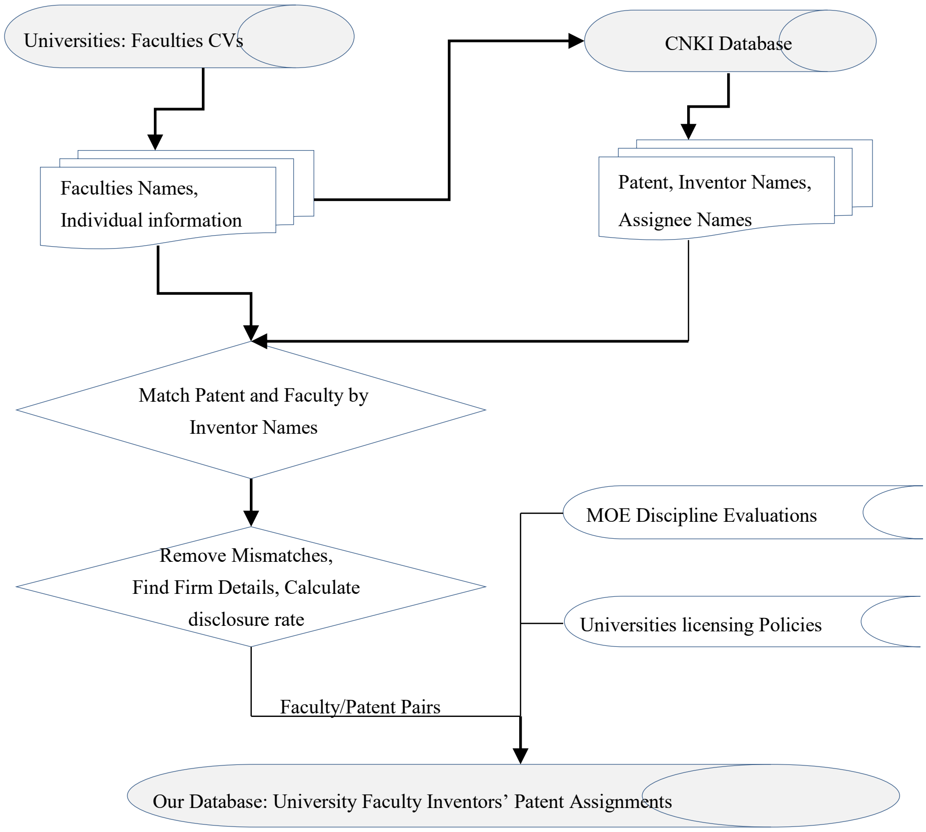

Figure B.1 Process of data collection

It is worth noting that our dataset is at the patent/inventor level. Because a single patent often has more than one inventor, I define a specific patent as the "faculty patent" only where the university faculty is the first inventor, and thus collect faculty patents according to the faculty name when faculty inventor is the first inventor in the patent document. This means that each patent appears only once in our dataset. In this way, patents in which the university faculty inventor takes part in R&D activities and is the second or third inventor will be excluded. Thus, I admit that our study has neglected some of the R&D collaboration activities between faculty and private firms. Perhaps the real proportion of university-firm assignment is higher than I claimed in this study.

Appendix C: Faculty Inventors in 35 China's Universities

NO	University	Status	Mechanical	Telecomm.	Life_Sci.
1	Tongji University	Prof	16 (83)	29 (183)	8 (42)
		No_Prof.	9 (15)	10 (22)	5 (11)
2	Shanghai Jiaotong Uiversity	Prof	67 (547)	57 (415)	21 (118)
		No_Prof.	93 (396)	79 (307)	12 (36)
3	Shanghai University	Prof	30 (151)	29 (178)	11 (96)
		No_Prof.	17 (50)	35 (132)	10 (28)
4	Donghua University	Prof	22 (357)	6 (42)	/
		No_Prof.	19 (102)	12 (36)	/
5	East China University Of Science and Technology	Prof	26 (146)	8 (24)	/
		No_Prof.	25 (64)	7 (17)	/
6	Fudan University	Prof	7 (13)	36 (454)	29 (443)
		No_Prof.	/	29 (138)	17 (120)
7	Tsinghua University	Prof	90 (872)	105 (1267)	19 (155)
		No_Prof.	122 (718)	164 (1035)	8 (21)
8	Beijing University of Aeronautics and Astronautics	Prof	54 (482)	19 (409)	9 (52)
		No_Prof.	45 (142)	41 (282)	18 (45)
9	Peking University	Prof	/	59 (446)	17 (79)
		No_Prof.	/	69 (337)	4 (5)
10	Beijing University of Technology	Prof	11 (124)	20 (147)	13 (71)
		No_Prof.	23 (60)	43 (127)	8 (31)
11	Southeast University	Prof	17 (119)	49 (504)	20 (206)
		No_Prof.	16 (81)	52 (282)	16 (63)
12	Nanjing University	Prof	/	24 (148)	28 (276)
		No_Prof.	/	26 (131)	11 (24)
13	Xiamen University	Prof	7 (30)	18 (89)	19 (111)
		No_Prof.	22 (71)	28 (79)	18 (45)
14	University of Science and Technology of China	Prof	11 (46)	14 (73)	9 (48)
		No_Prof.	18 (64)	24 (68)	1 (3)
15	Harbin Institute of Technology	Prof	57 (667)	9 (98)	2 (15)
		No_Prof.	51 (219)	25 (138)	6 (12)
16	Dalian University of Technology	Prof	28 (224)	25 (88)	9 (114)
		No_Prof.	45 (138)	18 (51)	12 (23)
17	Tianjin University	Prof	43 (351)	20 (195)	/

		No_Prof.	17 (157)	28 (154)	/
18	Nankai University	Prof	/	37 (189)	37 (333)
		No_Prof.	/	32 (59)	13 (30)
19	South China University of Technology	Prof	56 (468)	28 (337)	10 (77)
		No_Prof.	64 (246)	19 (122)	10 (52)
20	Sun Yat-Sen University	Prof	/	12 (342)	40 (346)
		No_Prof.	/	20 (70)	28 (70)
21	Sichuan University	Prof	24 (96)	13 (96)	21 (198)
		No_Prof.	11 (38)	3 (13)	19 (47)
22	University of Electronic Science and Technology of China	Prof	/	18 (102)	3 (6)
		No_Prof.	/	45 (177)	2 (2)
23	Jiangnan University	Prof	12 (81)	/	/
		No_Prof.	23 (66)	/	/
24	Zhejiang University	Prof.	41 (456)	20 (193)	25 (140)
		No_Prof	40 (251)	34 (203)	25 (116)
25	Zhejiang University of Technology	Prof.	16 (70)	21 (217)	/
		No_Prof.	/	31 (106)	/
26	Huazhong University of Science and Technology	Prof	51 (376)	71 (464)	24 (211)
		No_Prof.	43 (132)	58 (194)	14 (32)
27	Wuhan University	Prof	20 (65)	15 (55)	27 (258)
		No_Prof.	12 (43)	21 (41)	7 (26)
28	Shandong University	Prof	31 (185)	22 (272)	6 (12)
		No_Prof.	19 (40)	30 (175)	12 (39)
29	Northwestern Polytechnical University	Prof	27 (241)	13 (42)	6 (53)
		No_Prof.	44 (155)	19 (55)	8 (18)
30	Xi'an Jiaotong University	Prof	54 (457)	48 (322)	12 (60)
		No_Prof.	55 (241)	51 (178)	11 (21)
31	Chongqing University	Prof	31 (207)	41 (287)	5 (40)
		No_Prof.	33 (103)	70 (202)	3 (5)
32	Jilin University	Prof	25 (154)	14 (54)	8 (16)
		No_Prof.	22 (35)	10 (17)	4 (6)
33	Central South University	Prof.	26 (130)	21 (87)	4 (13)
		No_Prof	22 (47)	15 (37)	2 (3)
34	Hunan University	Prof.	28 (157)	24 (253)	/
		No_Prof.	28 (53)	13 (25)	/
35	Ocean University of China	Prof	20 (116)	9 (23)	/
		No_Prof.	10 (21)	6 (17)	/

[*]Source: 35 China's university website and CNKI database; the content in the brackets is the faculty/patent pairs; No_Prof includes associate professor and lecturers.

Appendix D: Example of "Prof. Ji" in Tsinghua University

University	Tsinghua University							
Patent NO.	1	2	3	4	5	6	7	9
Mechanical	1	1	1	1	1	1	1	1
Telecommunication	0	0	0	0	0	0	0	0
Life Science	0	0	0	0	0	0	0	0
Faculty as first inventor	季**							
Birth year	1964							
Gender	1							
Year obtained prof.	2012							
NO. Inventions	0	1	2	3	4	5	6	7
Status	0	0	0	0	1	1	1	1
Licensee	THU	THU; 荆州恒隆公司	THU; 荆州恒隆公司	THU; 荆州恒隆公司	THU; 武汉捷隆公司	THU; 武汉捷隆公司	THU; 武汉捷隆公司	THU; 武汉捷隆公司
University	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
firm	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Univ and firm joint	*0*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
Individual	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Claim	5	8	1	1	5	5	6	6
NO. Inventor	1	2	3	3	4	5	5	4
Patent name	A kind	A kind	A kind.	A kind.	A kind	A kind	A kind	A kind
Application year	2002	2007	2007	2007	2012	2012	2012	2012
Inventor's share of royalties	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Inventor's share of equity	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Discipline evaluation score	93.32	90	90	90	91	91	91	91

[*]"1" is equal to YES ("0" is equal to NO) while "1" is professor while "0" is associate professor or lecturer.

** Source: University website and Chinese National Knowledge Infrastructure (CNKI database)*

Appendix E: Proofs in this study

(1) Proof of Proposition 5.9

In TTE mode, in order to show that higher inventor share profit could encourage faculty and firms to put more effort into future investment, their derivative could be calculated as follows: $t_R'(\alpha) \geq 0,\ s'(\alpha) \geq 0$. I also obtained that $t_R''(\alpha) \leq 0,\ s''(\alpha) \leq 0,\ t_R'(r) \geq 0,\ s'(r) \geq 0,\ t_R''(r) \leq 0,\ s''(r) \leq 0$. Using $I = (p_\alpha', p_r')$, $B_\alpha = \left(t_R'(\alpha), s'(\alpha)\right)$, $B_{\alpha\alpha} = \left(t_R''(\alpha), s''(\alpha)\right)$, $B_r = \left(t_R'(r), s'(r)\right)$, $B_{rr} = \left(t_R''(r), s''(r)\right)$, and $B_{\alpha r} = \left(t_R''(\alpha, r), s''(\alpha, r)\right)$, it obtains that $p_\alpha' = \left(p_{t_R}', p_s'\right)B_\alpha^{\mathrm{T}} > 0$, and when $r \leq r_0$, $p_r' = \left(p_{t_R}', p_s'\right)B_r^{\mathrm{T}} > 0$, so I conclude that $p_{t_R t_R}'' < 0,\ IB_{\alpha\alpha}^{\mathrm{T}} < 0$ and $IB_{rr}^{\mathrm{T}} < 0$.

It obtain Hessian matrix $H = \begin{bmatrix} p_{t_R t_R}'' & p_{t_R s}'' \\ p_{s t_R}'' & p_{ss}'' \end{bmatrix}$, so H is a negative definite matrix, and it shows $p_{\alpha\alpha}'' = B_\alpha H B_\alpha^{\mathrm{T}} + IB_{\alpha\alpha}^{\mathrm{T}} < 0,\ p_{rr}'' = B_r H B_r^{\mathrm{T}} + IB_{rr}^{\mathrm{T}} < 0$, and $p_{\alpha r}'' = B_r H B_\alpha^{\mathrm{T}} + IB_{\alpha r}^{\mathrm{T}} < 0$.

(2) Proof of Proposition 5.10

In order to prove that there exists an optimal licensing contract to maximize the university TTO's utility, assuming the Hessian matrix of TTO's utility function is D.

$$D = \begin{bmatrix} U_{T_1}''|_{\alpha\alpha} & U_{T_1}''|_{\alpha r} \\ U_{T_1}''|_{r\alpha} & U_{T_1}''|_{rr} \end{bmatrix}$$

Then under the subject of $t_R = t_R^*, s = s^*, \alpha > 0, r > 0$, I know that

(1) When $r \leq r_0$, $U_{T_1}''|_{\alpha\alpha} < 0$, $U_{T_1}''|_{rr} > 0$, $U_{T_1}''|_{\alpha r} = U_{T_1}''|_{r\alpha}$, so the value of matrix D is larger than zero. The TTO's utility has the maximum value. Because point (0,0) is not stable, I claim that the maximum value of the TTO's utility could be obtained at the point of $(\alpha(t_R^*,\ s^*), \min\{r(t_R^*,\ s^*), r^0\})$. The TTO should share the proportion of $\alpha(t_R^*,\ s^*)$ with the faculty inventor and make the optimal patent licensing contract $(m, \min\{r(t_R^*,\ s^*), r^0\})$.

(2) When $r > r_0$, the value of matrix D cannot be confirmed, so I cannot be sure whether point $\left(\alpha(t_R^*, s^*), r(t_R^*, s^*)\right)$ is an optimal solution of the university TTO.

(3) Proof of Proposition 5.11

In TTS mode, in order to prove the positive relation between faculty effort and inventor share profit and royalty fee per unit, I find that $t_R'(\alpha) \geq 0$ and $t_R'(r) \geq 0$.

The premise condition that the faculty inventor will disclose the invention to the university TTO is as follows:

$$\alpha(p_2 r x_{22} + m) + \sigma(p_2 \pi_{22} - r x_{22} - m - C_t) + A_1 e^{-rT} \geq \sigma(p_2 \pi_{22} - C_t)$$

When $A_1 e^{-rT} - (\sigma - \alpha)(r x_{22} + m) > 0$, I obtain $t_R^0 > \frac{1}{a} \mathrm{Ln}\left(\frac{a\alpha r x_{22} p_0}{A_1 e^{-\gamma T} - (\sigma - \alpha)(r x_{22} + m)}\right)$. Thus, if $t_R \in [0, t_R^0)$, $p = 0$, otherwise $p = 1$. On the other hand, I order $U_R'|_{t_R} = 0$, then I get $t_R^{22} = \frac{1}{2} \mathrm{Ln}\left(\frac{pa\alpha r x_{22} p_0 + \sigma a \pi_{22} p_0}{A_0}\right)$ $(p = 0\ or\ 1)$. To summarize, when the invention is disclosed to the TTO, the faculty inventor's optimal effort is $t_R^* = \max\{t_R^0, t_R^{22}(p = 1)\}$; when the faculty establishes the start-up, his (her) optimal effort is $A_1 e^{-rT} - (\sigma - \alpha)(r x_{22} + m) \leq 0$; when the faculty inventor's optimal effort is $t_R^* = t_R^{22}$ $(p = 0\ or\ 1)$.

(4) Proof of Proposition 5.12

In order to find the optimal licensing contract to maximize the TTO's utility, because $p_\alpha' > 0$, $p_r' > 0$, $p_{\alpha\alpha}'' < 0$, $p_{rr}'' < 0$, and $p_{r\alpha}'' > 0$, so $U_{T22}'|_\alpha = (1 - \alpha) r x_2 p_\alpha' - (p r x_2 + m) > 0$, $U_{T22}'|_r = r p_r' + p > 0$, $U_{T22}''|_{\alpha\alpha} = (1 - \alpha) p_\alpha'' - 2p_\alpha' < 0$, $U_{T22}''|_{rr} = r p_{rr}'' + 2p_r' > 0$, $U_{T22}''|_{r\alpha} = r p_{r\alpha}'' + p_\alpha' > 0$, the value of the Hessian matrix of TTO utility is smaller than zero, the TTO's utility is a concave function , and there exists a maximum value of TTO utility.

Because TTO utility is increasingly a function of inventor share profit and royalty fee, its maximum value should be obtained at the boundary. Combining the results of Proposition 5.11, I conclude that when $A_1 e^{-rT} - (\sigma - \alpha)(r x_{22} + m) > 0$, the maximum value can be obtained at point $\{\alpha(t_R^*), r(t_R^*)\}$; when $A_1 e^{-rT} - (\sigma - \alpha)(r x_{22} + m) \leq 0$, the maximum value can be obtained at $\left\{\sigma - \frac{A_1 e^{-rT}}{r x_{22} + m}, r(\alpha^*, \sigma)\right\}$. Therefore, the maximum value of TTO utility is obtained at point $\left\{\max\left\{\alpha(t_R^*), \sigma - \frac{A_1 e^{-rT}}{r x_{22} + m}\right\}, r(\alpha^*)\right\}$.

(5) Proof of Proposition 5.13

Table E.1 shows the faculty's optimal effort, the firm's optimal investment, and the related probability of successful UITT in the traditional decentralized and centralized decision-making mode with the single royalty and equity payment.

When $U_{Sd}(\alpha,r) > U_{Sd}(\alpha,\theta)$, the royalty payment is used in the license contract. Then, for the given level of faculty effort and firm investment, I first denote $U'_{Sd}(\alpha)=0$, and have $(1+a)\alpha rx=\pi-rx$. Next, I denote $U'_{Td}(r)=0$, and obtain the optimal royalty fee (per unit) $r^*=\frac{1}{x}\left(\pi-\sqrt{\frac{\pi}{b}}\right)$ and the optimal inventor share rate $\alpha^*=\frac{1}{(1+a)(\sqrt{\pi b}-1)}$.

Similarly, when $U_{Sd}(\alpha,r) \le U_{Sd}(\alpha,\theta)$, I denote $U'_{Sd}(\alpha)=0$ and $U'_{Td}(\theta)=0$, then obtain the optimal equity rate $\theta^*=1-\sqrt{\frac{1+a}{\pi b}}$ and optimal inventor share rate $\alpha^*=\frac{(1-a)\sqrt{\pi b}+a\sqrt{1+a}}{(1+a)(\sqrt{\pi b}-\sqrt{1+a})}$.

Table E.1 Activities of faculty and firm in decentralized and centralized decision making

	Faculty's effort	Firm's technology investment	Success rate
Decentralized decision making with royalties	$s_{Rd}=\ln\frac{(1+a)a\alpha rx_d}{A_R b(\pi-rx_d)}$	$s_{Fd}=\frac{a+1}{b}\ln\frac{bp(\pi-rx_d)}{a+1}+\frac{a}{b}\ln\frac{A_R}{\alpha rx_d ap}$	$p_d=1-\frac{1+a}{b(\pi-rx)}$
Decentralized decision making with equity	$s_{Rd}=\ln\frac{(1+a)a\alpha\theta}{A_R b(1-\theta)}$	$s_{Fd}=\frac{a+1}{b}\ln\frac{(1-\theta)bp\pi}{a+1}+\frac{a}{b}\ln\frac{A_R}{\alpha\theta\pi ap}$	$p_d=1-\frac{1+a}{\pi b(1-\theta)}$
Centralized decision making	$s_{Rc}=\ln\frac{(a+1)a}{A_R b}$	$s_{Fc}=\frac{a+1}{b}\ln\frac{bp\pi}{a+1}+\frac{a}{b}\ln\frac{A_R}{ap\pi}$	$p_c=1-\frac{1+a}{\pi b}$

(6) Proof of Propositions 5.14 and 5.15

For Proposition 5.14, as shown in Table E.1, it is clear that $p_c > p_d(\theta)$ and $p_c > p_d(\alpha)$. The comparison between U_{Sd} and U_{Sc} also shows that $U_{Sc} \ge U_{Sd}(\alpha,r)$ and $U_{Sc} \ge U_{Sd}(\alpha,\theta)$.

In order to maximize the total social welfare, in this study, I consider the inputs required in centralized decision making as the benchmark, which enables us to make the following comparison:

$$s_{Rc}-s_{Rd}=\ln\frac{\pi-rx}{\alpha rx} \ or\ \ln\frac{1-\theta}{\alpha\theta}$$

$$s_{Fc} - s_{Fd} = \ln\left(\frac{\alpha rx}{\pi - rx}\right)^{\frac{a}{b}}\left(\frac{\pi}{\pi - rx}\right)^{\frac{1}{b}} \; or \; \ln\left(\frac{\alpha\theta}{1-\theta}\right)^{\frac{a}{b}}\left(\frac{1}{1-\theta}\right)^{\frac{1}{b}}$$

Thus, if $\alpha rx \leq \pi - rx$ or $\alpha\theta \leq 1 - \theta$, I have $s_{Rc} \geq s_{Rd}$ and $s_{Fc} \leq s_{Fd}$, otherwise the opposite trend occurs, particularly if $\alpha rx = \pi - rx$ or $\alpha\theta = 1 - \theta$, $s_{Rc} = s_{Rd}$ but $s_{Fc} > s_{Fd}$.

For Proposition 5.15, the result shows that the common license contract with single royalties or equity payments cannot make the $s_{Rc} = s_{Rd}$ and $s_{Fc} = s_{Fd}$ at the same time. This suggests that the common patent license contract with single royalty or equity payment cannot ensure matched effort and investment from faculty and firm as in centralized decision making.

Reference

Agrawal, A.K. (2001). University-to-industry knowledge transfer, Literature review and unanswered questions. *International Journal of Management Reviews*, *3*, 285-302.

Aghion, P., & Tirole, J. (1994). The Management of Innovation. *The Quarterly Journal of Economics*, *109*, 1185-1209.

Allen, S.D., Link, A.N., & Rosenbaum, D.T. (2007). Entrepreneurship and human capital, Evidence of patenting activity from the academic sector. *Entrepreneurship Theory and Practice*, *31*, 937-951.

Anderson, T.R., Daim, T.U., & Lavoie, F.F. (2007). Measuring the efficiency of university technology transfer. *Technovation*, *27*, 306-318.

Audretsch, D.B., Bonte, W., & Keilbach, M. (2008). Entrepreneurship capital and its impact on knowledge diffusion and economic performance. *Journal of Business Venturing*, *23*, 687-698.

Audretsch, D. B., Hülsbeck, M., & Lehmann, E. (2012). Regional competitiveness, university spillovers, and entrepreneurial activity. *Small Business Economics*, *39*, 587-601.

Audretsch, D.B., & Keilbach, M. (2008). Resolving the knowledge paradox, Knowledge-spillover entrepreneurship and economic growth. *Research Policy*, *37*, 1697-1705.

Baker, S., & Mezzetti, C. (2005). Disclosure as a strategy in the patent race. *Journal of Law and Economics*, *48*(1), 173-194.

Baldini, N., & Grimald, R. (2005, August). *Motivations and incentives for patenting within universities, A survey of Italian inventors*. Paper presented at the Annual Meeting of Academy of Management, New York, US.

Bekkers, R., & Bodas-Freitas, I.M. (2008). Analysing knowledge transfer channels between universities and industry, To what degree do sectors also matter? *Research Policy*, *37*, 1837-1853.

Boardman, C., & Ponomatiow, B. (2014). Management knowledge and the organization of team science in university research centers. *Journal of Technology Transfer*, *39*, 75-92.

Caldera, A., & Debande, O. (2010). Performance of Spanish universities in technology transfer, An empirical analysis. *Research Policy*, *39*, 1160-1173.

Callaert, C., Plessis, M.D., Looy, B.V., & Debackere, K. (2013). The impact of academic technology, Do modes of involvement matter? The Flemish case. *Industry and innovation*, *20*, 456-472.

Chapple, W., Lockett, A., Siegel, D., & Wright, M. (2005). Assessing the relative performance of U.K. university technology transfer office, Parametric and non-parametric evidence. *Research Policy*, *34*, 369-384.

Choi, J.P. (2001). Technology transfer with moral hazard. *International Journal of Industrial Organization*, *19*, 249-266.

Clancy, M.S., & Moschini, G.C. (2013). Incentives for innovation, Patents, prizes, and research contracts. *Applied Economic Perspectives and Policy*, *35*, 206-241.

Cohen, W.M., Nelson, R.R., & Walsh, J.P. (2002). Links and impacts, the influence of public research on industrial R&D. *Management Science*, *48*(1), 1-23.

Cohen, W.M., & Walsh, J.P. (2008). Real impediments to academic biomedical research. *Innovation Policy and the Economy*, *8*, 1-30.

Crama, P., Reyck, B.D., & Degraeve, Z. (2008). Milestone Payments or Royalty? Contract design for R&D licensing. *Operational Research*, *56*, 1539-1552.

Crespi, G.A., Geuna, A., & Verspagen, B. (2006). *University IPRs and knowledge transfer. Is the IPR ownership model more efficient*? Roundtable Engineering Entrepreneurship Research, Georgia Institute of Technology, Atlanta.

Curi, C., Daeaio, C., & Llerena, P. (2012). University technology transfer, How (in) efficient are French universities? *Cambridge Journal of Economics*, *36*, 629-654.

Czarnitzki, D., Hussinger, K., & Schneider, C. (2012). The nexus between science and industry, Evidence from faculty inventions. *Journal of Technology Transfer*, *5*, 755-776.

Damsgaard, E.F., & Thursby, M.C. (2013). University entrepreneurship and professor privilege. *Industrial and Corporate Change*, *22*, 183-218.

Dechenaux, E., Thursby, J., & Thursby, M. (2011). Inventor moral hazard in university licensing, The role of contracts. *Research Policy*, *40*, 94-104.

Dechenaux, E., Thursby, M., & Thursby, J. (2009). Shirking, sharing risk and shelving, The role of university license contracts. *International Journal of Industrial Organization*, *27*, 80-91.

Etzkowitz, H. (2003). Research groups as “quasi-firms”, The invention of the entrepreneurial university. *Research Policy*, *32*, 109-121.

Fini, R., Lacetera, N., & Shane, S. (2010). Inside or outside the IP system? Business creation in academia. *Research Policy*, *39*, 1060-1069.

Friedman, J., & Silberman, J. (2003). University technology transfer, Do incentives, management, and location matter? *The Journal of Technology Transfer*, *28*, 17-30.

Fuller, A.W. (2008). *University entrepreneurship, The role of US faculty in technology transfer and commercialization*. (Unpublished doctoral dissertation). Georgia Institute of Technology, USA.

Gallini, N. T., & Wright, B.D. (1990). Technology transfer under asymmetric information. *The RAND Journal of Economics*, *21*, 147-160.

Gans, J., & Murray, F. (2014). Markets for scientific attribution. Retrieved from National Bureau of Economic Research: http://www.nber.org/papers/w20677.

George, G., Jain, S., & Maltarich, M.A. (2005). Academics or entrepreneurs? Entrepreneurial identity and invention disclosure behaviour of university scientists. Retrieved from Social Science Research Network: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=799277.

Geuna, A., & Nesta, L.J. (2006). University patenting and its effects on academic research, The emerging European evidence. *Research Policy*, *35*, 790-807.

Gonza'lez-Pernia', J.L., Kuechle', G., & Pena-Legazkue', I. (2013). An assessment of the determinants of University Technology Transfer. *Economic Development Quarterly*, *27*, 6-17.

Gregorio, D.D., & Shane, S. (2003). Why do some universities generate more start-ups than others? *Research Policy*, *32*, 209-227.

Grimaldi, R., Kenney, M., Siegel, D.S., &Wright, M. (2011). 30 years after Bayh-Dole, Reassessing academic entrepreneurship. *Research Policy*, *40*, 1045-1057.

Guerrero, M., & Urbano, D. (2014). Academics' start-up intentions and knowledge filters: An individual perspective of the knowledge spillover theory of entrepreneurship. *Small Business Economics*, *43*, 57-74.

Haeussler, C., Jiang, L., Thursby, J., & Thursby, M. (2014). Specific and general information sharing among competing academic researchers. *Research Policy*, *43*, 465-475.

Hall, B.H., Jaffe, A.B., & Trajtenberg, M. (2001). The NBER patent citations data file, lessons, insights and methodological tools. Retrieved from National Bureau of Economic Research: http://www.nber.org/papers/w8498.

Harrmon, B., Ardishvili, A., Cardozo, R. Elder, T., Leuthold, J., Parshall, J., Raghian, M., & Smith, D. (1997). Mapping the university technology transfer process. *Journal of Business Venturing*, *12*, 423-34.

Hausman, J.A. (1978). Specification Test in Econometrics. *Econometrica*, *46*, 1251-1271.

Hausman, J.A., & McFadden, D. (1984). Specification tests for the multinomial logit model. *Econometrica*, *52*, 1219-1240.

Hellmann, T. (2007). The role of patents for bridging the science to market gap. *Journal of Economic Behaviour and Organization*, *63*, 624-647.

Henderson, R., Jaffe, A.B., & Trajtenberg, M., (1998). Universities as a source of commercial technology: A detailed analysis of university patenting 1965-1988. *The Review of Economics and Statistics*, *80*, 119-127.

Ho, J.C., Saw, E.C., Lu, L.Y.Y. & Liu J.S. (2014). Technological barriers and research trends in fuel cell technologies: A citation network analysis. *Technological Forecasting & Social Change*, *82*, 66-79.

Humberstone, R. (2009). *The impact of university licensing behaviour on scientist disclosure*. Retrieved from http://www.webmeets.com/files/papers/EARIE/2009/90/Humberstone-EARIE09.pdf.

Jaffe, A.B. (1989). Real effects of academic research. *American Economic Review*, *79*, 957-970.

Jensen, R., Thursby, J., & Thursby, M. (2011). *University-industry spillovers, government funding, and industry consulting*. Retrieved from National Bureau of Economic Research: http://www.nber.org/papers/w15732.

Jensen, R., & Thursby, M.C. (2001). Proofs and prototypes for sale: The licensing of university inventions. *The American Economic Review*, *91*, 240-259.

Jensen, R.A., Thursby, J.G., & Thursby, M.C. (2003). Disclosure and licensing of university inventions: ‘the best we can do with the s**t we get to work with’. *International Journal of Industrial Organization*, *21*, 1271-1300.

Jensen, R.A., Thursby, J.G., & Thursby, M.C., (2008). *In or out: Faculty research and consulting*. Retrieved from http://feb.kuleuven.be/eng/tew/academic/msi/_docs/workshops/2006-10-02.pdf.

Jiang, L., Thursby, J.G., & Thursby, M.C. (2012). *Scientific disclosure and the face of competition*. Retrieved from http://www.tiger.gatech.edu/REER%202012%20Papers/JiangThursbyThursby_V8.pdf.

Kabiraj, T. (2005). Technology transfer in a Stackelberg structure: Licensing contracts and welfare. *The Manchester School*, *73*, 1-28.

Kenney, M., & Patton, D. (2009). Reconsidering the Bayh-Dole Act and the current University invention ownership model. *Research Policy*, *38*, 1407-22.

Kenney, M., & Patton, D. (2011). Does faculty ownership encourage university research-derived entrepreneurship? A six-university comparison. *Research Policy*, *40*, 1100-12.

Kim, J.Y., Lee, S.J., & Marschke, G. (2005). *The influence of university research on industrial innovation*. Retrieved from National Bureau of Economic Research: http://www.nber.org/papers/w11447.pdf.

Kiškis, M. (2012). Faculty intellectual property right in Canadian university. *Baltic Journal of Law and Politics*, *5*, 81-108.

Link, A.N., Siegel, D.S., & Bozeman, B. (2007). An empirical analysis of the propensity of academics to engage in informal university technology transfer. *Industrial and Corporate Change*, *16*, 641-655.

Link, A.N., & Scott, J.T. (2006). US university research parks. *Journal of Productivity Analysis*, *25*, 43-55.

Lissoni, F., Llerena, P., Makelvey, M. & Sanditov, B. (2008). Academic patenting in Europe: New evidence from the KEINS database. *Research Evaluation*, *17*(2), 87-102.

Lissoni, F., Lotz, P., Schovsbo, J., & Treccani, A. (2009). Academic patenting and the professor's privilege: Evidence on Denmark from the KEINS database. *Science and Public Policy*, *36*, 595-607.

Lissoni, F., & Montobbio, F. (2012). *The ownership of academic patents and their impact: Evidence from five European countries*. Retrieved from http://cahiersdugretha.u-bordeaux4.fr/2012/2012-24.pdf.

Littunen, H. (2000). Entrepreneurship and the characteristics of the entrepreneurial personality. *International Journal of Entrepreneurial Behaviour & Research*, *6*, 295-309.

Liu, H., & Jiang, Y.Z. (2001). Technology transfer from higher education institutions to industry in China: Nature and implications. *Technovation*, *21*, 175-188.

Lowe, R.A. (2006). Who develops a university invention? The impact of tacit knowledge and licensing policies. *Journal of Technology Transfer*, *31*, 415-429.

Macho-Stadler, I., Martínez-Giralt, X., & Pérez-Castrillo, D. (1996). The role of information in licensing contract design. *Research Policy*, *25*, 43-57.

Macho-Stadler, I., & Pérez-Castrillo, D. (2010). Incentives in university technology transfer. *International Journal of Industrial Organization*, *28*, 362-367.

Markman, G., Panagopoulos, A., & Gianiodis, P. (2007). Scientists or entrepreneurs: Rent (mis)appropriation from discoveries made in university labs. *In Best paper proceedings of the American Academy of Management*. Retrieved from http://www.taranomco.com/wp-content/uploads/2013/11/140.pdf.

Mowery, D.C., & Sampat, B.N. (2005). The Bayh-Dole Act of 1980 and university industry technology transfer: A model for other OECD governments? *Journal of Technology Transfer*, *30*, 115-127.

Mowery, D.C., & Shane, S. (2002). Introduction to the special issue on university entrepreneurship and technology Transfer. *Management Science*, *48*, 5-9.

Murray, F. (2004). The role of academic inventors in entrepreneurial firms: Sharing the laboratory life. *Research Policy*, *31*, 1389-1403.

Murray, F., & O'Mahony, S. (2009). Exploring the foundations of cumulative innovation: Implications for organization science. *Organization Science*, *18*, 1006-1021.

Nizovtsev, D., & Thursby, M. (2007). Economic analysis of incentives to disclose software vulnerabilities. *Information Economic Policy*, *19*, 43-64.

Owen-Smith, J., & Powell, W.W. (2001). To patent or not: Faculty decisions and institutional success at technology transfer. *Journal of Technology Transfer*, *26*, 99-114.

Panagopoulos, A., & Carayannis, E.G. (2013). A policy for enhancing the disclosure of university faculty invention. *The Journal of Technology Transfer*, *38*, 341-347.

Pedro, O.A., & Ferran, V.H. (2014). University spin-offs vs. other NTBFs: Total factor productivity differences at outset and evolution. *Technovation*, *34*, 101-112.

Powers, J.B., & McDougall, P.P. (2005). University start-up formation and technology licensing with firms that go public: A resource-based view of academic entrepreneurship.

Journal of Business Venturing, *20*, 291-311.

Prabhu R. (2007). *Knowledge creation and technology transfer in nanotechnology at research universities* (Doctoral dissertation). Retrieved from ProQuest Dissertations and theses database. (NO. 3380625)

Rogers, E.M., Takegami, S., & Yin, J. (2001). Lessons learned about technology transfer. *Technovation*, *21*, 253-61.

Rothaermel, F.T., Agung, S., & Jiang, L. (2007). University entrepreneurship: A taxonomy of the literature. *Industrial and Corporate Change*, *16*, 691-791.

Rudyk, I. (2013). *Deferred patent examination*. Retrieved from http://www.sfbtr15.de/uploads/media/416.pdf.

Saragossi, S.V.P., & De la Potterie, B. (2003). What patent data reveal about universities: The case of Belgium. *Journal of Technology Transfer*, *28*, 47-51.

Savva, N., & Taneri, N. (2011). *The equity vs. royalty dilemma in university technology transfer*. Retrieved from http://faculty.london.edu/nsavva/111026_UTT.pdf.

Sen, D. (2005). Fee versus royalty reconsidered. *Games and Economic Behaviour*, *53*, 141-147.

Sen, D., & Tauman, Y. (2007). General licensing schemes for a cost-reducing innovation. *Games and Economic Behaviour*, *59*, 163-186.

Shane, S. (2005). *Academic entrepreneurship: University spinoffs and wealth creation*. Edward Elgar Pub Press. Retrieved from Elgaronline.

Shane, S. (2004). Encouraging university entrepreneurship? The effect of the Bayh-Dole Act on university patenting in the United States. *Journal of Business Venturing*, *19*, 127-151.

Siegel, D.S., Waldman, D.A., Atwater, L.E., & Link A.N. (2003a). Commercial knowledge transfers from universities to firms: Improving the effectiveness of university-industry collaboration. *Journal of High Technology Management Research*, *14*, 111-133.

Siegel, D.S., Waldman, D.A., Atwater, L.E., & Link A.N. (2004). Toward a model of the effective transfer of scientific knowledge from academicians to practitioners, qualitative evidence from the commercialization of university technologies. *Journal of Engineering and Technology Management*, *21*, 115-42.

Siegel, D.S., Wright, M., & Link, A.N. (2003b). Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: An exploratory study. *Research Policy*, *32*, 27-48.

State Intellectual Property Office. (2005). *Investigation into the protection of intellectual property rights in high education institutions in China*. Retrieved from http://www.sipo.gov.cn/tjxx/.

Thursby, J.G., Fuller, A.W., & Thursby, M.C. (2007). US faculty patenting inside and outside the university. Retrieved from National Bureau of Economic Research: http://www.nber.org/papers/w13256.pdf.

Thursby, J.G., Fuller, A.W., & Thursby, M.C. (2009). US faculty patenting: Inside and outside the university. *Research Policy*, *38*, 14-25.

Thursby, J.G., Jensen, R., & Thursby, M. (2001). Objectives, characteristics and outcomes of university licensing, a survey of major U.S. universities. *Journal of Technology Transfer*, *26*, 59-72.

Thursby, J.G., & Kemp, S. (2002). Growth and productive efficiency of university intellectual property licensing. *Research Policy*, *31*, 109-24.

Thursby, J.G., & Thursby, M.C. (2002). Who is selling the ivory tower? Source of growth in university licensing. *Management Science*, *48*, 1-15.

Thursby, J.G., & Thursby, M.C. (2011). Faculty participation in licensing: Implication for research. *Research Policy*, *40*, 20-29.

Thursby, M., Thursby, J., & Dechenaux, E. (2005). *Shirking, sharing risk and shelving: The role of university license contracts*. Retrieved from National Bureau of Economic Research: http://www.nber.org/papers/w11128.

Unico. (2004). *UK university commercialization survey: Financial Year 2003*, Retrieved from http://www.praxisunico.org.uk/uploads/2003%20Survey.pdf.

Venditti, M., Reale, E., & Leydesdorff, L. (2013). Disclosure of university research to third parties, A non-market perspective on an Italian university. *Science and Public Policy*, *40*, 792-800.

Wentzel, K.R., & Watkins, D.E. (2002). Peer relationships and collaborative learning as contexts for academic enablers. *School Psychology Review*, *31*, 366-377.

Wright, M., Clarysse, B., Mustar, P., Lockett, A. (2007). *Academic entrepreneurship in Europe*. Edward Elgar Pub Press. Retrieved from http://www.dig.polimi.it/fileadmin/user_upload/docenti/chiara_franzoni/Franzoni_Lissoni_A cad_entr.pdf.

Zaltman, G., Duncan, R., & Holbek, J. (1973). *Innovation and organizations*. Retrieved from https://www.coursera.org/course/innovation.

Zucker, L.G., Darby, M.R., & Armstrong, J.S. (2002). Commercializing knowledge, university science, knowledge capture, and firm performance in biotechnology. *Management Science*, *48*,138-153.