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INSTITUTIONAL ARRANGEMENT, TECHNOLOGICAL INNOVATION AND APPLICATION EVOLUTION: THE RISE OF CHINA'S EMERGING COMPUTING INFRASTRUCTURE

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ABSTRACT

This paper tries to explore the interaction of institutional arrangement, technological innovation and application evolution underlying the impressive growth of China's computing infrastructure. Drawing upon the actor-network theory, we construct a framework to explain how the elements identified forge the evolution of the sector. Our study hopes to provide the analytical lens and explanatory power to probe this growth process under the emerging contexts. We conduct an in-depth case study on the growth of China's emerging computing infrastructure to justify the framework. Chinese government has been deeply involved in the development of the computing infrastructures including the systems of supercomputing and cloud computing to build a nationwide computing backbone network. In the resent emerging of cloud computing, the networks which involved in much more diversified actors with heterogeneous interests are shaping under a more open setting. However, the facility-oriented strategies by the dominant state-owned players still exert great challenge to the cloud computing development which needs sustainable benefits generated from the infrastructure. Our paper tries to provide a systematic understanding on the growth of China's emerging computing infrastructure and offer some important insights to the emerging industries in other large emerging countries.

Keywords: Actor-network theory; China; Computing infrastructure; Cloud computing; Emerging information technology; Supercomputing;

INTRODUCTION

In the past decade, the IT infrastructure has gradually become the backbone for the knowledge intensive development in the large emerging economies like China. In today's data intensive world, IT infrastructure has also served as an important driver for the technological, industrial economical and social transformation. Failures to design such infrastructures are more common incurring huge losses in foregone investments, opportunity costs, and political and social problem (Hanseth & Lyytinen, 2010).

The rapid development of China's computing infrastructure in recent years has attracted great attention from the academia, business and politician internationally. Even American president highlights the rising of China's supercomputer infrastructure in terms of calculation speed and facility quantity which address both economic growth and scientific standing.[1] This emerging context which characterized by booming economy, transforming industries and growing technology brings new opportunities to the application of the computing. As the world's largest internet, computer, and mobile market, China owns great potential of computing application compared with other developing countries. Chinese government has been deeply involved in the development of the computing infrastructures including the systems of supercomputing and cloud computing to build a nationwide computing backbone network. Super-computing receive large amount of government support in the national "12th Five-year Plan", cloud computing was considered as one of the strategic emerging industries for China to re-motivate the economic slow-down after the financial crisis[7]. Since 2009, the enthusiasm of China's government for the cloud computing triggering the surge of nationwide investment even excesses the expectation of the industry itself.

When new technological innovation meets emerging context, the two uncertainties collide and complex the process of the computing infrastructure development. Then there maybe an urgent need for the research linking the transformation of the giant computing infrastructure to the particular social, economic, political and institutional contexts in the large emerging country. Using the actor network as an analytical lens, this paper aims for a deeper understanding of the key aspects of China's emerging computing infrastructure in a more open world.

Our paper is organized as follows: in the section of literature review, previous literature related to our research was classified and further analyzed. In the section of framework and methodology, we draw upon the ANT theory to primarily develop a conceptual framework for analyzing the growth of the modern computing infrastructure. Data collection method is also elaborated. In the section of case study of computing infrastructure, in-depth case studies of supercomputing and cloud computing in China were conducted to justify our framework. The last section is devoted to further substantiating this framework with the empirical study and this paper concludes with the discussion on further possible research direction.

LITERATURE REVIEW

The actor-network theory has gained increased attention from the researchers trying to extend its applications beyond technology adoption and design to broader areas (Walsham, 1997). A key feature of actor-network theory is that the actors include both human beings and non-human actors (such as a technology), together composing a network to be studied (Callon, 1991; Latour, 1996). It encourages the researchers to disclose the interplay of the market transformation and its social system. Actor-network theory examines the motivations and actions of human actors that enroll themselves into a network and align their interests around specific non-human artifacts. Yet, actor enrolment and interest alignment alone cannot fully explain the mechanism of a change. Then a holistic approach combined technology, market and institution needed be explored to examine the growth of an industry. "Inscription" and "translation" are key concepts

for understanding the interest alignment to form an actor-network. An inscription is a form of anticipated characteristics which actors, in one way or another, try to build into an artifact (Callon, 1991). Translation implies that an actor reinterprets or appropriates the interests of other human actors and the interests embedded in non-human actors according to one's own, and has these interests represented in the inscription. The actors' interests are flexible and can be translated, enabling the interest alignment and the maintenance of an actor-network.

The process of infrastructure innovation and adoption

The development of infrastructure is not only depends on the "technology-push" and "infrastructure innovation", it also needs "innovation adoption" and "business model" to exploit the potential of existing infrastructure. There are multiple definitions about the infrastructure. The emergence and extension of the infrastructure lowers the knowledge threshold to adoption and reduces the complexity of the technologies to the users (Gao, 2007). It decreases the adoption risks and creates user favouritism towards the technologies. It also guarantees the stability of the promoted technologies, triggers learning and thereby reduces costs (Attewell, 1992). Focusing on the domain of computing infrastructure, Foster & Kesselman (2004) identify it can create a universal source of pervasive and dependable computing power that supports dramatically new classes of applications. The computing infrastructure can accelerate and foster the adoption of innovations, so enterprises prioritize infrastructure to promote innovations and unlock new sources of value (Aymerich & Fenu, 2008).

Previous literature has provided a number of important insights, ranging from the motivations and factors that influence innovation adoption to the outcomes and processes of its diffusion (Cooper & Zumd 1990, Cool et al. 1997, Damsgaard & Lyytinen 2001). The situation of user adoption of technologies and services influences the innovation of infrastructure, and requires the infrastructure enabling the provision of new, appropriate services (Abbate, 1999). According to Christensen and Knudsen (2010), business model is critical to enabling innovation adoption. And it is introduced as part of framework for thinking about systemic change, which also includes enabling technology and a careful market adoption strategy (Christensen& Knudsen, 2010). Business model is also referred to as the conceptualization and adoption of new ways of conducting economic exchanges among transaction participants (Zott & Amit, 2008), which greatly influence the innovation and adoption of a technology.

Open the black box of social network

The development and adoption of the emerging technology depends on the coordination and negotiation of different actors within the social system. For example, Muller-Veerse (2000) considers government agency, intra-governmental organizations, equipment vendors, network operators and content providers play their different roles in promoting innovation. Tilson and Lyytinen (2004) identified services designers need to understand the complex needs of all stakeholders in the overall social system. Gao (2007) defines the users, providers of mobile services and other relevant institutions as three groups of actors that represent the social interests in mobile telecommunications market. As the openness nature of cloud computing, Edwards et al. (2007) implies that social and technical diversity and heterogeneity will increase along with

the evolution of technology.

Interaction between social and technological systems

ANT adopts a socio-technical perspective into the design and analysis of technological systems in which the world is viewed as being comprised of networks of technical and social actors (Sarker & Sidorova, 2006). The central argument of actor-network is that successful networks of aligned interests are created through the enrolment of a sufficient body of actors that inscribe their interests into the network (Walsham & Sahay, 1999). A key feature of this theory is that actors are taken to include both human beings and nonhuman actors (or artifacts), such as a technology, which together compose one network (Callon, 1991). Gao& Damsgaard (2007) define mobile telecommunications market as the non-human artifact and its players consisting of social system as human actors, they use actor-network theory to analyze the social-technological evolutionary process of mobile telecommunication market innovation. Social structure and technological architecture co-evolve as technical problems are solved, and the services and products are adopted in the social domain (Tuomi, 2002).

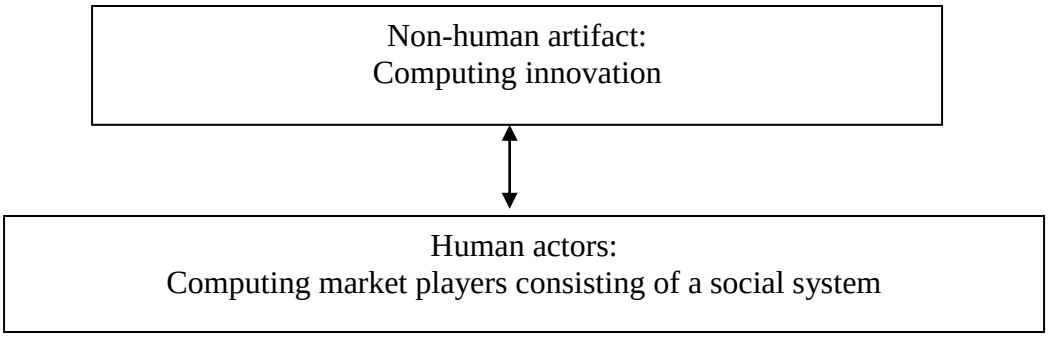

Figure 1: The preliminary framework of actor-network analysis

Literature review of computing infrastructure

There are several researches focus on the development of computing infrastructure from the perspective of technology, business, prizing, adoption and security in the developed countries (Shirley&Carol，2011). Vouk& Sills et al. (2010) exploit the integration of high-performance computing into cloud computing services from the technological perspective, they discuss a very successful production level architecture and policy framework for supporting HPC services within a more general cloud computing infrastructure. Wei (2009) identify that cloud computing makes super-computing power via the Internet free flow became possible while there still exist obstacle in fully integrated super-computing power into cloud computing. There are also some literatures concentrate on cloud computing from either technological or organizational perspective. Although some commentators categorize cloud computing services somewhat differently, the most common approach segregates services into three-part taxonomy (Foster et al., 2008; Vaquero et al., 2009; Mell & Grance, 2009). It means that the cloud computing can provide services at different layers of the resource stack, namely IAAS (infrastructure as a service), PAAS (platform as a service) and SAAS (software as a service). Some literatures also

address the merits of cloud computing in terms of reducing costs, aggregating demand, increasing reliability and transforming capital expenditures into operating expenditures (Weinhardt, et al, 2009; Leimeister, et al., 2010; Koehler and Anandasivam, 2010).

Despite there are researches focus on technology, business, prizing, adoption and security of computing infrastructure, few studies link the institutional arrangement with technological innovation especially under the context of emerging countries. And computing infrastructure is a kind of socio-technical system involving both technical and social elements and their interactive relationships. Through the lens of actor network theory, this paper tries to explore the interaction between technology, market and institution related to China's emerging computing infrastructure and then hope to provide some theoretical and empirical insights to other emerging countries.

FRAMEWORK AND METHODOLOGY

Based on the literature and analysis in the above sections, we propose an analytical framework to examine the socio-technological mechanism for the computing infrastructure innovation, as shown in Figure 2.

In terms of the business firms involved in cloud computing, here we define four types of actors including system providers, service providers, institution and users to represent the interest in our social network. In identifying these elements, it is necessary to consider whose interests these human candidates represent (Walsham, 1997). System providers mainly concentrate on the computing facilities and terminal while the service provider concentrates on creating, configuring, operating and distributing services for the users.

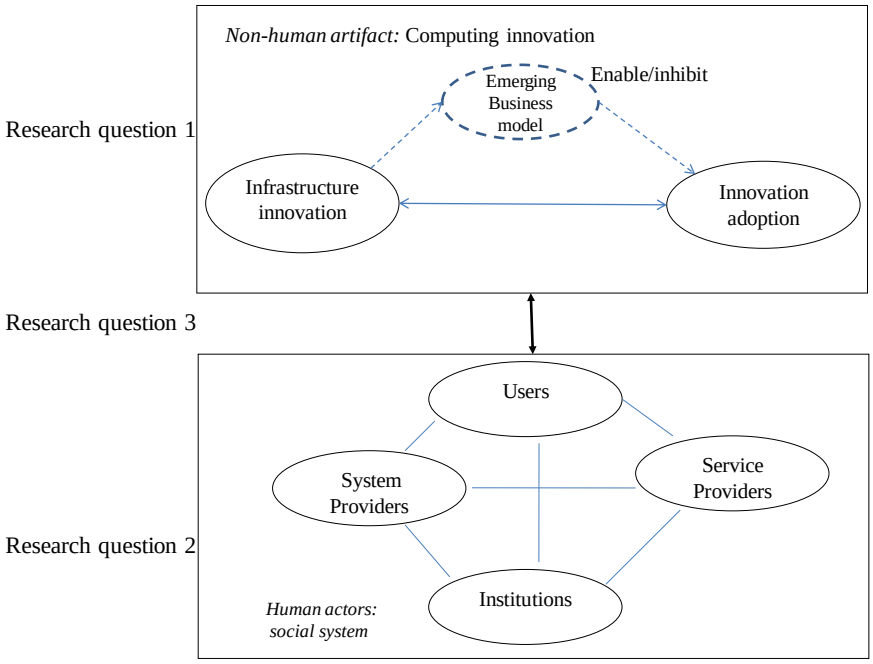

Figure 2: A framework for analyzing computing market innovation

As depicted in the framework, the research questions we try to explore and exploit are as follow:
Question 1: How do the infrastructure innovation, business model and innovation adoption co-evolution?

Question 2: What actors are enrolled into the social system in the development of supercomputing and cloud computing?

What are the characteristics of their interactions in the social system? What are their roles in computing innovation?

Question 3: How does the social system determine the innovation, and in return how does the innovation situation influence the properties of the social system?

We have conducted a case study of China to justify our framework. Specifically, we draw upon our framework to give a systematic analysis on the development initiatives of the supercomputing and cloud computing which promote computing market innovation. In line with our framework, the case study argues that it is the status of the interplay between the innovation and its social system that determine the successful or failed diffusion of a specific technology.

DATA COLLECTION

Carrying out a longitudinal study on the transformation of China's computing infrastructure requires capturing changes in information technology and the market, analyzing the dynamic contexts within which the transformation takes place, and exploring key stakeholders' perceptions of the market change (Walsham, 1995). The authors of this paper first engaged in the field observations (Yin, 1994). Second, from October 2010 to December 2012, more than thirty interviews were conducted in the main players including major system vendors, research institutions, public authorities, and operators in Chinese computing market. Finally, to identify the order of critical events within the computing infrastructure development in China, the authors used archival documents, including news reports in official newspapers, speeches of ministers and national leaders, and the annual reports of computing infrastructure development in China published by MII, MOST and MIIT.

The data collected by these different means were cross-validated before use (Strauss and Corbin, 1998). We engaged in two types of dialogical reasoning while interpreting the collected data. During the discussion between the authors, we triangulated the data from one perspective that had a deeper Chinese background. And from another perspective, we analyzed it from the view point of several outsiders generally entrenched in policies and businesses. This dialogical perspective also allowed us to engage in discussion with the practitioners who acted in the Chinese context (Monterio and Hepso, 2002).

Case Study of China's Computing Infrastructure

China was confronting more pressure from global market after joining in WTO and was trying to alter their current business models from low-cost, low-margin to an orientation that supports innovation and collaboration along the global value chain. There are also the increasingly needs for data storage, data processing and data computing to speed the economic transformation of the millions of SMEs in China. Effective design for such service capability to support the transformation by exploiting the existing computing infrastructure becomes critical to China.

Table1, 2 and 3 condensed the analysis of our case study to verify the framework. We will elaborate them in this section.

Table 1: Computing innovation

	Super computing	Cloud computing
Infrastructure Innovation	There is a rapid development of China's super computer both in terms of quality and quantity	Supported by broadband networks, the high-efficiency and green data-processing center as well as large-scale distributed storage and computing capacity supports various businesses.
Innovation	The innovation adoption was	The adoption of cloud computing

	Super computing	Cloud computing
Adoption	limited to the macro project in the domain of energy, climate and others. Only few large enterprises can get access to these computing resources.	follow a service oriented strategy, which involve a collection of users various from large enterprise, SMEs, government to individual.
Business model	Lacking of Effective business model	Business model is imperative to enable the transformation from technology innovation to innovation adoption in cloud computing.
Dynamics	Facility oriented	Service oriented

Table 2: Comparison of social system between supercomputing and cloud computing

	Super computing	Cloud computing
Institutional intervention	Intervening in the technology innovation and adoption directly follow the performance-based paradigm	Intervening in the deployment of infrastructure rather than innovation adoption.
System providers	The public universities, institutes and state-owned companies like NUDT (National University of Defense Technology), CAS (Chinese Academy of Sciences) and Sugon.	The domestic equipment provider such as, Lenovo, Sugon and Huawei, the transnational equipment manufacturers such as IBM, EMC and Intel
Service providers	Specific supercomputing center	The domestic internet companies represented by Sina, Tencent and Alibaba, telecom operator such as China telecom, China unicom and China mobile as well as the cloud computing centers that collaborate with local governments.
Users	Academic institutes, Large state- owned enterprise,	Large enterprises, SMEs, government, academic institutions, universities, public agencies and individuals

	Super computing	Cloud computing
Institutional intervention	Intervening in the technology innovation and adoption directly and following the performance-based paradigm	Compare with intervention in the deployment of infrastructure the stimulation in innovation adoption has relative lagged behind.
Interrelation between service providers, system providers, users and institution (interest mechanisms)	Both service providers and system providers were directly initiated and guided by government, users concentrate on the macro projects in the domain of energy, climate and others.	Government push the wide application of cloud computing. The emerging business model which involved in large range of enterprise, individual and institute (suppliers and users) serves as the engine of cloud computing.

Table 3: Research questions addressed

Question 1	➢ China's supercomputing capacity mainly adopted in the domain of energy, climate and others. Both the technological innovation (the development of super-computer and the establishment of supercomputing centre) and service adoption are promoted by the institutional intervention, while the effective business model was lacking to bridge the gap between infrastructure innovation and innovation adoption. ➢ Cloud computing can provide broad spectrum service to heterogeneous users like large enterprise, SMEs, government, individual, and among others. China's quick development of broadband networks and related computing facilities motivates the adoption of cloud computing by domestic users. Emerging business model enable the wide innovation adoption of cloud computing and self-reinforcing development of the computing market.
Question2	➢ In supercomputing, China's government follows facility oriented strategy to directly intervene into the development process of super computers, the operation of supercomputing centers and the application of computing capacity by system providers, service providers and users respectively. China's highly specified system providers supply super computer and related facilitates to or cooperate with the service providers. Service providers tailored the facilities by the approach of directional bidding among domestic system providers which is administrated by the

	government procurement. These supercomputing service providers provide computing service to the national institutions according to government's guidance.
	➢ In cloud computing, central and local government's investment incentives play a critical role in enhancing the dynamics of system providers and service providers. By the end of 2011, nearly 20 metropolitan governments announced large cloud computing and data center investments and projects. It demands more coordinated response from governmental agencies. System provider need to ensure the scalability, flexibility and reliability of the computing facilities, and optimal the facilities' cost and maintenance expenditure to enhance their attractiveness for service providers. New service capabilities of the service providers could be tried out by tackling a new problem with enough complementary capabilities or new applications.
Question3	➢ In supercomputing, both the technology innovation and adoption were greatly stimulated by the institutional intervention of Chinese government. For example, the Tianhe1A and Dawning Nebulae are mainly supported by national 863 projects. These established computing infrastructures are serving for the national researching and engineering projects, which are dominated by the state owned institutions.
	➢ Chinese central and local governments have tried to address the infrastructure innovation and innovation adoption by encouraging capital investment of domestic service providers. The establishment and maintenance of reliable computing infrastructure also stimulated the engagement of relative actors from different sectors.

The development of supercomputing (from 1989)

1. From technology innovation to innovation adoption

The development of Chinese supercomputing follow a top-down and facility oriented strategy. The development of supercomputing was motivated by government's initiative to stimulate the rapid development of pillar industry and ensure the sovereignty and security of the country. In 1989, the State Planning Commission, the State Science and Technology Commission and the World Bank jointly launched a project to develop networking and supercomputer facilities including three supercomputer centers in China (Fan, 2001). China gradually accumulated technological capability and research expertise under government's facility oriented strategy. Then the first decade of the 21st century witnessed the dramatic progress of supercomputing in

China, the computing peak speed of the fastest supercomputer climb from 51st in June 2003 to 5th during 2005 in the top 500 list[9]. By mid-2010, China's supercomputer Nebulae had reached the 2nd spot and a Chinese supercomputer, the Tianhe-1A, from the National Supercomputing Center in Tianjin briefly became the world's fastest at the end of 2010(Jonathan, 2010). As for China, the race to build the fastest supercomputer in the world has become a source of national pride to some extent.

Although there has been a rapid development of China's super computers in terms of theoretical peak speed, the innovation adoption was limited to the macro projects in the domain of energy, climate or scientific. Generally they are targeted to small groups of public institutions, who were interested in accessing powerful and expensive computing resources. Few large firms can get limited access to these computing resources and the computing potential is far from being fully utilized.

As one director of National Supercomputing center[10] said in an interview:

"Currently, we tend to purchase the supercomputer equipment from the domestic providers like Sugon or Lenovo other than foreign firms. The speed performance of domestic products can meet our operation requirement since the architecture of the supercomputer become mature. As for our customers, the academic computation demands mainly come from large domestic research institutes, only few large state-owned enterprises in oil or aviation sectors need supercomputing service. Actually, our computing service charge only covers the electricity cost. The investment and maintenance cost of our machines mostly come from the government, and we have very limited initiative to explore the new market. "

Both the technological innovation and innovation adoption are promoted by the direct institutional intervention, while the effective business model was lacking to bridge the gap between them. Address government intervention and neglect business model forming cannot ensure the sustainable and self-reinforce development of supercomputing industry.

2. Social system

Supercomputing industry involves in a small number of actors that is designated by government. The powerful computing systems owned by the government are valued for their ability to solve mission tasks for national interests in areas like climate, energy, finance, science and defense. This industry operates as a stand-alone system rather than a scalable and shared user re-configurable resource (Vouk et al., 2010). Government support the emerging and recent development of supercomputing through national programs. From the late 1990s, China launched one research program named "national HPC environment". From 2001 to 2005, the mega project about high performance computer and core software was started. In the late 2000s, MOST (Ministry of Science and Technology) founded the "Mega 863" project concentrate on "High performance computer and grid service environment" which aims to develop the high performance computer capable of carrying out thousand trillion level calculations a second and established the high performance computer capable of carrying out 300 trillion calculations a

second. Supported by the "national 863 project", National University of Defense Technology (NUDT) research and developed Tianhe1A which ranked the world first in October 2010. The government has followed the facility-oriented strategy to directly intervene into the development and operation process of super computers by system providers and service providers respectively. After the development of domestic supercomputer, several supercomputing centers are being built in Changsha, Shenzhen and Beijing. These Chinese systems are depending on chips made by the American companies like Intel and Nvidia while the key interconnect, or networking technology, developed by Chinese researchers(Ashlee,2010).

Table 4 depicts the 'China Top10 List of Super Computer in 2011', we can observe that the leading system providers for supercomputing are mainly domestic actors like NUDT, NPCETR [11] or Sugon, which supplies the supercomputers and related facilitates. They have established the stable interest alignment with the national supercomputing centers which provide the computing service to the targeted limited national institution users. These computing users concern more about the computing speed and technological capability. Other foreign system providers like IBM choose to supply their products to the business users.

Table 4: China Top10 List of Super Computer in 2011

Rank	Vendor	Country original	System	Installation Location	Service area	Linpack (Gflops)
1	NUDT	China	TianHe OneA	National Supercomputer Center in Tianjin	Scientific Computing /Industry	2566000
2	NPCETR	China	SunwayBlueLight	National Supercomputer Center in Jinan	Scientific Computing /Industry	795900
3	NUDT	China	TianHe OneA-HN	National Supercomputer Center in Changsha	Scientific Computing /Education	771700
4	Sugon	China	SUGON NEBULA/	National Supercomputer Center in Shenzhen	Scientific Computing /Industry	749200
5	IBM	U.S.	xSeries x3650M3/	Network Company	Internet Service	636985
6	IPE,CAS	China	Mole-8.5 Cluster/	Institute of Process Engineering, Chinese	Scientific Computing	496500

Rank	Vendor	Country original	System	Installation Location	Service area	Linpack (Gflops)
				Academy of Sciences		
7	Sugon	China	Sugon NEBULA/	National Supercomputer Center in Shenzhen	Scientific Computing /Industry	342300
8	IBM	U.S.	xSeries x3650M3/	Telecom Company	Industry	204754.4
9	IBM	U.S.	xSeries x3650M2 Cluster/	Network Company	Internet Service	196228
10	Sugon	China	Magic Cube/SUGON 5000A/	Shanghai Supercomputer Center	Scientific Computing /Industry	180600

Source: "2011 China TOP100 List of High Performance Computer" released by the Specialty Association of Mathematical & Scientific Software (SAMSS), CSIA

3. Interaction of computing innovation and social system

Both the technology innovation and development of supercomputing were greatly stimulated by direct institutional intervention of the government. China's supercomputing industry is strongly motivated by the government's pursuing of technology breakthroughs with a technologically elegant innovation in one great leap. These established computing infrastructures are mainly serving the national science programs in the domains of energy, climate, astronomy, geography and medicine, which are dominated by the state owned institutions. However, these computing infrastructures couldn't be fully exploited and contribute to the social and economic development directly. Only the limited public users can access such expensive and centralized computing resources. Then the infrastructure designers, developers and users couldn't be effectively intertwined to build strong interest communities for the infrastructure.

Emergence of cloud computing (from early 2009)

Since 2009, the advent of cloud computing has somewhat changed the traditional supercomputing landscape in China. Cloud Computing is more considered as an IT deployment model than a pure technological breakthrough, where resources, in terms of infrastructure, applications and data are deployed via the internet as a distributed service by one or several service providers. These services are scalable on demand and can be priced on a pay-per-use basis and the cloud computing utilizes on-demand network access as a means to connect the user to a shared pool of resources (e.g., networks, servers, storage, applications, and services) based

in the cloud (Shirley & Carol, 2011). This new paradigm is regarded as a solution for reducing IT investment costs, minimizing management effort, and improving business process (Armbrust et al. 2010).

Affected by the worldwide financial crisis in 2008, China suffered a sharp reduction her export and manufacturing sectors. In the effort to resist this recession, China was forced to transform its developmental engine from low cost based manufacturing and assembling sectors to knowledge intensive sectors. However, the computing facilities supporting millions of SMEs are still quite weak. The emerging cloud computing model based on the growing computing infrastructure becomes an attempt to enhance the competence of the Chinese firms under the global fierce competition.

1.Computing innovation

Since 2009, a significant change emerged in terms of the business models and service patterns of computing architecture in China. As an service oriented innovation, cloud computing emphasize more on the reconfiguration of market and industrial structure rather than just concentrate on the disruptive technology advancement. Main cloud computing service and solutions are based on utilizing existing IT technology and infrastructure, which greatly speed the constructing of the industrial value chain. By utilizing cloud computing, large amount of SMEs can exploit the potential of their obsolete computers or other computing facilities in the future. Since the early 2000s, the large internet companies such as Alibaba, Baidu and Shanda start to provide cloud based services like SaaS solutions. A lot of SMEs benefit from this internet-based computing services like e-commerce data mining, a big data processing and data customization.

Stimulated by the increasing needs of knowledge and information based industrial transformation, China attached great importance to the establishment and maintenance of supporting infrastructure like broadband network. After several decades of development, China's network user scale ranked first in the world and maintained high growth rate. As of December 2010, China had 457 million internet users and 126.34 million broadband subscribers [3]. Although there were large number of broadband network users, the statistics show China's broadband network penetration rate was 9.49% percent in 2010(MIIT).

As the low penetration rate of the broadband network and the unbalanced development of networks in different areas restrain the development of cloud computing in China, incumbent telecommunication operators become a central actor for the cloud computing under such contexts. Since 2009, China Mobile, China Telecom and China Unicom began to launch their cloud computing research and development centers under the support of provincial and cities' governments. Their most IDCs (Internet Data Center) can be extended from providing original server hosting and renting function to support data storage, processing and service supporting various Internet and e-commerce businesses. In 2010, these telecommunication giants enlarge their investment breadth to extend and rebuild the IDCs into cloud computing centers. For example, China Mobile established its international information harbor especially concentrate on IDC centers in Beijing. China Unicom's IDC center and cloud computing operation center was

positioned in Shanghai, which will invest 500 million in the next five years.

Table 5 : The capital investment of Chinese telecom operators to IDCs from 2009 to 2010

	2009	2010
China telecom (million)	69.81	109.86
China Unicom (million)	46.22	75.74
China Mobile (million)	14.18	24.47

Source: Cloud computing market report of CCIDC consulting(2010)

Compared with supercomputing segment, the system providers in cloud computing sector need not to concern about over-provisioning for a service with least popularity, thus wasting costly resources, or under-provisioning for one that becomes wildly popular, thus missing potential markets and revenue (Michael et al.,2010). The virtualization, one of the core enabling technologies for cloud computing allows the computing power of a single machine to be subdivided into a number of smaller virtual machines which will ensure the ubiquitous and unlimited providing of computing utility for the business application. The increasingly diversified demand which exploit the innovation potential and motivate the infrastructure deployment.
Users can also benefit from cloud computing by purchasing software, storage and computing power on a pay-as-needed basis. The successful adoption of cloud computing need a kind of service-oriented strategy, which involve a collection of users like large enterprises, SMEs, government agencies and individual. Recently, Most of the business models adopted by domestic service providers are transplanted horizontally from large MNCs in the similar business domain with minor localized modification. So the emerging business model which is tailored to China's context is imperative to enable service adoption.

By the end of 2011, nearly 20 metropolitan governments such as Beijing, Chongqing, Shandong, Shanghai and others have announced large cloud computing and data center investments and projects. These local governments are targeting to the great needs for local economic upgrading. By September 2011, China has invested about £98 billion in cloud computing to build the data hub in Asia[2]. The system providers and service providers also actively involved in this investment surge to capture more business value.

As one senior official of local government said in our interview:
"We consider our cloud computing center which equipped with thousands of computer servers as a high-end image for local industry upgrading. The cloud computing is the next generation IT technology, and it seems to create a 'high-tech' investment environment and infrastructure like high-speed railway. You know, we must compete with other large cities in China in the 'emerging industries'. Those large telecommunication operators also hope to collaborate with us as they hope to capture more business value from the customers by exploiting their existing network and data centers if the whole cloud computing industries really take shape. Those large domestic system vendors also hope to sell their computing servers or other equipments to us

under the grand cloud computing plan.

We tend to cooperate with these large state-owned firms as they can attract more policy supports and national programs from the central government. Furthermore, we consider' cloud computing' as a strategic platform to stimulate the quick growth of our electronics hardware and software industries even the cloud computing itself could not earn money in the future . "

Table 6: Investment activities and main partners of local governments in cloud computing

City	Established time	Development visions announced	Main Partners
Wuxi	Feb. 2009	Cloud Valley of China	IBM, Sugon
Chengdu	Dec.2009	Cloud computing centre in middle west, Supercomputing centre in Chengdu	CAS; Sugon
Shanghai	Aug.2010	Asia-Pacific cloud computing centre	China Telecom, Shanghai Supercomputing center
Shenzhen	Sep. 2010	Cloud computing centre of Yangtze Delta	Sugon
Beijing	Oct. 2010	Cloud computing industrial centre in the world	Sugon, China Telecom
Tianjin	Oct. 2010	National leading cloud computing centre	HP
Ha'erbin	Nov. 2010	Chinese cloud valley， Data-centre city	China Mobile, Inspur
Foshan	Feb. 2011	Cloud computing centre of Guangdong province	China Telecom
Ningbo	April.2011	Cloud computing application centre	China Telecom
Chongqing	Mar.2011	International off-shore cloud computing trial district	CAS, Sugon
Dongguan	Mar. 2011	Innovation and cultivation centre of Cloud computing	CAS
Qingdao	May 2011	Data centre of northern China	China Unicom

City	Established time	Development visions announced	Main Partners
Hangzhou	May 2011	National developmental and training platform of cloud computing	Microsoft
Suhzou	July 2011	National cloud computing platform	SIP International Science Park Development Co. Ltd; Tsinghua University
Jinan	Aug. 2011	High-tech park computing centre in China	Inspur corporationu
Nanjing	Aug. 2011	National base of cloud computing	Sugon
Hefei	Nov. 2011	Cloud computing application platform	Inspur corporationu
Huhehaote	Nov. 2011	Largest data center for cloud computing in China	China Telecom, China Mobile
Xi'an	Dec. 2011	National cloud computing application platform	China Telecom,

Source: Data are collected from the government documents and the annual reports published by MPT and MII, then compiled by the author.

2. Social system

The actors identified in the social system are the system provider, service providers, users and institution. These actors can represent the interest inscription and transcription of the whole social system. Compared with supercomputing, cloud computing enroll much broader interest of different sectors. The system providers in China composed of foreign equipment providers, domestic equipment providers and SMEs, The service providers include the domestic internet companies and telecom operators as well as some cloud computing centers built by local governments. In terms of social system, the networks of much more diversified actors with heterogeneous interests are becoming to shape for the could computing. Internet firms and traditional telecommunication operators are also engage in cloud computing as service providers. which have missed the supercomputing development. These actors formulate diverse convergence strategies to pursue their own interests, they also interact with other actors to make the network possible. They still haven't been intertwined to develop the necessary communities.

The service providers of cloud computing required the reliable, efficient, and secure equipments from the system providers. New service capabilities of the service providers could be tried out

whenever the users with problem and enough complementary capabilities could leverage upon the new application. And the cloud users are diversified in large enterprises, SMEs, government, academic institutions, universities, public agencies to individuals. The institutional intervention is necessary to mobilize resources, to create economies of scale, or subsidize innovation (King et al., 1994). After the financial crisis, the central and local governments in China are eager to upgrade the giant low-cost based industry. Centre and local government's investment incentives play a critical role in enhancing the dynamics of system providers and service providers.

In late 2010, the Chinese government announced their 12th Five Year Development Plan outlining their plans for social and economic development for 2011-2015, and designating 'next-generation information technology' as one of seven 'Strategic Emerging Industries'. These industries will receive special investment and development to create the basis of China's long-term economic growth and home-grown innovation. Cloud Computing was highlighted as one of the key investment areas within next generation IT by government for development of new digital technology and infrastructure.

More and more metropolitan cities in China are trying to build up the cloud datacenters and establish the cloud platform to improve the local investment environment. The local government is expected to adopt more aggressive measures to introduce more service provider and system provider to leverage the infrastructure. In October 2010, the trial projects for cloud computing services are decided to be launched in Beijing, Shanghai, Shenzhen, Hangzhou and Wuxi [4]. Cloud computing has then come into the trial and implementation phase in China. China also established two major cloud computing technology industrial parks in Beijing and Shanghai, attracting billions of investment.

In October 2011, the central government provided the development subsidiary for the domestic technology companies including the Alibaba and Baidu by providing assistance in research, planning, and guiding their technology and product roadmaps to make them more competitive in local and global markets against the international players. Given the enormous market potential in the long term, many international service providers hope to entry China's cloud computing market with different partnerships. For example, Microsoft has announced partnership with China Mobile on Cloud solutions and SAP has announced partnerships with China Telecom to provide cloud applications in China.

Given the promotion and investment by the central and local government, the security and standard emerged as a prominent obstacle stumble the widely adoption of cloud computing. And in most cases, the government is still absent in administrating the standardization, security and privacy of data. For the vast personally identifiable information as well as financial information, cloud data security has become the largest concern. Government need to make regulations to intervene the cloud-based solutions and assure these institutions that their data are being handled in a way that preserves confidentiality by giving users greater ability to control the manner in which their traffic passes through the access networks.

Considering the emerging and transforming context of China's economy, service providers can enhancing the data storage and process efficiency of diversified users by exploited the potential of cloud computing. For large company users, the service providers can mitigate the need to establish and maintain server and storage capacity by these companies. As for most SMEs, they often lack enough computing resources supporting business applications. The computing service from service providers which needs no upfront investment will allow the SMEs access the vast computing resources with the affordable prices. Cloud computing has great market potential because China possess large amount of SMEs with poor IT facilities and applications. By providing the computing services to heterogeneous users simultaneously, service providers aggregating users' demand and reduce the decentralization which helps achieve higher utilization rates than individual enterprises achieve on their own.

3. Interaction of computing market and social system

China's knowledge intensive and information oriented development stimulate almost the entire industry participants, enterprises and users to confront this emerging market innovation. Both the Chinese government and industries realized that China is now behind leading MNCs in leveraging the existing computing resources. Many service capabilities have been established when the market needs have been recognized by the service and system providers.

The networks of aligned interests for cloud computing in China are still in the initial shaping stage. The infrastructure developers and users need to be the innovators for service capabilities and organizers for the interest alignment. The central and local governments have tried ambitiously to address the infrastructure innovation and innovation adoption. The cloud computing also demands more coordinated response from the institutional system other than direct investment. Government also supports infrastructure buildinglike broadband network which are imperative to innovative products or processes.

The computing infrastructure in China: past, present and future

In 1989, a program to develop networking and supercomputer facilities including three supercomputer centers was launched in China. Afterwards, China's technology and application capability of supercomputing was accelerated gradually. The national 863 program greatly stimulate the capability enhancement of supercomputing and enable China's super computer took off after 2000. Tianhe-1A and Dawning Nebulae even ranked among the world's fastest super-computers in 2010. However, these super computing resources mainly cater to the need of national institutions in the domain of energy, climate and others. Though China's computing infrastructure has grown over the years enormously in terms of new services and capacities, a proactive business model was still lacking and the supercomputing technology met great difficulties in finding mainstream business application.

Since early 2009, the initial deployment and application of cloud computing began to emerge in China. Motivated by the central and local government, the cloud computing was developed rapidly by various actors. The cloud computing provides the service for the heterogeneous users from large enterprises, SMEs, government to individuals. This diversified demand is

different to be met by supercomputing which only need to provide specific high speed computing resources to the limited public users. At current stage, supercomputing and cloud computing serve their users respectively in China. And some large enterprises are transforming their computing demand from supercomputing to cloud computing for their relative low requirement of computing speed.

There is a trend of sector confluence are in computing industry. After the broadband network developed and the flexibility of supercomputer enlarged to a certain extent, some existing supercomputing facilities can evolve into the basic infrastructure of cloud computing which will provide broader service to the more diversified users.

Although the need is limited in the beginning stage of cloud computing, more market application will be discovered later when new service capabilities of the actors start to grow. And more actors can be attracted to try some of the novel characteristics of the cloud-based application. The system providers and service providers also need work together to configure application capabilities for the sustainable development. Thus the computing infrastructure in China can provide a much more ubiquitous, fast and reliable service to its users.

Table 7 : Milestone of computing infrastructure in China

Time	Events
Aug. 1989	The State Planning Commission, the State Science and Technology Commission and the World Bank jointly launched a project to develop network and supercomputer facilities including three supercomputer centers in China
May 1990	The computer network center of Chinese Academy of Science was founded
Apr.1994	China's computing and network facilities connected to American internet, which marks the establishment of first international connection internet in China
Apr. 1995	The establishment of supercomputing centre of Chinese Academy of Sciences
Dec. 2000	The establishment of Shanghai Supercomputing Center
Feb. 2006	Supercomputer development was highlighted into “National Guideline on Medium-and Long-Term Program for Science and Technology Development of China(2006-2020) ”
Nov. 2008	Chinese super computer named “Magic Cube” ranked 10th in the international top 500 supercomputer

Time	Events
Sept.2009	Alibaba establish the sub-company specialized in cloud computing
Dec. 2009	Chengdu supercomputing center was founded as the commercialized computing centre for cloud computing.
Otc.2010	Tianhe-1A supercomputer reach the top spot in the world
Otc.2010	MIIT (Ministry Of Information And Industry Technology) and NDRC (National Development and Reform Commission) issued a circular regarding cloud computing services innovation trials and announced five cities for conducting trial cloud computing service.
Otc.2011	NDRC established the special funding which including 660 million RMB investment to support the companies engaged in pilot cloud computing projects in five trial cities.
Until the end of 2011	Nearly 20 metropolitan governments have announced the large cloud computing and data center investments and projects

Source: Collected by the authors from diversified reports and verified by the interviews

DISCUSSION, LIMITATION AND CONCLUSION

Today's computing infrastructure involves higher complexity that extends beyond what can be addressed by traditional supercomputing approaches. As China's computing infrastructure is still rapidly growing, we should explore it from a dynamic perspective. Through the lens of actor network theory, we explore the social-technological evolution across the institutional arrangement, technological innovation and application evolution of China's computing infrastructure. Here we define four types of actors in the social system to represent the different interest communities. The framework was constructed to explain how the interactions among the actors identified forge the growth of the infrastructure.

We then conduct an in-depth case study of computing infrastructure in China to justify our framework. The case study demonstrates that, our analytical model offers a higher explanatory power compared with a traditional innovation, adoption or business model theory. China's economic and political environment determined the growth characteristics of her computing infrastructure. We find that computing infrastructure is not intentionally built but emerging in nature and continuously growing. The infrastructure innovation, business model and innovation adoption co-depend during the growth process. Therefore, the capabilities of involved actors were enforced to exploit potential of the established computing infrastructures.

Initially, the performance-driven supercomputing becomes the prominent component of China's computing infrastructure. The development of supercomputing in China follows a relatively closed paradigm. As it enrolled few large state-owned enterprises and the interest translation and inscription is relative clearly. This closed paradigm can efficiently coordinate the interests among limited actors in social system and stimulate the facility oriented and performance driven development of domestic supercomputers.

The increased processing power and higher transmission and storage capacity have made it possible to build the computing infrastructure with higher flexibility for the more diversified users in China. As Lyytinen and Yoo (2002) identifies, ubiquitous computing will come of age and the challenge of developing ubiquitous services will shift from demonstrating the basic concept to integrate it into the existing computing infrastructure and build widely innovative mass-scale applications that will continue the computing growth.

The emergence of the cloud computing began to reconfigure the structure of the computing infrastructure. Under a highly open setting, cloud computing enrolled much more diversified players originally in different sectors which enhance the complexity of interest capture and transformation among the different actors. As cloud computing is a mix of resources and services that have profound economic and social impacts. Then organizing and connecting the heterogeneous actors with diversified interests are critical for the sustainable growth of the computing infrastructure. The computing infrastructure will grow adaptively and re-organize constantly with new connections between different actor communities. Chinese central and local governments also used preferential policies to support the emerging cloud computing in constructing a broad and flexible computing infrastructure for the industrial upgrading.

However, China still adopts the facility-oriented strategies in cloud computing development while the appropriate business model forming becomes somewhat overlooked. Given the premature developing stage of Chinese knowledge intensive and information oriented industries' transformation, the interest alignment within the actor network couldn't be achieved with the pure facility-expansion paradigm. In this case, demand for computing market heavily depended on the incentives that policies created and there also existed the possibility that public spending crowds-out private investment (Goolsbee, 1998). However, as the investments that took longer to pay off, the uncertainty in market expectations may have dampened the potential incentives of social capital.

When linking the institutional arrangement, technological innovation and application evolution to explore the evolution of sector in emerging context, institutional arrangement plays a critical role. This facility-based and mission oriented policy paradigm will encourage the involved firms to pursue technology breakthroughs with a technologically elegant innovation in one great leap or leapfrog (Spencer and Murtha, 2005). However, the direct intervention in the infrastructure innovation and innovation adoption will limit the actors in social system. Lacking of efficient business model affects the sustainable growth of China's computing infrastructure. Therefore, Service oriented policy paradigm should be adopted, as the diffusion of certain new technologies in the market is the result both from the providers' push and the users' pull, subject to the influence of different institutions (King, 1994). This service -oriented strategy

concentrates on acquisition, diffusion and assimilation of technologies existed in the relative sectors and enrolls much broader actors in the social system.

Considering the special institutional context of China, in order to maximize the potential benefits of cloud computing, government needs to establish the legal and regulatory framework that promoting innovation, stimulating the construction of infrastructure to guarantee the privacy, security and safety of data. The innovative computing services demands that technological, business and social concerns be integrated effectively into the overall design. More attentions need to be paid to manage the critical relationships with regulators, correct timing, and effective and continuous meshing of the concerns for the data security, privacy and standardization. However, the frequent changes of the policies in China made potential market demand volatile. A predictable and transparent policy regime will decrease the uncertainties of the institution and motivate this sector by attracting more actors home and abroad into the social system. The policies about data security and service standardization also need to be consistent with the local, regional, and national levels can also stimulate the incentives of market players.

As the computing infrastructure of China is still in its infancy, more research needed to be conducted to beyond Chinese context. Our model may be used to examine and compare computing infrastructure in different emerging countries.

Notes:

[1] The Wall Street Journal *Text of Obama's State of the Union Address* January 25, 2011
[2] Anuradha S., China to invest £98 billion in cloud computing – Computerworld UK, 14 Sep 2011, "Cloud Readiness Index," published by the Asia Cloud Computing Association
[3] Source: MIIT
[4] Source: The document of NDRC and MIIT
[5] Source: http://www.022net.com/2012/3-27/435217372478690-2.html
[6] American President Barack Obama in his State of the Union address stressed China's advancement in the fastest super-computer .
[7] State Council's Decision to Accelerate the Development of Strategic Emerging Industries

[8] According to the literal information from Huawei Cloud-computing Conference 2011
[9] http://www.top500.org/
[10] National Supercomputing center is approved and invested by government to provide high-performance computing services.
[11] Jiangnan Institute of computing technology

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APPENDIX

Interviewee

	affiliation	position	Actor categories
1	China HP	Managing Director and Vice President of Global Sales.	System providers
2	Intel Corporation	Director of infrastructure, Enterprise and Word Ahead Organization	System providers
3	Microsoft corporation	General Manager of Marketing and Operations Chief Cloud Officer	System providers
4	Microsoft corporation	Global Vice President of Technology Policy	System/Service providers
5	Cisco System, Inc.	Vice President of Cisco China	System providers
6	AMD corporation	Vice president	System providers
7	Chongqing Economic and Information Commission	Director	Government
8	China Academy of Telecommunication Research of MIIT	Vice President	Government agency
9	China Telecom	Senior Manager of Beijing Branch	Service providers
10	China Mobile	Assistant president of the central institute	Service providers
11	China Mobile	Senior Manager of the cloud computing	Service providers
12	China Unicom	Senior Manager of Broadband Department	Service providers
13	China Unicom	Vice president of the central institute	Service providers
14	Lenovo	Vice president of the central institute	System providers
15	Alibaba corporation	Senior Manager of Research institute	Service providers
16	Shanghai Government	Vice director of planning and development committee	Government
17	Wuxi Government, Jiangsu Province	Director of IT &Computing	Government
18	Chongqing Government	Vice director of	Government

	affiliation	position	Actor categories
		informationalization and industrialization	
19	MIIT	Vice director of technology department	Government
20	MIIT	Chief Engineer of Research institute	Government
21	ZTE corporation	Vice president of cloud computing	System providers
22	Huawei Technologies	Deputy director of Technology department	System providers
23	Chinese Academy of Sciences	Vice Department Director of Center of Network	Research institutes
24	NDRC	Vice Division Director of Department of High-tech	Government
25	Information Committee of Beijing	Department Director	Government
26	Shanghai Supercomputing Center	Vice Director	Service providers
27	Beijing Supercomputing Center	Director	Service providers
28	Institute of Computing, Chinese Academy of Sciences	Research professor	Research institutes
29	Institute of Computing, Chinese Academy of Sciences	Vice President	Research institutes
30	Intel China	Senior manager for cloud computing	System providers
31	NSFC	Department Director of Information Department	Government agency

(The summary of interviews with names of interviewees ambiguous by request)