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Four dimensions to observe a Triple Helix: invention of 'cored model' and differentiation of institutional and functional spheres

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Abstract

This investigation utilizes a matrix observation method to analyze triple helices. Firstly, by analyzing a unique Chinese academic phenomenon, the university-run enterprise (URE), a 'cored model' is proposed to complement the existing non-cored model of a triple helix study. The URE remains within the university administration, in contrast to the US spin-off firm that exits quickly. This difference raises the issue of how boundaries among the institutional spheres should be defined. Secondly, institutional and functional spheres are differentiated as separate concepts. Based on the theoretical research, a matrix observation method of a triple helix is invented. Finally, as a typical case, we observe Chinese triple helix (CTH), showing how to use the observation method. The most important contribution of this research is that it develops a methodology to analyze a triple helix through a matrix with four dimensions (Table one). Two questions have been explored and they are as follows: (1) Should a URE remain within university administration? (2) How may the Chinese triple helix with a dominant government role be improved?

Keywords: Triple helix cored model; Chinese triple helix (CTH); University-run enterprises (UREs); Institutional sphere; Functional sphere

Multilingual abstracts

Please see Additional file 1 for the translation of the abstract into the five official working languages of the United Nations and Portuguese.

Introduction

A triple helix of university-industry-government relations based upon independent, overlapping institutional spheres in which each can interact freely and 'take the role of the other' has been identified as a form of social organization that is highly conducive to innovation (Etzkowitz & Leydesdorff 1995; Leydesdorff & Etzkowitz 1996; Etzkowitz 2003, 2008). It shows as Figure 1, typically.

However, this model came from the observation of academic entrepreneurship and knowledge-based regional development of the US, especially MIT and New England's renewal (Etzkowitz 2002) and Stanford and the rise of Silicon Valley (Etzkowitz 2008). China has a very different political system and cultural tradition from the USA. Even

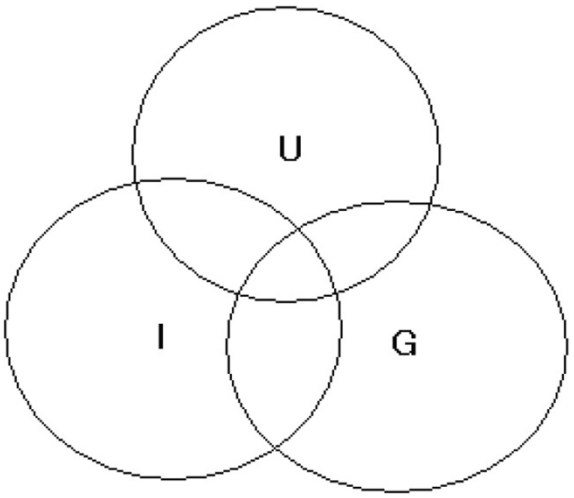

Figure 1 Current triple helix illustration of university-industry-government sphere relations.

though innovation and development of a country primarily rely on economic indicators, the political system is a critical factor. Can the original triple helix model be used to investigate China's triple helix? What improvements in triple helix study can be realized from the analysis of the CTH? We examine how the Chinese triple helix, with a dominant government role, has changed following China's reform and opening and then suggest how it may be further improved.

In order to clearly understand university-industry-government relations in China, a particular phenomenon, university-run enterprises (UREs), will be discussed. UREs established and run by a university date back to the tradition of 'university-run factories' founded for students' internship and faculty industrial practice. Although these enterprises occasionally sold products or performed services for remuneration, their primary objective was training and practical production.

The development of the contemporary URE model, the operation of businesses for profit, occurred during the nascent stage (1978 to 1985) for accumulation of scientific and technological outcomes. In this era, UREs typically marketed goods and imported new research results but did not engage in product development. In the following development stage (1985 to 1992), university faculty applied their technology and knowledge to create enterprises for technology/knowledge transfer. This phase was driven by the success of Peking University Founder Group Corp established in 1986, focused on IT products based on Xuan Wang's inventions in laser typesetting systems, which provided a model for emulation. In the rapid development stage (1993 to present), a significant number of well-known enterprises were established such as Beida Weiming, Beida Jade Bird, Tsinghua Tongfang, NEU-ALPINE, and Shanghai Jiao Da Only Co., Ltd. Some of these UREs became larger than the universities that owned and controlled them.

UREs are different from 'spin-offs' in the USA where the University is not involved in ownership and financial/business management, although some universities retain minority equity positions. The spin-offs operate in the hybrid space among universities, industries, and governments. Since the UREs belong to the university and are under the leadership and control of the university administration, in exploring China's

institutional sphere relations, we must address the UREs issue: should a URE remain within the university administration unlike the spin-offs in the USA?

Prior to the reform and opening of the People's Republic of China (from 1949 to 1978), influenced by the former Soviet Union, the university mainly engaged in teaching. Public research institutions (PRIs), especially for military-oriented and national key projects, primarily conducted R&D activities. PRIs operated apart from university and industry as an independent social institution. Therefore, 'government-industry-academia triple helix' is a better term with a G-I-A order to reflect China's case, in which academia (includes university/research institution) conducting R&D, with the government playing a dominant one role. From 1992 to 2002, a higher education institutions' merger and recombination movement created multidiscipline universities with a general purpose. Governments strengthened research universities through schemes such as the 'Project 985'[a] and 'Project 211'[b] and encouraged universities to increase their incomes by using their teaching and research resources to provide (adult) training programs, renting facilities, creating joint projects with industrial enterprises, and forming firms (UREs). Through these third-mission-oriented activities, a university is run like an industrial enterprise, which originated from academic entrepreneurship. The UREs achieved significant growth and returned considerable income to their founding universities. These university-born firms, however, remained within the university administration, rather than being spun off as independent firms outside, even though they are separated from their mother bodies in geographical location and operate as a self-running business. In other words, the mother university that owns most shares authorizes UREs' managers to run its businesses independently.

A similar process of creating enterprises from available resources took place in Eastern Europe, when research institutes lost most of their government funding after the demise of the Communist regime. However, in the abrupt transition from a statist to a laissez-faire regime, the sponsoring organizations lost most of their resources and were typically not able to provide significant support to grow these enterprises. In contrast to Eastern Europe, China is exploring a way to gradually reform the statist regime, avoiding an abrupt transition to laissez-faire.

The premise of an optimum triple helix is that the institutional spheres are relatively independent, with the ability to take initiative. Government, industry, and academia spheres in China traditionally operate in a statist triple helix in which government overwhelmingly controls most academia and industry, resulting in a party-oriented and government-pulled economic growth and social development. In this framework, all leading research universities are public and most large-scale industrial enterprises that refer to national strategy are owned by the state or survived relying on the government rather than the market. As key actors for innovation, they work together with the government as its two wings or satellites. In the Chinese triple helix, the three spheres thus are not independent essentially due to state ownership.

However, as the state ownership system is reformed and functions change, China is gradually moving towards an 'interactive triple helix model', in which each sphere is relatively independent and interactive with others, as additional sources of initiative are activated. The institutional spheres, the hybrid institutions, and the functions of the actors in the triple helix change during the movement from the statist model. In order to observe the transition of a triple helix regime, this study provides four dimensions

through the invention of a 'cored model' and the differentiation of institution and function.

Research methodology

The research takes theoretical thinking forward, more than empirical investigation, although it includes a case study of China. In order to take more fully the Chinese innovation situation into account and seek answers to the given questions, a cored model is proposed to compensate the 'existing non-cored model'. It is argued that institution and function as primary concepts in a triple helix study must be differentiated to improve the existing non-cored model that lacks distinction of institution and function concepts. The Chinese triple helix is thus shown more clearly based on this theoretical exploration, where cores of both institutional and functional spheres overlap. The relations among the spheres result in a government-pulled model that is evolving to an optimum triple helix.

This is an exploratory study, at a very early stage, inspired by academic exchange with Professor Loet Leydesdorff and Henry Etzkowitz. The findings of this study are descriptive, primarily derived through a dialectical analysis of statistical data on the Chinese triple helix (CTH). In order to provide an overall understanding of a triple helix in construction, the exploration combines history, present, and future perspectives. Interviews with innovation researchers and practitioners were also carried out to explore the study hypotheses.

Triple helix cored model[c]

Henry Etzkowitz and Loet Leydesdorff first proposed the triple helix model from three perspectives: evolutionary economics, the sociology of science and technology, and the sociology of higher education, as well as policy analysis with an evaluative perspective, (Etzkowitz & Leydesdorff 1995). Since then, this theme has been developed further in the course of eleven triple helix international conferences. Nevertheless, like other theories, it continuously needs new thinking to develop.

The triple helix model is traditionally described as a chart like Figure 1. It was devised to describe triple helix relationships among university, industry, and government spheres. In order to derive a cored model to understand more clearly the relations and interactions among the spheres, we draw upon here the 'field' concept from physics, following the 'science and technology field' study considering the interaction between science and technology (Zhou 2001, 2002) as shown in Figure 2.

In this figure, 'triple helix sphere' is used, instead of 'institutional sphere'. In later sections, we differentiate institution and function, so that triple helix spheres can be understood from institutional and functional perspectives.

A cored model is delineated in which each triple helix sphere has an internal core and an external field. The internal core is defined as the central part of a sphere, which consists of 'non-hybrid' or 'pure' components with stable and unique characteristics; while the external field is defined as the space surrounding the core of a triple helix sphere, in which interactions among spheres can occur to form the 'hybrid components' (not contained within the core institutions) that promote innovation. For example, Stanford University as a social institution is located in the core of the institutional sphere, but the hybrid organizations, which emerged from the university in cooperation with local governments, and firms as social organizations such as Joint Venture Silicon

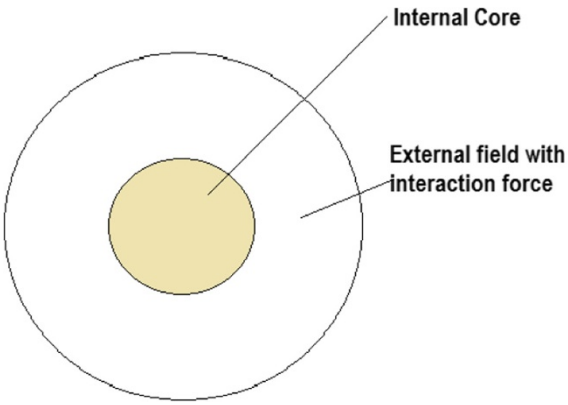

Figure 2 Internal core and external field of a triple helix sphere.

Valley and various high-tech startups, are formed by interactions of the three spheres in the external fields.

To measure the interaction intensity among physical objects such as celestial bodies, electric charges, or magnets, the field concept was introduced into physics from mathematics. If a physical variable has a corresponding value at any point to all of the space or part of it, its field will be confirmed in the space. The field can act upon its surroundings. In an electric field, for example, the effect on charges in field space is represented by electric field force (F). The force endured by per unit charge is defined as electric field intensity (E), describing the degree that the field acts to the charge in it. In triple helix field, field intensity concept can also be introduced, meaning the degree that one helix acts the things around it. Electric field intensity of a charge can be formulized as follows:

$$\mathbf{E} = \frac{F}{Q} = \frac{kQ}{r^2},$$

where k is a constant, Q represents the electric amount of the charge, and r represents the distance between a point in the field and the charge. If the corresponding optimum values of Q and r are found, in theory, the optimum E value can be determined. Each sphere gives rise to field intensity in the triple helix field. If for one of them the field intensity is too strong or too weak, an interactive triple helix cannot be formed, instead of forming a statist or laissez-faire model.

The cored model as shown in Figure 3 can complement the original triple helix model (Figure 1). It will help explain why three helices keep their independent status and how they interact and furthermore discuss why a university can play industry's role but not as a true enterprise, and the same holds for industry and government. We can also find whether the spheres must be independent as they interact with each other. However, institutional and functional concepts must be differentiated to understand triple helix interactions through the cored model.

Differentiating institutional and functional spheres

In the original triple helix theory, there are two key terms: institutional spheres and interactions among them. This model did not differentiate institution and function. However, function is basically 'the action for which a person or thing is particularly

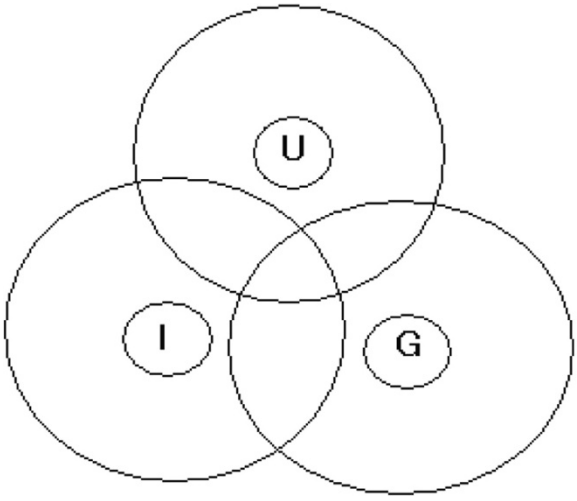

Figure 3 Triple helix cored model.

fitted or employed'; while institution is defined as the structure or mechanism of social order governing the behavior of a set of individuals within a given community. Institutions are identified with a social purpose. The reciprocity of the three institutional spheres forms the motivation for the spheres to interact; however, it is the similarity and complementarity among the functions that create the possibility to interact. Once functional and institutional spheres are differentiated, it should be recognized that there are internal core and external fields of functional or institutional spheres. Actually, each institutional sphere is essentially different and needs to keep its own institutional core and unique functions separate from the other two. The new thinking in this section draws from 'overlapping,' 'independence,' and 'interaction' in previous triple helix study, which includes what is overlap and independence among the institutional spheres and what is the necessary condition for the actors to interact.

Relative independence of an institutional sphere core

This study separates institutional spheres from functional spheres as different types of concepts. The institutional spheres with different missions and value interact for innovation, simultaneously maintain relative independence. Dialectically, an institutional sphere is dependent but also independent. It must be dependent in the external field to seek for collaboration, on one hand, as its internal core keeps independent. This needs clear judgment and understanding as to boundaries between the spheres. Since interactions must only take place between two bodies being mutually independent, the relative independence makes the institutional spheres interact, on the other. We thus believe that the external fields of institutional spheres must be overlapping so that interactions can occur, but the internal cores should be separated or relatively independent for generating interactions. The critical problem of the statist model is boundary confusion caused by a state-owned system characterized by lack of university and industry independence. Government command replaces the interactions. In the laissez-faire model, the spheres with 'over-independence' do not have enough opportunities to transcend distance in order to interact (Figure 4).

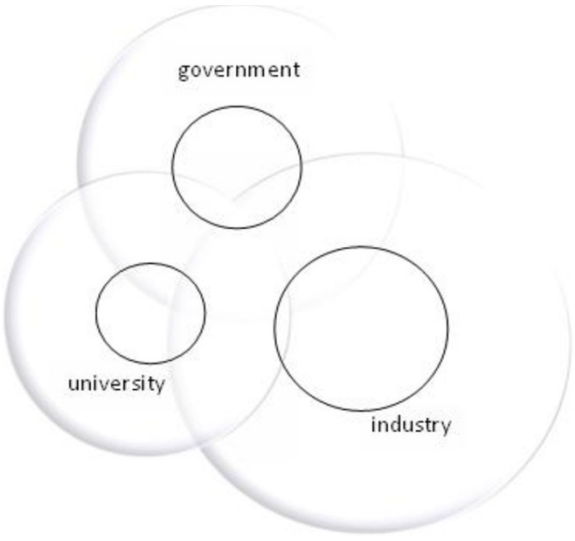

Figure 4 Relative independence and overlap of the institutional spheres in perspective of triple helix cored model.

Therefore, first it is confirmed that the internal core of an institutional sphere should be relatively independent. Non-independence or ownership gives rise to a leadership or dependency relationship, rather than active and equal interactions. A scope-limited core of an institutional sphere must be considered in terms of social contract or social labor division, and hybrid organizations should be established in the external field space where interactions take place. In other words, an institutional sphere must have an internal core keeping independence and stability, though it is dependent on others during the interactions in the external field.

Overlap of functional sphere cores: unique functions and shared functions

If one actor is lacking, the ability to optimally perform its role, another one may 'take its role' (Etzkowitz 2008). The key to achieve a triple helix is to create balanced helices through functional overlap. In the functional perspective, each sphere can play the other two roles. For example, governments can have state-owned enterprises and training programs, playing the industrial and university's role. The cores of functional sphere thus are overlapping (Figure 5).

Functions of a triple helix sphere here can be divided into shared functions and unique functions. Unique functions that came from historical accumulation decide internal cores of functions and are irreplaceable. Shared functions that are the same as other spheres' functions can be received in the short term to contribute to potential collaborations, but they are not unique. For example, the university functional sphere has teaching, research, and social service functions as its unique functions; at the same time, it has 'shared functions' such as technology transfer, policymaking consulting, and spin-off startups. The motivation for the actors to commit to innovation does not only lie in the functional complementarities (shared functions) but also in the unique functions of each sphere. It is the latter that creates the mutual needs for one to actively interact with the other two for coevolution.

For example, universities contribute to regional innovation through providing knowledge and quality human resources; many university-originated start-ups, as they

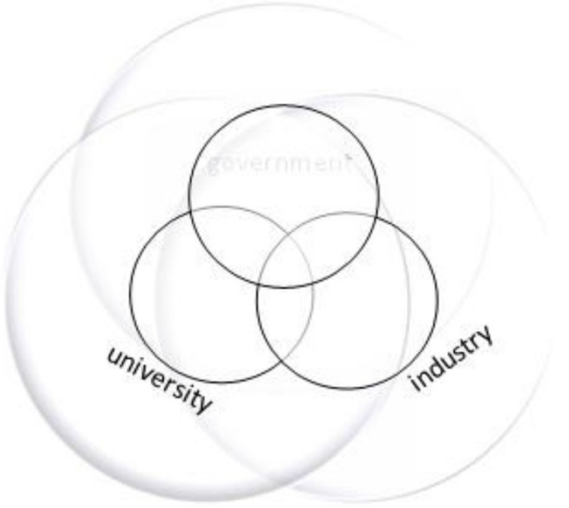

Figure 5 Triple helix internal core-external field model in functional sphere perspective.

became successful, acted as angels to newly emerging firms, providing a source of venture capital (Etzkowitz and Pique 2005) on the other. 'Take the role of the other' in triple helix study implies shared roles (functions). In a statist triple helix, governments' unique and shared functions are both very strong, like a gravitational force, so that a circumstance in which the other two helices turn around will be formed. There is enough force from the government to integrate the unique functions of the university and industry spheres. In practice, both kinds of functions of each helix need to be strengthened to create its value as an actor in a triple helix.

An observation of the CTH

From the above theoretical study, we conclude that a triple helix can be observed by following four dimensions (Table 1). This method can be used to observe triple helix in any country. This paper gives an example of the CTH.

CTH is a political party-oriented, government-pulled, and highly unified in the context of a heretofore less knowledge-based economy and is characterized by a lack of local flexibility, creativity, and diversity of paths. Having differentiated institutional and functional spheres, based on the cored model, the CTH's status and change in both institutional spheres and functions can be observed, respectively, through the above four dimensions.

Table 1 Four dimensions to observe a triple helix

	Internal core	External field
Institutional spheres	Independent cores?	Interactions in hybrid areas?
	Government	Hybrid organizations (including interface platform organizations)
	University	Non-hybrid areas
	Industry	
Functions	Unique functions?	Shared functions?
	Government	Interactive areas
	University	Non-interactive areas
	Industrial	

Overlapping internal cores of institutional spheres: impossible to be relatively independent

Government

At the national level, many key governing agencies generating national goals, strategies, policies and IPR laws, programs, and specific projects, such as the Ministry of Science and Technology, Ministry of Education, National Development and Reform Commission, Ministry of National Defense, Ministry of Industry and Information Technology, Ministry of Finance, Ministry of Human Resources and Social Security, and Minister of Justice, are involved in innovation activities now. The departments/committees/bureaus of which they are in charge are responsible for project implementation, resources distribution, and fund allocation, at national and local levels. In the statist system, the internal core of government sphere is obviously not limited to administrational agencies, but expands to state-owned universities/institutes and enterprises, even non-state-owned institutions. In the statist model, which lacks relative independence among the actors, the government institutional sphere includes the industrial and university spheres.

University (HEI) and research institutes

Since the early 1980s, higher education has recovered from the destruction of the Cultural Revolution and developed further, especially entering the end of 1990s when the university system undertook an enrollment expansion strategy. So far, there has been an over 25% gross enrollment rate and 2,137 higher education institutions (HEIs). However, most universities and research institutes are under the administration of the government. The state sector and government's role is overwhelming in the system as evidenced by Table 2.

Typically, postgraduate programs promote academic research. China postgraduate education by universities and research institutes has also developed fast in scale. All the institutions are state-owned and run under the administration of the government (Table 3).

Table 2 The HEIs of China (by 23 May 2011)

	Regular HEIs	Non-State Regular HEIs	Adult HEIs	Non-State Adult HEIs	State-approved independent colleges
HEIs affiliated by central ministries & agencies	110	0	14	0	0
HEIs under local authorities.	1,991	386	340	2	309
Providing undergraduate education	823	79	N/A	0	309
Providing postgraduate education	481	0	0	0	0
Total faculty number	1,343,127	N/A	45,887	N/A	126,720
Faculty number with Doctor's Degrees	200,337	N/A	770	N/A	N/A
Faculty number with Master's Degrees	463,401	N/A	8,324	N/A	N/A
Institution totals	2,101	386	354	2	309

Source: The data were drawn from MOE, 2011. List of Regular Institutions of Higher Education in China, List of Non-State Regular Higher Education Institutions in China, List of Institutions of Adult Higher Education in China, and List of State-approved Independent Colleges at http://www.moe.edu.cn/publicfiles/business/htmlfiles/moe/moe_2812/200906/48836.html and the Ministry of Education of P.R.China, Statistic Data in 2010, at http://www.moe.gov.cn/publicfiles/business/htmlfiles/moe/s6200/list.html.

Table 3 Institution numbers providing postgraduate programs (in 2010)

	Universities	Research institutes
HEIs under Central Ministries & Agencies	374	276
HEIs under Local Auth.	423	40
Graduate number of Doctor's Degrees	43,214	5,773
Graduate number of Master's Degrees	326,613	8,000
Total	481	316

Source: The data were drawn from the Ministry of Education of the People's Republic of China statistic data in 2010 at http://www.moe.gov.cn/publicfiles/business/htmlfiles/moe/s6200/list.html.

Industry

The most active agents of innovation are 'high-tech industry' and large and medium-sized enterprises (LMEs). Ever since 1995, the proportion of a high-tech industry in manufacturing moved up from 12.8% to 16.1% in 2004, down to 12.9% in 2008 (MOST 2009). The export value of high-tech products has increased from $218, 250 billion in 2005 to $492,380 billion in 2010; the import value was from $197,710 billion in 2005 to $412,660 billion in 2010 (MOST 2011b). Table 4 gives the contribution of the high-tech industries in 2010.

The criterion of LMEs includes the Standards by National Bureau of Statistics (2012), and in over 800 employees, there is at least 20 million CNY registered capital and more than 10 million CNY turnover. In the 2005 to 2009 periods, innovation of LMEs had been accelerating. The R&D institutions affiliated by LMEs increased from 9,352 to 15,217, 62.7%; the number of LMEs which carried out R&D activities is from 6,874 (24.06%) up to 12,434 (30.48%), with an 80.9% increase (MIIT and CASS (Ministry of Industry and Information Technology and Chinese Academy of Social Sciences) 2011).

In 2008, the country had 25,817 high-tech enterprises including 1,743 state-holding enterprises and 9,296 foreign-invested enterprises (MOST 2009). Gross industrial output increased from 34,367 million CNY in 2005 to 74,709 in 2010; profits from 1,423 to 4,880, taxes and profits from 2,090 to 6,753. In this year, R&D intensity of high-tech industry was 1.18%, over the average value of LMEs 0.84%. The value in aircraft and spacecraft sector was 4.47%, but only 0.49% in computers and office equipments sector (MOST 2009).

Overlapping external fields of institutional spheres: hybrid organizations

Government supports innovation through government procurement, making policies, enacting laws, direct investment, or indirectly encouraging (venture) investment as well as developing medium and small enterprises (SMEs). Under the leadership of a strong

Table 4 High-tech industry and as a percentage of gross industrial output (2010)

100 million CNY	Expenditure on R&D	Percentage of gross industrial output
Aircraft and spacecraft	92.8	5.81
Computers and office equipments	117.6	0.59
Electronic and telecommunication equipments	572.4	1.59
Medical equipments and meters	62.4	1.11
Pharmaceuticals	122.6	1.04
Total	967.8	1.3

Source: (MOST 2011c).

government, policies and laws play a critical role. Since 1980s, many have been created to promote S&T development, technological industrialization, and high-tech industry such as 'Suggestions On Strengthening Universities to Economic and Social Development', encouraging university-industry-research institute collaborations to build 'industrial technology alliances'; jointly developing 'colleges with industrial features' by the Ministry of Education and other agencies (up to 2009, 22 have been involved).

Hybrid organizations including interface platform organizations like university-industry joint ventures, state-owned enterprises, public non-profit organizations, state-affiliated universities, science parks, incubators, high-tech development zones, technology and intellectual right market, information-shared system in R&D, as well as industrial clusters have appeared since the end of the 1980s. Here, science parks can exemplify the characteristics of the hybrid organizations in China as they develop as the result of government-industry-university coexistence.

Since the first science park of China was established in 1989 close to the campus of Northeastern University, up to the end of 1998, 33 science parks were established. MOST and MOE confirmed 22 national science parks in March of 2001. From 2001 to 2006, 63 university science parks were approved as 'National University Science Park', with more than 128 universities involved. These universities participate the administration of the parks and develop their UREs in it, while the parks become places for student internship. The national science parks are characterized by:

a) Operate in the overlapping areas of the institutional spheres.
b) Strong government policy support: government formally did not push the development of science parks until 1999. Before that, it was extremely difficult for universities to develop science parks in China. Government played a key role through establishment of policies, provision of land and capital.
c) In a 'socialist market economy with Chinese characteristics',[d] university-enterprise collaborations operate according to a combination of market mechanisms and rules of the socialist market economy. Government establishes the operating conditions of this market. Government can guide and attract social capital and venture capital to support science parks. Moreover, numerous universities have established University Science Park Corporations based on UREs administration department to operate their science park, providing a mechanism to separate the day-to-day activities of firms formed by the university from the mother body. UREs grow up in the parks and stay in the facilities for a number of years.
d) Rely on university resources: universities are encouraged to actively build their science park utilizing their academic resources. To improve the science park has been mandated as a part of their President's responsibility.

Overlapping cores and external fields of functional spheres: unique functions and shared functions

The factors and mechanisms to decide the trajectory of each helix are very complex. The most important factors includes the R&D capability and financing ability of the university; in industry, investment in R&D activity and absorptive capacity, feasibility and effectiveness of government support by policy and laws, or by direct investment. Moreover, interaction capacity of each sphere determines its roles in triple helix as an

actor. For example, the state-ownership implies that only the government is capable to become RIO, i.e., regional innovation organizer, exercising leadership, thus generating a 'government-pulled model' (Etzkowitz & Zhou 2007). The university has become a leading force in regional and national triple helix in the US, where the triple helix represents a model pushed by the universities that were greatly successful in driving regional innovation and helping create new industry, forming a 'university-pushed model'. It is observed that in Europe, some countries have a 'corporate-led triple helix model'. Whether one sphere can play a critical role depends on its intensity in functions listed in Table 5. This may vary in different countries.

Government

Since Xiaoping Deng proposed that science and technology is the leading cause of productivity in 1975, the Chinese government promulgated a series of policies and laws to encourage technological innovation to assist economic growth. Enterprise performance is predominantly influenced by government actions, including those firms that have been changed into private ownership. However, university and industry were previously weak in innovation capacity. From the National Science and Technology Conference in Beijing in 2006, the government confirmed that the university can contribute to innovation and industrial firms should be the actor for innovation. An effort was made to strengthen university and industry's capacity in knowledge production and application; while the government's role was decisive, providing market protection and

Table 5 The functions of the institutional spheres for innovation in China

	Government	University	Industry
Unique functions	• Make policies, regulations, and laws	In general, produce, disseminate, and apply knowledge to create spirit value	In general, applying scientific and technological knowledge to create material value
	• Consider significant national programs and organizing key projects	• Provide quality human resources for R & D	• Produce products
	• Provide funding for key national and regional R & D projects	• Commit to basic research	• Engage in experimental development
	• Supervise the competition order	• Develop education in innovation and entrepreneurship	• Finance business
	• Organize university-industry traffics		• Marketing
Shared functions		• Help policy making and decision making through consulting	
		• Invent new technologies	
	• Provide various professional training		
	• Provide consulting for business		
	• Promote postgraduate education		
	• Foster SMEs		• Foster SMEs
	• Take care of environment protection		• Take care of environment protection
	• Construct innovation culture in the society		
	• Provide public service through consulting		
	• Help firm-formation		
	• Build the shared information platform		

incentives for the adoption and use of domestic products, when indigenous Chinese firms started to compete directly with joint ventures (Mu and Lee 2005).

The government-pulled triple helix has the following characteristics: (1) government initiates and controls significant projects for innovations as innovation organizer; (2) all or most research universities, key research institutes, and large-scale enterprises are affiliated to central or local government; (3) the top (Party and government) leader's thought gives direction to the triple helix: government policy and resolution are the 'batons' which guide the process and directions of innovation; and (4) it is believed typically that anything can be promoted by a national or local government plan or project. This model has its advantage: being able to promote large-scale innovation projects, such as National Innovation Project, National University Science Park Project, as well as previous Satellite Project and A-Bomb, form consensus in regional innovation, organize innovation routine, and build platform for regional innovation. Nevertheless, it entails some disadvantages: (1) heavy government financial burden: this is why it is emphasized that enterprises as the main actors invest for innovation; (2) great stress on governance: since government's optimum role is a supporter to influence and guide innovation efforts by policy and law, it can neither replace knowledge producer nor become the key player of technological innovation; and (3) less authority and creativity for university and industry in decision-making as innovation actors: in many cases, they have to follow the government completely and limited by it.

University

It is believed that universities should assist the economy through enhancing technology transfer or connecting with local industries. Incubators or science parks are viewed as effective means to achieve the goal. The key problem is how a university can 'independently' produce new technologies to become an engine to produce knowledge, rather than just help import them from other countries, that is, how to enhance independent research on campus. China's universities need more financial support in teaching and research and policy assistance, on one hand, if they are seen as one of the main sources of research. Most income from running UREs is used to expand the enterprises, rather than raising the level of research. So far, national centers of technology transfer, with missions to accelerate technology transfer, obtain advanced technologies, and upgrade traditional technologies and industries, have been established in six top-ranking universities[e]. Some universities have even set up international centers for technology transfer, supported by government and university administration, with enterprises participation.

In fact, China is not behind in article and patent production worldwide (Table 6), but rather lacks top ranking higher education institutes and high quality research results to apply in industries. This is caused by the following reasons: (1) Staff: now, only 14.3% (201,815) have doctor's degree. (2) Postdoctoral fellows: the number should be increased, but there is inadequate financial support. (3) The quality of postgraduate education: weak and hard to strengthen due to 'educational corruption'. For example, admission offices control and determine the enrollment following Guan Xi's[f] rules; professors allow those with poor quality dissertations to graduate. Recently, however, the government acknowledged awareness of this situation and emphasized that postgraduate education needs to be strengthened[g]; however, it is very hard to recover or go

Table 6 S&T papers (indexed by SCI and EI) and invention patents (IPs) of some countries

Country	SCI (rank) in 2010 million	EI (rank) in 2010 million	Domestic IPs in 2009	Foreign IPs in 2009	Total of IPs of the country in 2009 (rank)
China	122 (2)	112 (1)	65,391	63,098	128,489 (3)
USA	390 (1)	95 (2)	82,382	84,967	167,349 (2)
Germany	105 (4)	29 (4)	10,284	4,151	14,435 (9)
Japan	97 (5)	35 (3)	164,459	28,890	193,349 (1)
Total worldwide	1,421	480			

Source: IPs data were drawn from WIPO, Industrial Property Statistics (2011) and the paper numbers from MOST 2011a.

forward in the short term. Quality must be achieved by gradual accumulation, rather than through a 'big jump' in quantity. (4) Research capability: faculty's performance assessment focuses on research publications (number of papers and books), rather than knowledge application in practice such as patents licensing and consulting for firms.

Industry

A planned economy with lack of competition results in poor innovation capacity and motivation of enterprises. They pay more attention to existing technique and process improvement, instead of technological innovation or distinct change. From our interviews in 2005, only a few large-scale enterprises are involved in the whole innovation process from basic research to technological development to product to market. More recently, firms with weak R&D capacity recognized that low-tech products cost increasing reduced natural resources but have fewer added values. Thus, typically, they start to develop their resources for innovation to become the main actor of technological innovation. Technological progress contribution to manufacturing efficiency has become visible. R&D project numbers of LMEs increased from 70,580 in 2005 to 133,852 in 2009, near 90%; the number of the projects for new products goes up from 81,033 to 152,770 in the period (MIIT and CASS (Ministry of Industry and Information Technology and Chinese Academy of Social Sciences) 2011). The proportion of expenditure of foreign technologies purchase has been rising from over 85% (in 2000) up to around 60% in 2009 [MIIT and CASS (Ministry of Industry and Information Technology and Chinese Academy of Social Sciences) 2011, p.23]. In addition, according to the Department of Development Planning of the Department of Development Planning of the MOST (2013), industrial enterprises above designated size have transformed from highly relying on technology import to technological innovation-based, supplemented by technology import (Figure 6). An era beyond relying on developed countries for new technology to one of self-supply is coming.

Among 2.554 million person-years R&D personnel in 2010, the business sector's proportion is 73.4%, research institutes 11.5%, and HEIs accounts for 11.3%. The 80.1% is committed to experimental development, 13.1% to applied research, and 6.8% is working for basic research. The 97.5% of industrial GERD is used to carrying out experimental development, 2.4% to applied research, and 0.1% to basic research. As its R&D capacity focusing on experimental development rises, the shared function of China's industry is continuously enhanced. It will work together with the university where basic research is primarily carried out. Research institutes have primary responsibility for applied research while the government is in charge of policy and shaping implementation measures.

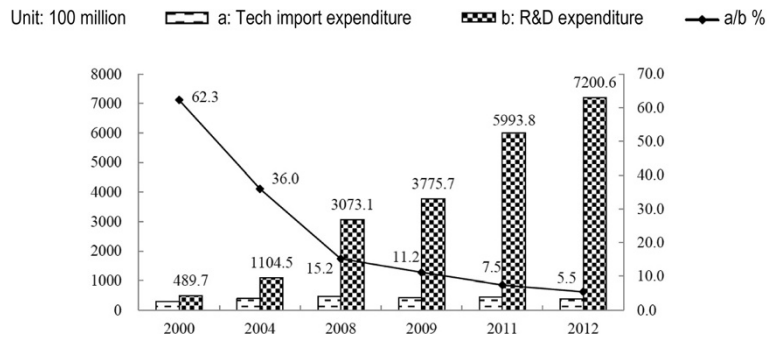

Figure 6 Expenditure of industrial enterprises above designated size for technology import and R&D activities (2000 to 2012).

Results and discussions

The future evolution of Chinese triple helix in institutional and functional perspective based on the cored-field model

Transformation from a statist into an interactive triple helix model refers to the change in institutional and functional spheres. As private business and private HEIs grow up, the core of each institutional sphere is changing to become distinguished, just as shown in Figure 3. This section will explore the future of Chinese triple helix based on the research above.

Removing overlapping internal cores of institutional spheres: UREs' spin-off

University research results with commercialization potential were rarely transferred into industry. Firstly, the performance assessment indicators to university faculty by the Ministry of Education did not include technology transfer contribution such as consulting for industry and founding new firms (startups), since the faculties who are involved in these activities are recognized to work for themselves, not the school. Thus, to fulfill technology transfer, the university encourages the faculties to represent their own school to consult for industrial firms and achieve knowledge capitalization through establishing a special organization affiliated to itself, URE, with double or multiple attributes.

There is a crucial difference in firm formation in different triple helix models. Although both spin-offs and UREs are encouraged and supported by the university, a spin-off by definition is an economic entity of academic origin that becomes an independent entity; whereas a URE is a business enterprise, part of the administrative structure of the university, remaining under the ownership of their mother that is directly responsible for their management and liabilities;

Based on self-interest considerations, universities are reluctant to give up the ownership of UREs and huge profits (Table 7). We argue that UREs may be better established by universities, but must spin-off from the core of the institutional sphere when they 'grow up'. A certain number of years could be set for them to stay under the university administration, and business income can be shared between the school and the enterprise in a proportion in the future.

URE's survival and development essentially derived from the state-owned higher education system in which the universities are all 'public', the same as the Government. If there are government-run enterprises (GRE) existing in the economic system, why

Table 7 Total assets of group companies of UREs in China (Top ten, as of 31 Dec 2010)

Ranking	Company	Total assets (10 K CNY)
1	Peking University Asset Management Company Limited 北大资产经营有限公司.	6,752,347.90
2	Tsinghua Holdings Co., LTD. 清华控股有限公司.	5,060,424.00
3	Northeastern University science and Technology Industry Group Co., Ltd 东北大学科技产业集团有限公司.	1,194,610.31
4	Shanghai Tongji Science & technology Industrial Co., Ltd 上海同济资产经营有限公司.	711,519.86
5	Wuhan Huazhong Numerical Control Co., Ltd 武汉华中科技大产业集团有限公司.	614,569.87
6	Shanghai Jiao Tong University Industrial Invest & Management Co. Ltd. 上海交大产业投资管理 (集团)有限公司.	471,187.69
7	China University of Petroleum Holding Ltd. Qingdao 青岛中石大控股有限公司.	398,432.07
8	Zhejiang University Yuan Zheng Holding Group Co., Ltd 浙江大学圆正控股集团有限公司.	353,298.22
9	Scientific and Technological Industrial Group Ltd of SWJTU. Chengdu 成都西南交通大学产业 (集团)有限公司.	281,052.51
10	ShanDong University Industrial Group, Ltd 山东山大产业集团有限公司.	231,751.96

Source: Official website of Science and Technology Development Center, Ministry of Education, see http://www.cutech.edu.cn/cn/kjcy/xbcytj/2012/05/1331845780456224.htm.

could not URE as part of state-owned university exist and be successful? GREs are also part of the administrative structure of government, even when nominally owned by a state company. For example, a city government can jointly establish an airline with aviation industrial sector. As a result, the internal cores of the institutional spheres are overlapping (Figure 7). To remedy this situation, the government has recently taken steps institutionally to separate university firms from the mother, through the establishment of university S&T enterprises groups. However, the mother bodies still are holding them as the largest shareholders; the ownership has not essentially been changed.

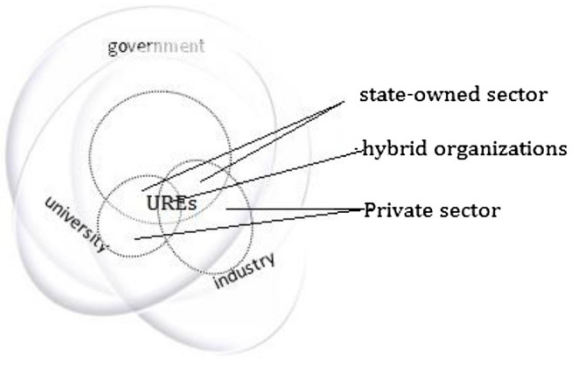

Figure 7 The current university-industry-government relationship as institutional spheres in China.

UREs that are owned by their mother universities are in the internal core of university institutional sphere, rather than in the external field; a spin-off arises from the mother university, but is independent to the mother institutionally. The key point is who owns the enterprise, rather than who is running it. As an enterprise, the URE has an industrial firm attribute, but its president and managers are typically from the faculty and still keep an ID in the university. They may be the president, CEO, senior managers, or key staffs. UREs' development has raised the issue of university's purity as public facilities, diverging from its core missions. It will cause a more blurred university-industry boundary if the URE stays in the core of the university institutional sphere long term.

The role of the university in a society is generally determined not only by economic logic but also by the 'social contract' concerning the division of labor. There have increasingly been complaints that the university is becoming an 'industrial enterprise'. [h]For example, university is taking on enterprise actors in innovation through its advantage in high-tech research; the tension between university and industry is increasing; and since university has its own companies, excessively competitive university-industry relationship will eventually induce a difficult technology transfer from university to industry (Mowery et al. 2004). Eun et al. suggested that the absorptive capacity of industry affects the university's decision to establish UREs. When it is weak, the university feels that it is the only path to fulfill its technology transfer or the industrialization mission is to set up UREs and make them flourish. As absorptive capacity increases, universities prefer transfer technology and UREs decline (Eun et al. 2006).

Spin-offs in Boston and Silicon Valley show that universities have made a tremendous contribution to local economic and social development. Many UREs have also taken the leading role in creating China's high-tech industry. Tongfang, Wangxin, and Dongruan Gufen established and operated by Tsinghua University, Zhejiang University, and Northeastern University, respectively, have become the top Chinese S&T firms. They exemplify the advantages of UREs as high-growth enterprises.

Nevertheless, it is contrary to the traditional social contract that the university runs its enterprise. The university is viewed as a non-profit organization, not a business according to the historical contract. If the university increasingly develops UREs, it will become the strongest social institution with economic and academic impacts, even influencing the political process of the nation through its alumni and economic strength, potentially becoming a social institution more important than the government of China. If the existing social contract still works, UREs as 'enterprises possessed by universities' should not operate in the internal core of university sphere. The factor that brings the university to the external field space is its third mission for innovation through its technology transfer and firm formation functions. UREs should be encouraged to contribute to the mother university by donation. Based on self-interest considerations, universities are reluctant to give up ownership. It will be a struggle whether UREs can really come out from the core to become 'spin-offs'.

Strengthening unique functions

If a sphere's shared functions are considerably stronger than the other ones, it will 'take the role of others' for innovation. Therefore, shared functions should be limited to a modest degree, while unique functions should be enhanced continuously.

A smart strategy is to seek for modest shared functions and strengthen unique functions. For example, the development of aviation, electronic computer, and semiconductor industry greatly in the US depends on government support. During the 1960s, the government bought 37% to 44% of all integrated circuit products, thereby accelerating the development of the industry even though the overt purpose was simple military procurement. In Silicon Valley, one-fourth order forms are from the US government.

But the government did not invest much as an investment company. An over active government could actually weaken the investment for innovation from firms because of a crowding-out effect. The information superhighway project needed $400 billion, but the US government only put in $30 billion. At present, functional cores of institutional spheres in China (Figure 8) will evolve from a separated to an overlapping relationship.

Decreasing government's shared functions and increasing interactions

Over-strong shared functions of the government sphere came from state-ownership that cuts back the independence of university and industrial spheres. Therefore, in the external field of government functional sphere, instead of running state-owned enterprises and public universities, the government should get involved in helping hybrid organization formation and creating triple helix knowledge, innovation, and consensus spaces (Etzkowitz 2008). Its premier task is construction of 'knowledge space.' To achieve this, the government has initiated large projects to support key universities and research institutes. The government projects to develop universities help recruit excellent researchers from abroad and provide resources for professors to participate in path-breaking work on key S&T projects. A secondary objective is to develop the 'innovation space' through innovation platforms, networks, and hybrid organizations. Consensus space is naturally available in China, with the government's dominant leadership.

The university and industry should be in the external field of government functional sphere. The university should be oriented to provide new knowledge to be applied to

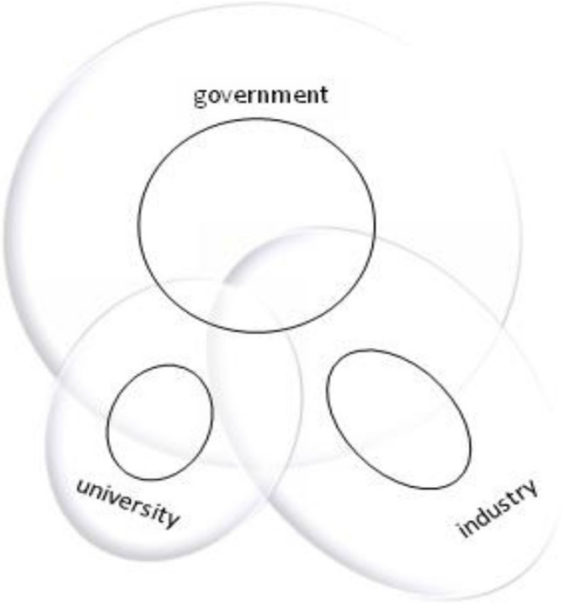

Figure 8 The current relationship of functional cores of institutional spheres in China.

assist experimental development in industry, evolving towards autonomy. Though many research results have been achieved, e.g., the number of patents granted from the university in 2010 accounted for 28.8% (48,294) of the country total, they could not be locked in drawers. In addition to raise the quality further, they need users that are identified and selected by industries.

In spite of private sector appearance, since China's industry is traditionally over-influenced by the government intention in a state-owned system, the government finds it difficult to give up any of its authority to control other institutions, even the market. This overwhelming power not only results in corruption but also distorts the 'market economy' into a 'state monopoly' economy.

Conclusions

The argument presented here attempts to better explain an apparently idiosyncratic university-industry-government relationship through inventing a cored model. It is hypothesized to divide an institutional sphere into a relatively stable internal core and the external field space around the core. As the institutional spheres of a triple helix should be relatively independent, how they can interact with each other? The answer is that the interactions take place by (unique and shared) functions in the external fields of institutional spheres. Unique functions led to needs to interact (necessity), and shared functions make interactions possible (possibility).

We thus differentiate institutional and functional spheres to analyze a triple helix. Using the cored model and differentiating institutional and functional spheres, we analyzed the Chinese triple helix according to four dimensions. In the end, we argue that China should resolve the problems existing both in the cores and field space of the institutional and functional spheres, that is, to separate the cores of the institutional spheres and strengthen the unique functions.

Endnotes

[a]'Project 985' is a project that was invented to promote the development and reputation of the Chinese higher education system by founding world-class universities in the 21st century and eponymous after the date of the announcement, May 1998, or 98/5, according to the Chinese date format. The project involves both national and local governments allocating large amounts of funding to certain universities in order to build new research centers, improve facilities, hold international conferences, attract world-renowned faculty and visiting scholars, and help Chinese faculty attend conferences abroad.

[b]'Project 211' is a project of National Key Universities and colleges initiated in 1995 by the Ministry of Education of the People's Republic of China, with the intent of raising the research standards of high-level universities and cultivating strategies for socio-economic development. During the first phase of the project, from 1996 to 2000, approximately US $2.2 billion was distributed. The name for the project comes from an abbreviation of the 21st century and 100 (approximate number of participating universities.

[c]The original thinking of this model came from Henry Etzkowitz and Chunyan Zhou's Theme Paper for Triple Helix International Conference VI in Singapore in 2007 (Etzkowitz & Zhou 2007), based on the idea in Zhou's Ph.D dissertation on science and technology field in 1999 (Zhou 2001).

[d]'Socialist market economy with Chinese characteristics' is based on the dominance of the state-owned sector and an open-market economy, with its origins in the Chinese economic reforms by Deng Xiaoping. The ideological rationale is that China is in the primary stage of socialism, an early stage within the socialist mode of production, therefore has to adapt capitalist techniques to thrive. The system has widely been cited as a form of state capitalism.

[e]The six universities are: Tsinghua University, Shanghai Jiaotong University, Xi'an Jiaotong University, China East University of Science and Technology, China University of Science and Technology and Sichuan University.

[f]'Guan Xi': personal connections. It is called 'social resources' sometimes.

[g]See http://www.moe.gov.cn/publicfiles/business/htmlfiles/moe/moe_838/201202/131256.html.

[h]Similar to critique of US universities. See Wasburn J Kept University.

Additional file

Additional file 1: Multilingual abstracts in the five official working languages of the United Nations and Portuguese.

Competing interests
The author declares that she has no competing interests.

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