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Establishing a CoPs-based innovation ecosystem to enhance competence – the case of CGN in China

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Abstract: This research investigates how complex product systems (CoPs)-based innovation ecosystem is created in terms of structure and interactions among players, as well as how technology, value and capability evolve at different stages of an innovation ecosystem. Based on an exploratory case study on the innovation ecosystem of a nuclear power giant-China general nuclear power group (CGN) for the period 1987–2014, this paper presents a framework to explicate the micro-foundation of the formation mechanism of an innovation ecosystem for CoPs. Three ecosystem stages are identified: ecosystem incubation, ecosystem figuration and ecosystem self-renewal. Through the three stages, CGN has been extending its ecosystem gradually from core business to extended network and ecosystem periphery. This study provides theoretical and managerial implications for building and managing innovation ecosystems in developing countries.

Keywords: innovation ecosystem; ecosystem establishment; complex product systems; CoPs; co-evolution; technology system; value networks.

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1 Introduction

Nowadays, China still lags behind many of the developed countries in many emerging industries (Chen et al., 2014). Chinese enterprises continuously import a large quantity of advanced technologies and value intensive products, such as airplanes and heavy construction machines, which are typical complex product systems (CoPs), whereas caught in a vicious cycle ‘import, lag-behind; re-import, re-lag-behind’ (Liu et al., 2011). Against the background, the nuclear power industry in China, also started as a latecomer, is rising with the ambitious expansion and emergence of several magnates in recent years (Zhou et al., 2011). This raises an interesting question. Why are China’s nuclear power constructors able to rapidly catch up with global technological advancement and gain competence through innovation? We argue that the remedy lies in establishing an efficient and effective innovation ecosystem.

According to Autio and Thomas (2014), innovation ecosystem is a network of interconnected organisations, connected to a focal firm or a platform that incorporates both producer and user, as well as creates and appropriates value through innovation. Interdependency and dynamic co-evolutions are two important features of an innovation ecosystem (Adner and Kapoor, 2010). On the one hand, networks of institutions, individuals and other actors around an ecosystem are characterised by simultaneous interaction (Afuah, 2000); while on the other hand, an ecosystem is evolving with the changing environment through dynamically optimising the complementary capabilities, resources, and knowledge of actors embedded in it (Jackson, 2011; Willianson and De Meyer, 2012).

Few innovation ecosystem literature concentrates on CoPs, and even fewer illustrates the micro-foundation of the formation process of ecosystems, while if any merely focus on the technology dimension (Adner and Kapoor, 2015). In this research, we propose that besides technology, value and capability subsystems also count a lot for an ecosystem. In an innovation ecosystem, the continual realignment of synergistic relationships of resources, knowledge and people for both transformational and incremental value co-creation (Gastaldi et al., 2015) indicates that what makes sense is no longer about who gets the bigger piece of the pie (Casadesus-Masanell and Yoffie, 2007), but how well partners work together to make the pie bigger, i.e., shared value creation (Porter and Kramer, 2011). Furthermore, the success of an innovation ecosystem also depends on dynamic capabilities which contain integrating, building, and reconfiguring internal and external organisational skills, resources, and functional competences in response to the changing environment (Teece and Pisano, 1994; Teece et al., 1997).

Our research is based on an in-depth and process-oriented case study of china general nuclear power group (CGN), an outstanding nuclear power engineering company in China. Based on reviewing the development of China's nuclear power industry and the innovation ecosystem life cycle model that is put forward in literature, we divide the evolution of CGN's innovation ecosystem into three distinct but interacted stages: ecosystem incubation, ecosystem figuration and ecosystem self-renewal. We aim to reveal the formation process of CoPs-based innovation ecosystem by investigating how interactions among players and structure of the ecosystem transform as well as how technology, value and capability dimensions evolve at different stages, so as to uncover the mechanism of China's nuclear power industry gaining competence.

This study tries to contribute to the literature on innovation ecosystem and innovation management of CoPs in three aspects. First, the ecosystem construct provides a new angle in strategic planning to gain competence, superior to other traditional lenses, e.g., industrial and resource-based-view, and value chain. Second, we extend extant literature on innovation ecosystem to CoPs, which reveal distinctive features comparing with the commonly discussed mass-produced goods. Last, we shed light on the formation of an innovation ecosystem based on a process-oriented analysis on technology, value and capability dimensions, which provides a dynamic and holistic view for understanding innovation ecosystem.

Following the introduction section, Section 2 proposes a theoretical framework based on reviewing literature on innovation ecosystem, technology system, value network and dynamic capabilities. In the next section, the research question is defined, and the process-based case research design is outlined. Section 4 analyses the case of CGN to illustrate our proposition. Finally, we summarise the research, discuss the managerial implications, and posit several limitations for further research.

2 Theoretical framework

2.1 CoPs-based innovation ecosystem

CoPs can be regarded as 'an applied system whose components have multiple interactions and constitute a non-decomposable whole' (Singh, 1997). Pursuing innovation in CoPs presents a challenge for firms, as technology and value intensive projects or engineering-based products are confined to low volumes and high investments, with contributions from networks of suppliers tailored to the unique requirements of business customers (Davies and Brady, 2000; Liu and Rong, 2015). When firms need to replicate managerial experiences from one bid or project to execute a growing number of similar projects, facing a dilemma of delivering more complex solutions while maintaining corporate focus and efficiency, a strategic reform to manage these complex and dynamic activities is called for (Davies and Brady, 2000; Willianson and De Meyer, 2012). We argue that the ecosystem perspective serves as a tool superior to other static and linear perspectives in facilitating the innovation and evolution of CoPs.

The concept of business ecosystem was first proposed in 1993 as an insightful alternative in contrast to old frameworks under which companies go head-to-head in an industry and battle for market share (Moore, 1993). Thus, a company should not be viewed individually, but as part of a business ecosystem (Moore, 1996). The ecosystem metaphor was then broadly adopted and developed by scholars in the fields of innovation to study the interconnected innovation networks (Autio and Thomas, 2014). In line with the traditional notion regarding a biological ecosystem to be the habitat for a variety of different, yet related, species that co-exist and influence each other (Bateson, 1979), innovation ecosystem models the economic dynamics of competitive and cooperative arrangements through which firms combine their individual value creating activities together with capabilities co-evolving around an innovation (Adner, 2006; Jackson, 2011; Moore, 1996). While there is no consensus on the key constructs defining an innovation ecosystem construct yet, some common features such as interdependency and dynamic co-evolution are extracted based on existing literature (Peltoniemi, 2006).

On the one hand, the evolving nature, fluid boundaries and loosely coupled network structure of an ecosystem make it a distinctive organisational mode comparing to hierarchy and market (Iansiti and Richards, 2006; Kandiah and Gossain, 1998; Thorelli, 1986; Willianson and De Meyer, 2012). An ecosystem covers a community of diverse stakeholders with common objectives and identities, including organisations directly connected to the core business, and indirectly related organisations such as governments, associations and intermediaries(Autio and Thomas, 2014; Iansiti and Levien, 2004a). It encompasses both the production and use sides of complementary assets as well as external media and culture-based public discourse referred as an essential part of the ‘quadruple helix’ model (Autio and Thomas, 2014; Carayannis and Campbell, 2009). In terms of coordination, Möller and Svahn (2003) suggest that hubs naturally exist in networks as a controlling artifact which lends hub and spoke configurations more readily for coordination than distributed networks with no central firms. Furthermore, Zhang and Liang (2011) and Moore (1996) define an innovation ecosystem as three circles, respectively ‘core business’, ‘extended network’ and ‘ecosystem perisphere’, so as to facilitate dividing the ecosystem members into groups according to their different contributions and influences on the creation of core values. This also provides a way of looking at the structure, interaction and exchanges among ecosystem elements and contexts at the system level (Anggraeni et al., 2007).

On the other hand, considering the dynamic business environment nowadays (Chen et al., 2014), Moore (1996) proposes a basic framework for the stages of a business ecosystem, including pioneering, expansion, authority and renewal (or death). Rong (2011) further develops a business ecosystem life cycle model consisting of five sequential phases: emerging, diversifying, converging, consolidating and renewing. In reality, the evolutionary stages blur and the managerial challenges of one stage often pop up in another, while what remains the same is the process of co-evolution: the complex interplay between competitive and cooperative innovation strategies (Moore, 1993). This makes an innovation ecosystem outperform in overcoming the inherent incumbent inertia and core rigidities of an individual organisation relying on the resource-based view and the industrial approach to gain competence (Frels et al., 2003; Leonard-Barton, 1992; Porter, 2008; Prahalad and Hamel, 2006).

Prior literature on innovation ecosystem reveals three gaps. Firstly, researches on innovation ecosystems are mostly conceptual and case studies in particular industries, such as IT and mobile communications with economies of scale (Gunasekaran and Harmantzis, 2008; Kim, et al., 2015; Rong et al., 2013; Zhang and Liang, 2011), while less attention is paid to CoPs manufacturing,. Secondly, limited work has been done on the process of creating and nurturing an innovation ecosystem considering both the emergent and intended forces interactively causing it to evolve over time (West and Wood, 2008). Lastly, prior studies mainly view innovation ecosystem from the technology dimension. Nevertheless, such 'hardware' oriented perspective (McKelvey, 1978) is limited in understanding and explaining a complex innovation ecosystem involving multilevel tasks. Thus, more 'software'-based aspects, such as value and capability, should be included.

2.2 Technology evolution and technology system

Technology is an essential building block of innovation ecosystem (Carayannis and Campbell, 2009). The innovation ecosystem perspective elaborates a framework depicting a system of technologies consisting of both the focal technologies and the external substitutable, complementary or competing technologies, and explains the evolution and dynamics of technological change and substitution (Adner and Kapoor, 2015). At the same time, building on the population approach and the technology and product hierarchy approach, innovation ecosystem literature emphasise that individual technologies cannot be considered in isolation (Dosi, 1982; Ethiraj, 2007). The interdependent relationships among multiple technologies and environmental forces, as well as an ecological system of co-evolving artefacts are highlighted (Adner, 2006; Adomavicius et al., 2007; Ziman, 2003). Thus, technology substitution and evolution can be viewed as an interplay between the pace at which a new technology's ecosystem overcomes its emergence challenges and the pace at which the old technology's ecosystem exploits its development opportunities (Adner and Kapoor, 2015), which articulates the micro-foundations of a technology ecosystem.

Many studies demonstrate that the technology development course of catching-up countries like Korea, India and China is quite different from that of advanced countries (Malerba and Nelson, 2011). Kim (1997) proposes a three-stage model of the technological trajectory for CoPs, e.g., acquisition, assimilation and improvement, which is in line with the findings of a case study on the high speed rail industry in China (Liu et al., 2011). During the acquisition stage, packaged technologies and products are directly imported or in-licensed from a benchmarking country (Chen et al., 2014), and learning and reverse engineering take place in debugging problems in the initial implementation operations (Amsden and Chu, 2003). In the assimilation stage, the acquired assembly processes and production know-how are quickly diffused so that related products are able to be locally adapted through imitative efforts (Kim, 1997). Increased competition from new entrants and diversity of customer requirements spur downstream and upstream partners to co-specialise and integrate their assets and activities to produce differentiated items (Ceccagnoli and Jiang, 2013). The two stages lead to gradual technological improvements and thus enter a stage targeting at indigenous R&D and re-innovation via constructing an intensive and open innovation network that integrates stakeholders such as industrial players and research institutions (Amsden and Chu, 2003).

2.3 Value network and shared value

The purpose of an ecosystem is to create value through innovation (Autio and Thomas, 2014). However, nowadays no individual firm would be able to single-handedly pursue major innovations or systemic product offerings because of the dispersion of technological resources and knowledge (Möller and Svahn, 2003). The traditional value chain approach (Porter, 2008) has gradually been extended to value networks or ecosystems (Allee, 2008; Peppard and Rylander, 2006; Pisano and Teece, 2007). As to CoPs, the performance of which is determined by interactions within and across three levels: the system, the components, and the firms that design and manufacture the components (Ethiraj, 2007). The concept of value network can better describe the mutual adjustments with respect to network scope, capacity and the technical properties of the concurrent activities, based on its nature of complementarity and dynamics (Peppard and Rylander, 2006).

A benign ecosystem facilitates value creation and enables its members to invest towards a shared future in which they anticipate profiting together (Moore, 1993). Some value networks are goal-oriented in which intense collaboration is practiced and driven by continuous production/service provision activities to capture a single opportunity; some others may be long-term oriented strategic partnership aiming at providing a supportive environment nurturing the configuration and development of collaborative networks to cope with emerging opportunities (Camarinha-Matos et al., 2009). In particular, value co-creation with customers (Hearn and Pace, 2006) calls for involving users as a key ecosystem construct, as the perceived value is ultimately defined by end customers (Möller and Svahn, 2003; Peppard and Rylander, 2006). Moreover, the concept of shared value can be further defined as policies and operating practices that enhance competitiveness of a company while simultaneously advancing the economic and social welfare of the communities in which it operates, thus the goal of shared value co-creation is extended to the business environment (Porter and Kramer, 2011).

2.4 Dynamic capability

Specific organisational capabilities are required to dynamically achieve shared value creation from the technology system. The capability lifecycle perspective provides a common language of thinking about the evolution of capabilities; when an internal or external selection event intervenes, capability transformation will occur, shown in different stages responding to threats and opportunities (Helfat and Peteraf, 2003). Furthermore, the school of dynamic capabilities describes how capabilities adapt and change over time and how firms renew and adapt capabilities; in this model, dynamic capabilities are treated as a set of routines guiding the evolution of a firm's resource configuration (Lavie, 2006; Teece and Pisano, 1994; Zott, 2003). Defining ordinary or 'zero-level' capabilities as those that permit a firm to 'make a living' in the short term, one can define dynamic capabilities as a hierarchy of higher-order capabilities that extend, modify or create ordinary capabilities (Collis, 1994; Winter, 2003).

Teece (2007) goes further by utilising the ecosystem construct to assess the development of dynamic capabilities within the business environmental context. In this way, dynamic capabilities not only include difficult-to-replicate capabilities required to adapt to changing customer needs and technological opportunities, but also enable shaping ‘rules of the game’ through innovation (Moore, 1993; Teece, 2007). Teece’s framework thus goes beyond traditional emphasis on the traits and processes needed to achieve good positioning in an ecosystem, and explicates new strategic considerations that ensure opportunities, once sensed, can be seized, and then be reconfigured (Teece, 2007). In this sense, an organisational capability comprises not only a simple operational capability performing a collection of routines or tasks to fulfil an activity (Helfat and Peteraf, 2003), but also capabilities of designing an architecture under which the extended enterprises can replicate or redeploy the existing capabilities, or acting as an platform orchestrator so that network partners can recombine or renew their capabilities for joint value creation through nurturing mutual learning, creativity and innovation (Helfat and Peteraf, 2003; Wallin, 2006).

3 Research design

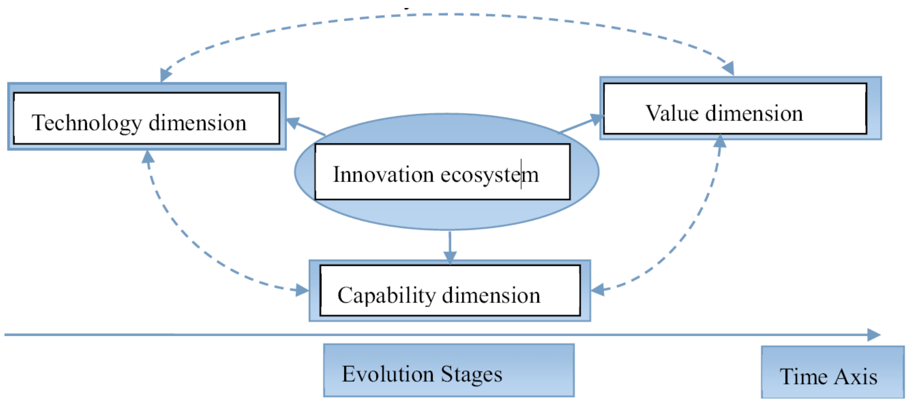
3.1 Research questions

From the above literature review, we can conclude that firms are prone to make strategic planning within or around an ecosystem they reside (Iansiti and Levien, 2004b). Yet, prior literature on innovation ecosystem is fragmented (Autio and Thomas, 2014). In particular, a framework to provide systematic assistance for understanding the underlying strategic logic of the evolutionary trajectory of an innovation ecosystem, including ecosystems of CoPs, is highly needed. Based on evidences from a representative CoPs of China, this paper aims to fill the above gap by proposing two research questions:

Q1 How is a CoPs-based innovation ecosystem formed over time in terms of structure and interactions among players?

Q2 How do technology, value and capability dimensions evolve during different stages to gain competence? (see Figure 1)

Figure 1 Elements of an innovation ecosystem framework (see online version for colours)



3.2 A case study approach

As Clark and Fujimoto (1991) argue, questionnaires and models are constrained by rigid limits, and not appropriate to analyse the 'soft' aspects of innovation management, whereas qualitative design leads to new and creative insights, exploratory theory building, and is preferred in examining a 'how' or 'why' question, and the units of study are not fully understood, with unclear boundaries, and hard to be isolated from complex real-life context (Bessant and Tidd, 2007; Meredith, 1998; Voss et al., 2002; Yin, 2009). Especially when we want to examine the complexity of interactions among multiple actors and capture the hidden and dynamic issues, a process theory will work better. Thus, we adopt a process-oriented case study to investigate the evolutionary processes of innovation ecosystem of the nuclear industry in China, and the dynamics of technology development, shared value creation and organisational capabilities cultivation.

3.3 Case selection: China's nuclear power industry and CGN

3.3.1 China's nuclear power development

As one of the seven strategic emerging industries listed by the Chinese government, the nuclear power industry in China has experienced rapid expansion in recent years, with 49 reactors currently operating or under construction and additional reactors being planned across the country[1].

Similar to other CoPs related industries such as the high-speed railway, China is a latecomer in commercial nuclear power technology and has been sticking to the principle of "introduction, digestion, assimilation and re-innovation" (Liu et al., 2011). Under the strict supervision of the government, China has mastered the generation 2 technology, and is updating rapidly to generation 3 designs. Researches on generation 4 of nuclear fusion technology conducted by Chinese research institutes have also emerged at the frontier. New reactors being built currently in China vary from generation 2 (CPR600, CPR1000, CNP1000 and AES91) and generation pp. –AP1000 and ERP) to generation 4 (HTR-PM) reactors (Wang and Chen, 2012). Related Chinese nuclear enterprises have accumulated rich experiences in nuclear power station construction, operation and management, many of which are even busy developing home-grown reactors for potential export in the coming years. Thereby, in light of policy initiatives and key events, we divide the evolution of China's nuclear power industry during 1987–2014 into three stages.

3.3.1.1 Stage 1: slow transition (1987–2004)

In the 1980s, Chinese leaders decided to establish initial civilian nuclear power program based on previous military nuclear infrastructure. Consequently, Qinshan-1 and Daya Bay projects were established. However, due to the lack of powerful and professional commitment from top officials, long-term strategic planning, and sufficient financial support, the commercialisation of nuclear development was rather modest and discontinuous until 2005. Following the principle of 'combining foreign technology transfers with domestic design and production', China determined to go ahead with the domestically optimised generation 2 pressurised-water reactor (PWR) technology after struggling for years (Zhou and Zhang, 2010).

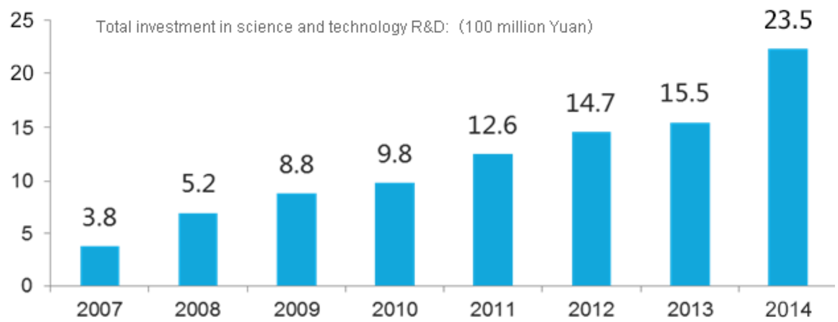
3.3.1.2 Stage 2: booming expansion (2005–2010)

Under pressure of air pollution and coal shortage, significant attention was paid on nuclear energy, and a series of policy initiatives were taken. In the medium and long-term nuclear power development plan (2005–2020), the Chinese government pledged to raise China's nuclear capacity to about 40 GWe by 2020, and shifted nuclear energy progress to a more active role in the 11th five-year plan. By the end of 2005, China had developed its own nuclear reactor designs with generation 2 technology, CNP-300, CNP-600, CNP-1000 and CPR-1000, and 19 out of 25 units under construction were of Chinese design until September 2010 (Zhou et al., 2011).

3.3.1.3 Stage 3: safety-first struggle (2011–2014)

Cautioned by the Fukushima nuclear accident in 2011, the global landscape was shifting with countries like Germany, Italy and Switzerland deciding to shut down existing plants or suspended new ones (Mu et al., 2015). After slowing down the approval process of new projects for a period of time, the Chinese government picked up nuclear development again, with the safety issue becoming the premise of industrial development. According to the 12th five-year plan, digesting and absorbing the third generation technology of nuclear power plant has become the key tasks in the coming years (Wang and Chen, 2012). After 2016, only generation 3 plants will be launched. The new situation provided both challenges and opportunities for nuclear energy related industries to achieve leapfrogging development.

Figure 2 Annual spending on scientific research spending of CGN (see online version for colours)



3.3.2 Introduction of CGN

Following China's reform and opening-up policy, as well as the nuclear power promotion program, CGN was set up in September 1994 as a giant Chinese state-owned enterprise (SOE). With nuclear power as its core business, by the end of May 2014, CGN's 11 nuclear generating units in operation involve a total installed capacity of 11.62 million kW, and the installed capacity of other 13 units currently under construction has reached 15.50 million kW[2]. CGN has been increasing its R&D spending (see Figure 2)[3] and has currently set up seven state-level nuclear power R&D centers[4]. Specialised and compatible infrastructures scattered across different regions, such as UK, Romania and South Africa, were also established for nuclear fuel supply, nuclear power

R&D, construction and operation, which allows CGN to become the undisputed leader with around 60% market share[5]. In December 2014, CGN raised $3 billion through an initial public offering (IPO) in Hong Kong Stock Exchanges[6], and sales revenue for 2014 increased dramatically by 18.8% to CNY 19.33 billion, and its annual profit increase by 35.6% to CNY 6.88 billion[7].

3.3.3 Case selection rationale

We chose CGN as the focal case in our study for three reasons. Firstly, the global nuclear industry has undergone different technological transitions from the 1950s, offering a rich setting to examine technology diversity and patterns of change. With little prior experience and knowledge involving management of emerging technology and inter-partner initiatives, CGN as a latecomer has won a place in the battle with more than ten major international gold diggers fighting for multiple technical routes and potential nuclear power plant sites during the rapid technological development (Zhou and Zhang, 2010). Secondly, modern nuclear energy facilities and applications have reached a high degree of sophistication. Through collaborating with nuclear classified equipment manufacturers, research institutions, universities and other players within the ecosystem, CGN has become an expert in effectively managing parallel nuclear projects and complex stakeholders with diverse interests in CoPs. Thirdly, CGN is one of the three Chinese enterprises licensed to own and operate nuclear power plants. Unlike China National Nuclear Corporation (CNNC) and China Power Investment Corporation (CPIC), who have strong political and military backgrounds, CGN shows it uniqueness. As a rising star it relied on revenues from selling electricity to Hong Kong as collateral for financial support[8] and enjoys significant competence over peers depending much on its open market-driven mechanism, technological innovation and organisational reconstruction. Overall, the CGN case offers a particularly worthwhile and typical context to explore the interdependency and dynamics of an innovation ecosystem. As a successful exploration of SOE in the market economy, CGN's experience will definitely represent insightful implications applicable under a broader context, which enhances the external validity of the study.

3.4 Data collection and analysis

Both primary and secondary data are used to illustrate the evolution stages and to facilitate further analysis. In terms of secondary data sources, we examined various open access publications about CGN and nuclear power industry from multiple channels, which enabled us to form a preliminary understanding of the development trajectory of the innovation ecosystem of CGN. Firstly, we surfed the web pages of nuclear power related government agencies and industry associations, and analysed major policies and regulations, to capture a picture of the evolution and trend of nuclear energy at home and abroad. Secondly, we dissected CGN's annual reports and internal documents, in comparison with its counterparts CNNC and CPIC, through which we grasped CGN's development status and competence in the nuclear industry. Thirdly, we explored academic papers and research programs concerning nuclear power industry, to sort through the transition of major projects and R&D collaboration at different stages. In addition, we also traced activities through newspaper articles and consulting reports in hopes of learning the changing attitudes of the public and other stakeholders towards nuclear power. Our secondary research took about eight months, from May 2014 to December 2014, and we performed subsequent updates with information from the latest news reports at the end of May 2015.

With regards to primary data, from 20 May 2014 to 22 May 2014, we stayed in CGN for three days with intensive interaction and observation. Under the support of China Enterprise Confederation, we conducted multiple interviews with 18 industry experts from a variety of positions within the ecosystem, from top to bottom, covering R&D staff, equipment manufacturers, constructors and suppliers, managers and consultants, most of whom had been associated with the industry for over ten years. The interviews were semi-structured combined with observations, each interview lasts around 1.5 hours on average (see Table 1).

Table 1 Interview schedule

Schedule		*Subject*	*Interviewees*	*Content*
May 20	8:30–11:30	CGN introduction	General manager office	Company strategy/reform process/AE model
	14:30–17:30	Plant visit	General manager office/plant safety and quality office	A general picture of the engineering and operation process
May 21	8:30–10:00	Project construction	Project management department	Project management mode/collaborative operation among departments
	10:00–11:30		Designing institute	Designing platform management
	13:30–15:30		Equipment procurement and assembly centre	Supply chain management/equipment localisation and safety control
	15:30–17:30		Construction management centre/debug centre	Organisational learning/on-site safety management
May 22	8:30–11:30	R&D management	Engineering and R&D department	R&D system evolution and R&D outputs
	13:30–15:30	Company reforms	Planning and operation department	Responsibility and incentive mechanism/strategic direction
	15:30–17:30		Human resources department	Hierarchical and decentralised mode/organisational change and process control

Following a simple introduction of the innovation ecosystem idea, we began to engage in detailed discussions with informants after breaking down our research questions into themes. Discussions covered the development trajectory of CGN, strategies that CGN enacted during different phases, reforms, challenges they came cross in implementation, the way in which ecosystem partners influenced the adoption of new technologies and new initiatives, as well as measures had been taken to help ecosystem partners align objectives and renew capabilities. We asked all the interviewees the same questions with slight modifications according to specific departments and business functions (see Table 1). In order to probe deeply into the interactive mechanism among players and the evolution of technology, value and capability dimensions, we encouraged the interviewees to tell vivid stories related to projects they involved in, and asked them to clarify certain key events or constructs. It is worth noted that interviewees were prone to use terms in line with the ecosystem approach such as network, collaboration, cooperation, alliance, etc., to express their views.

We recorded all the interviews, transcribed them verbatim, and then coded and sorted the primary and secondary data by building a database, resulted in around 600 pages of notes with more than 200,000 words. Collected data show a chronological sequence of critical events, ten ranging from strategic planning, project construction to organisational reform and collaborative R&D. These critical events played significant roles at each stage of the ecosystem over the last two decades, providing rich information for longitudinal analysis.

In order to ensure the validity and reliability of the data, triangulation principles (Jick, 1979) were adopted. Each author of the study independently cross-checked information from diverse sources to keep them in line with each other, and then followed up via e-mails and phone calls to interviewees for verification where inconsistencies and confusions were noted. Furthermore, the three authors exchanged reflections and thoughts constantly in order to avoid potential bias as far as possible.

4 Case findings: the evolutionary trajectory of CGN's innovation ecosystem

In accordance with the three evolutionary phases of China's nuclear power industry, we divide evolution of CGN's innovation ecosystem into three stages, i.e., incubation, figuration, and self-renewal, inspired by Moore (1996) and Rong's (2011) life cycle model.

4.1 Stage 1: ecosystem incubation (1987–2004)

By 1987, the Guangdong Daya Bay Nuclear Power Station (GNPS), which was the predecessor of CGN and the first-ever large commercial nuclear power station in Mainland China, was commenced with its equipment and technologies totally imported from France. At that time, CGN was only an engineering project management company. It undertook tasks of procurement, assisted construction and design for the plant. Until then, the nuclear power industrial chain in China was still weak and fragmented, without a dominating power able to taking over the whole nuclear power project. Yet CGN, who enjoyed nothing more than the administrative authority entitled as a SOE, was obliged to improve the whole industry. Therefore, an interdependent and collaborative relationship among CGN and its followers was initially formed. The priority for CGN was to devote limited resources to self-improvement as well as promoting the industrial environment to shape an innovation ecosystem. Of all the tasks, setting up an effective quality and responsibility system was the most essential. One deputy general manager commented:

> "A large number of companies related to nuclear power gradually entered the market, most of which were initially converted from military industries. As a focal firm, we regarded a lack of quality and responsibility system as our greatest enemy. Only if each company met the strict requirements of design and quality at every link, could the final product, that was the nuclear power plant, be constructed and functioned as a power generator. However, during the first years, professional authority and supervision over each nuclear power-related activity was absent. Thus, evasion and prevarication happened now and then when problems and biases occurred, while we could not find out who was responsible. It was a legacy from a centralised economy."

In the meantime, CGN proposed slogans such as 'doing right things in one go' and 'safety first, quality foremost, pursuing excellence' as the core values of the firm, and deeply inserted the philosophy of collaboration into different departments and all the staff within the whole firm.

When GNPS was put into commercial operation in 1994, CGN had forged good relations with many domestic construction and installation units and grasped preliminary capabilities of collective procurement, engineering and design for the whole set of equipment based on its quality system, mutual negotiation and learning by doing.

In 1997, in accordance with the state council's guideline of "utilizing returns from existing nuclear power plants to nurture further growth of nuclear power in a rolling-on manner"[9], the second largest commercial nuclear power station Lingao Nuclear Power Station (LNPS) Phase I was launched. It took GNPS's experience as a reference and made 52 significant improvements by investing over 15 million dollars every year since 1994[10]. As a result, a number of companies gained experiences and became fully specialised in nuclear plant construction, installation, project management, testing and operation, while parts of engineering and equipment manufacturing were done locally with an average localisation rate of 30%[11]. Other institutes like energy companies, financial institutions, and provincial governments were also attracted around the nuclear reactor projects and became essential components comprising a prototype of a nuclear power ecosystem.

4.2 Stage 2: ecosystem figuration (2005–2010)

By adoption of more than 50 technical improvements through close collaboration with domestic design and research institutes[12], LNPS phase 2 started in 2005, using the generation 2 technology CPR1000. More CPR1000 units subsequently being planned in Liaoning Hongyanhe (LHNP), Fujian Ningde (NDNP) and Guangdong Yangjiang (YJNPS) symbolised that CPR1000 had been comprehensively mastered by CGN with its owned brand and was stepping towards standardisation and scale construction. Besides, with the dominant design shifting faster to generation 3, competition among multiple technical routes like AP1000 and EPR was increasing in China, which posed huge challenges to CGN. Consequently, a profound organisational reform, namely nuclear power AE (Architect Engineering Industries Inc.) model[13] was commenced. One project manager commented:

> "Our localization rate reached 80% in LHNP. Localization was a market oriented requirement, more than a national task. At that time, we were experiencing rapid expansion of nuclear plant construction. Resources in developed countries could not meet that trend any longer. On the other hand, we did not want to be restricted by foreign technology in the long run. Therefore, we had to implement a reform to manage multi-concurrent projects scattered in different locations in China, and then the AE model was adopted, which meant reconfiguration of the whole organization."

CGN further conducted organisational restructuring, and a matrix organisation was suggested to adapt to the AE model. One operation manager commented:

> "The matrix structure improves the degree of specialization. For example, the process of manufacturing a RPV can be decomposed into 15,774 motions, and each motion must be finished according to a unified standard and speed, which allows effective control over risks of safety, quality and schedule. We also modified our way of thinking. It is really hard for Chinese to learn to collaborate, so we tried to cultivate a sense of teamwork and serving for the whole by resetting rights and liabilities and reconstructing the interest distribution mechanism."

In this way, integration and collaboration could be achieved along the industrial chain, which enabled CGN to become an unassailable industrial leader and ultimately surpass other ecosystems. One procurement manager commented:

> "Take Dongfang Electric Corporation (DEC) as an example, which is one of our equipment manufacturers. Its first nuclear power equipment was a steel tube with a diameter of over one meter and it planned to spend three months manufacturing it. However, it took one year, far behind our schedule. So we helped DEC to solve technical problems and keep detailed records for all procedures and operation processes so that the sources of problems could be traced."

An engineer said:

> "Firms are virtually profit-seeking. So we have made great efforts to promote our partners' capabilities so that they can gain rapid growth and high profitability and consequently become an interest community in the long run. As long as they can make a profit, they will be willing to help others along the chain, and thus shared value creation and collective technological improvement come true."

Moreover, although CGN sometimes exerted pressure on suppliers and customers to join up, the established interdependency, externalities and constant value creation played critical roles in improving the whole ecosystem's continued performance and increasing the opportunity cost for helping other emerging ecosystems. One engineering manager commented:

> "It is impossible to control our upstream and downstream partners through merely signing up contracts. CGN becomes the focal firm because we have an overall view of the architecture that connected the key technologies and components. This is the foundation of collaborating along the whole chain. The cost of opt-outing certain dominated product classes will be very high."

4.3 Stage 3: ecosystem self-renewal (2011–2014)

Natural ecosystems sometimes collapse when environmental conditions change radically (Moore, 1993). Under the post-Fukushima context, CGN extended its ecosystem through a series of new measures and strategies which turned CGN into a huge magnetic field with high conformity and synergy that prioritise safety (see Figure 5).

At this stage, CGN even established collaboration with its competitors to improve the competence of the whole industry, and developed plants with more strict safety standard for the benefits of the whole society. With reference to the world's first class generation 3 technology, ERP and AP1000, CGN made steady progress in the R&D of ACPR1000+ with its own intellectual property rights, based on which CGN worked together with its competitor CNNC and jointly created one of the most competitive generation 3 nuclear power technologies worldwide, HPR1000. On the other hand, the flourishing of nuclear power industry also played a positive role in the development of other related industries. One project manager commented:

> "Our nuclear energy brand has strong spillover effect. There are many generic technologies and equipment in the nuclear power industry and other related industries, such as aerospace and aviation industries, and petroleum industry. The improvement in the capabilities of our suppliers can also enhance other industries' infrastructural power. We built nuclear industrial parks, R&D centers and platforms based on collaborations with universities and research institutions. Our partners in turn made investments in promoting and leveraging these platforms. This created a virtuous cycle. As a state owned enterprise, we feel proud that we have made contributions to achieve national interests."

A human resources manager said:

> "70 percent of our workers in construction site are from rural areas with an annual attrition rate approaching 40 percent. So we have invested a large sum of money to train them, even though the project is outsourced to third party. We help them get into the social security system and create books and materials with pictures to make them better understand our AE model. In this way, they begin to view the construction of nuclear power plants as their long-term career which forms the cornerstone of collaboration. We regard our efforts to push forward the training of qualified workers as one of our responsibilities to serve the society. This is the typical case: the leading company has to share value with stakeholders and make them innovate jointly."

Just as the general manager of CGN commented:

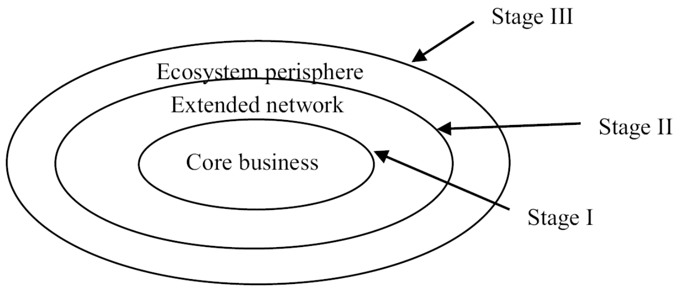
> "By meeting the requirements of the stakeholders and making great efforts to facilitate common progress, the overall level of the nuclear industry in China has realized a major breakthrough, which in turn provides CGN with modified ecological environment. Therefore, in the long run, it does not mean value loss for CGN."

5 Discussion

5.1 The innovation ecosystem of CoPs

The hierarchical view separates an ecosystem into three circles, 'core business' to 'extended network' and 'ecosystem periphery' (Moore, 1996; Zhang and Liang, 2011). The CGN case provides a clearer picture of how the three circles were extended successively during the three stages of setting up a CoPs-based ecosystem (see Figure 3). Combining the hierarchical view and lifecycle approach, ecosystem creation can be seen as a series of path-dependent stages driven by common underlying process (Autio and Thomas, 2014). The structure and interactions among partners have been evolving according to the respective objectives and challenges at different stages.

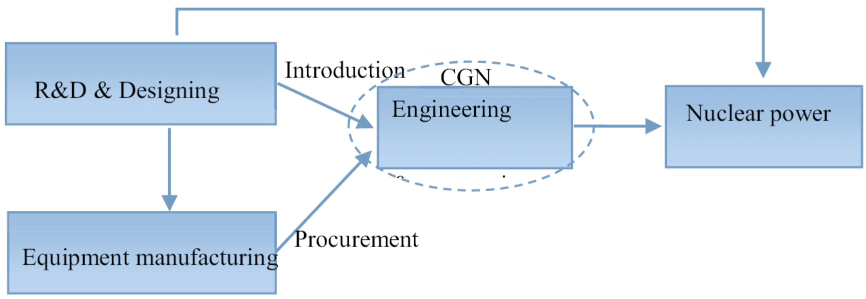
Figure 3 Three ecosystem levels at three stages



5.1.1 Stage 1: ecosystem incubation-core business

The first stage ends with all essential elements completed and an ecosystem developing slowly based on each element's preliminary function. The objective at this stage focuses on the core business, i.e., the national mission of making a nuclear power plant imported abroad successfully constructed in this case. With the entitled authority by the Chinese government, CGN focuses on internal collaboration and self-promotion, and at the same time holds on the challenge of finding out what the ecosystem lacked and attracting important followers to help fill out the full package of value (Moore, 1993). The structure of the ecosystem reveals as a simple supply chain with CGN as the key provider of the core business and its limited partners connected by short-term contracts and temporary collaborations (see Figure 4).

Figure 4 Ecosystem structure at Stage 1 (see online version for colours)



5.1.2 Stage 2: ecosystem figuration-extended network

The ecosystem figuration stage finishes when an ecosystem structure gets into shape and able to cope with aggressive growth and profitability to outperform potential competitors. The goal comes to promote collaboration within an extended network including upstream and downstream component suppliers, complementary products and services operators to meet end users' requirements. In this case, CGN focuses on dealing with multi-projects operation by adopting design with own brand. Circling the core architecture based on the AE model, CGN maintains strong power by developing its unique position as a hub. In this way, a reasonably stable hub and spoke configuration mentioned by Möller and Svahn (2003) is formed tied up with a series of interdependent value-adding partners (see Figure 5).

Figure 5 Ecosystem structure at Stage 2 (see online version for colours)

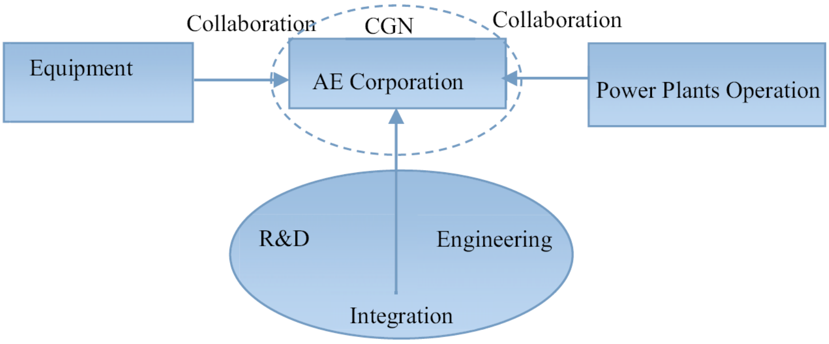
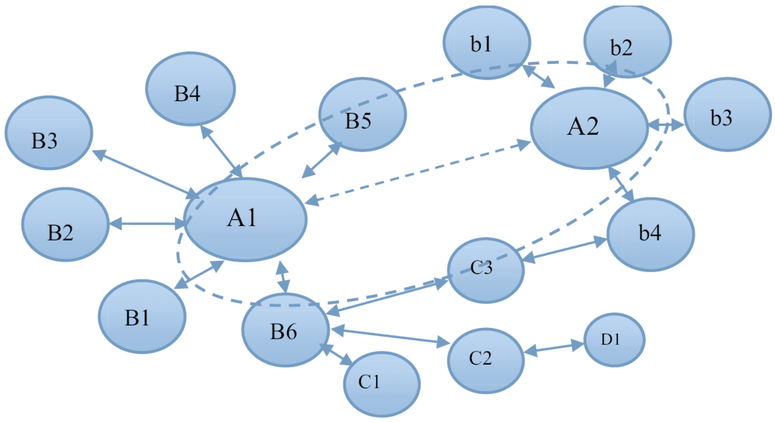


Figure 6 Ecosystem structure at Stage 3 (see online version for colours)



5.1.3 Stage 3: ecosystem self-renewal-ecosystem periphery

The ecosystem self-renewal stage describes a state in which new innovations are incorporated to maintain its competence and keep balance between stability and new change. As shown in Figure 6, A1 represents the position of CGN, around which large and medium-sized enterprises (B1, B2,…, Bn) and small enterprises (C1, C2,…, Cn) that supply key and auxiliary technologies and equipment constitute the core business and extend network circles. Accordingly, the ecosystem further enlarges its scope by absorbing stakeholders at the ecosphere circle, e.g., intermediary and financial agencies, R&D institutions and universities, regulators, governments, related industries and even rival ecosystems (D1, D2,…, Dn), which have relatively indirect but important influences on the network (Zhang and Liang, 2011). All the players mutually collaborate and learn through both formal contracts and symbiotic relationships (Pierce, 2009). In the meantime, other network hubs such as CNNC and CPIC (A2), serve as a shared platform for the whole network together with CGN, drawing the entire community towards a grander future (Cusumano and Gawer, 2002).

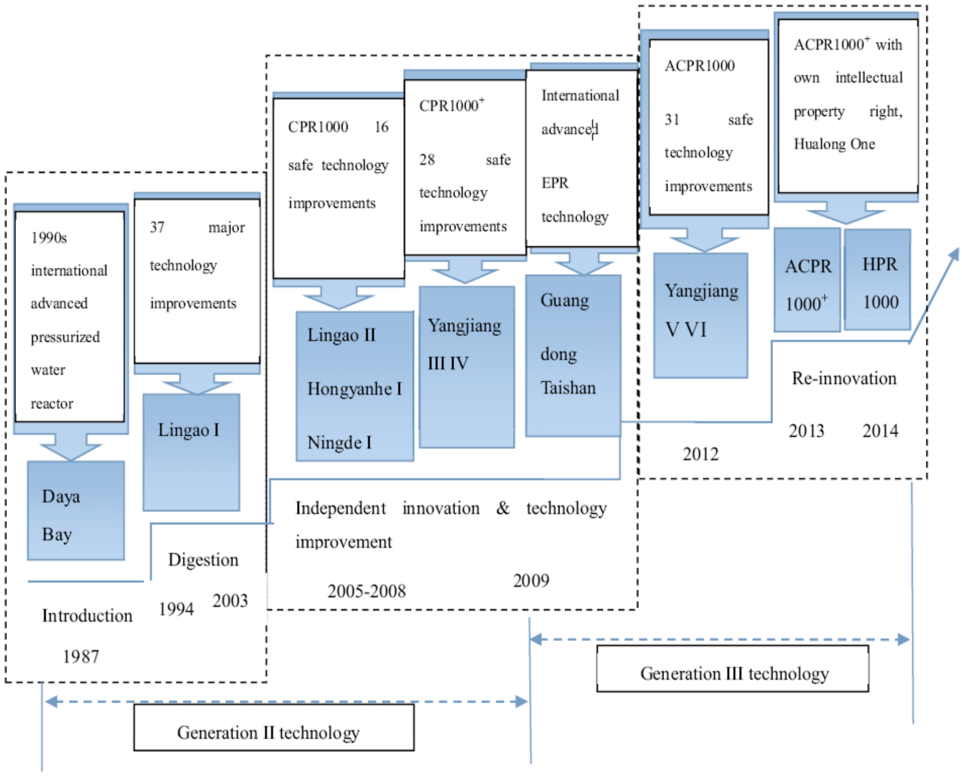
5.2 The evolution of three dimensions

5.2.1 Technology dimension

Technology management activities are listed as identification and selection of technologies, tools and techniques needed to exploit and utilise these technologies, as well as design principles of shared technological domain (Autio and Thomas, 2014; Cetindamar, 2009). CGN fulfils the technological pattern of catching up countries demonstrated by Kim (1997) and Malerba and Nelson (2011), and achieves great competence through effective technology management activities. These initiatives e.g., interplay between the focal and complementary technology, battle with an emerging ecosystem for the dominant design, and balance between structured experience and specific requirements in multi-parallel projects points to the characters of technology management activities under the context of CoPs-based ecosystem in a good way.

Specifically, Amsden and Chu (2003) regard learning as a key driver of catching-up. This is the case when CGN at the first stage develops a learning-by-doing process by benchmarking and establishing an effective communication mechanism with its French technology provider to effectively access, interpret, encode, and manipulate new knowledge and insights. It also applies to the subsequent fact that CGN enters the generation 3 cycle by purchasing and learning from two French-designed EPR reactor units, while with a higher starting point based on the accumulated experience and improved knowledge base in the generation 2 cycle. At the second stage, the adoption of AE model calls for a transition of the technology and knowledge management orientation from recognition (know-what) to acting (know-how) and understanding (know-why) (Desouza, 2005), so as to achieve user-based imitative innovation towards large scale construction. Thus, close alliances between CGN and components manufacturers or integrators with complementary technologies are built to boost the overall technological level within the extended network. Consequently, as Ceccagnoli and Jiang (2013), Pierce (2009) and Rong (2011) and suggested, co-specialisation is triggered with all the partners' technological solutions co-designed, converged and then consolidated surrounding the hub's modular design and related standards. Last, to generate continual improvement and indigenous innovation, CGN further opens its key interfaces by collaborating and sharing resources such as channels and complementary technologies with its prior competitors and local research institutions or universities. This open innovation practice proves to be more effective than keeping the technological domain concealed (West and Wood, 2008) (see Figure 7).

Figure 7 Technology dimension evolution (see online version for colours)



5.2.2 *Value dimension*

The value dimension addresses the logic and vision of shared value creation and appropriation (Peppard and Rylander, 2006). Value here includes both tangible forms such as goods, services and revenue, as well as intangible value, such as a sense of community and common identity, shared culture, and customer loyalty (Allee, 2008). An innovation ecosystem illuminates the flowage of tangible value, and unites the actors in the CoPs-based ecosystem to co-create a commonly accepted identity, culture and intangible value system which further facilitate tangible value creation.

At the first stage, the vision is solely to achieve the state task. Value co-creation and sharing are limited to CGN and a few key suppliers in the core business level. When it comes to the figuration stage, following the eventual adoption of AE model, value co-creation and sharing activities are operated in the extended network, particularly with users included (Peppard and Rylander, 2006). Around the AE corporation as the hub, actors are aligned to deal with users' changing requirements under multi-parallel projects. However, the process of shared value creation cannot be achieved in vacuum. It is usually challenged by prior assessment and allocation mechanisms emphasising on individual profit maximisation. For example, the role of landlords mentioned by Iansiti and Levien (2004a) may destroy the entire ecosystem by extracting too much value from others. CGN's practice in coping with these challenges echoes contributing factors discussed by some previous researches, such as a collaborative culture, transparent governance principles, common operating infrastructures, explicit incentive mechanism and performance measurements, as well as a matrix organisation structure(Camarinha-Matos et al., 2009; Danilovic and Browning, 2007; Ethiraj, 2007; Liu and Rong, 2015).

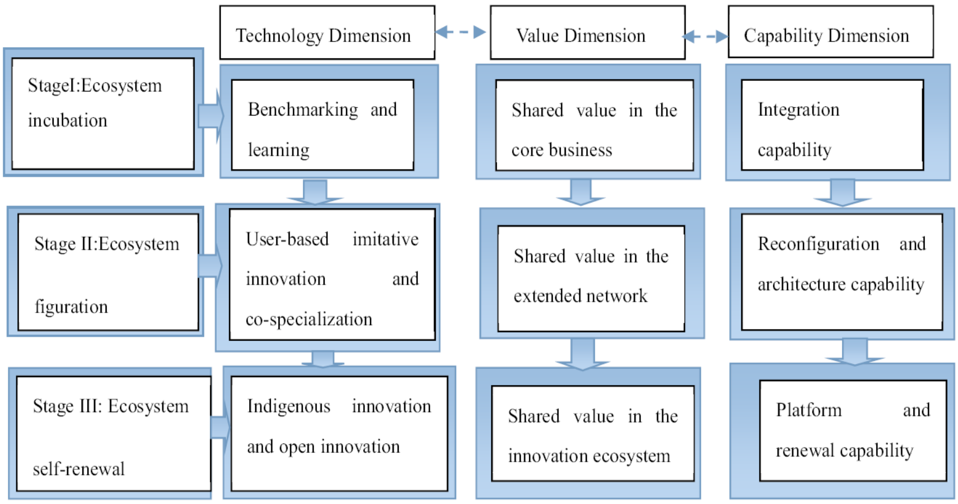
With broader stakeholders deeply involved in the ecosystem, the value creation and sharing norms and schemes among core actors are thus expanded to the whole ecosystem. Different from the incubation and figuration stages at which value creation is goal-oriented and stems from exploiting existing opportunities, at the self-renewal stage, with long-term oriented strategic alliances, the ecosystem actors are united as a community sharing common value, identity and culture (Camarinha-Matos et al., 2009). CGN's practices such as worker training, performance measurement, nuclear industrial park and security platform building show its efforts in achieving common benefits within the whole ecosystem. Such ecosystem enjoys broader boundaries than networks following market principles based on transactions of specific products or services (Santos and Eisenhardt, 2005).

5.2.3 Capability dimension

Under rapid changing institutional settings, explicit technological trajectory and incentive alignment are necessary but not sufficient for sustained competence. What also counts is the dynamic capability (Teece, 2007), which determines the potential of transforming technology and knowledge into co-created value. System integration capability is core for CoPs enterprises (Hobday et al., 2005). At the stage of ecosystem incubation, there are scarce resources and a lack of experience for CGN to implement the core business and serve its subscribers. Therefore, CGN tries its best to integrate all the internal and external resources, technical skills and knowledge obtained throughout the country and even abroad, which is no more than basic operational capability (Helfat and Peteraf, 2003). As CGN gradually masters activities of procurement, construction and design by incremental improvements, it becomes an architecture engineer, who sets standards and regulations under which high-level routines and distinctive ways of doing things along the industrial chain are achieved. Subsequently, it pays more attention to related organisational and managerial reconfiguration and supplementary measures to support the launch of AE model. Thus, architecture and reconfiguration capabilities are keys to sensing and seizing opportunities, and quickly reconfiguring and transforming the firm's asset structure under multi-projects with high coherence and low cost. At the last stage, CGN continuously tries to incorporate new innovations to realise self-renewal and help stakeholders build and expand their core capabilities. This is in accordance with the comments of Teece (2007) which emphasised not only adapting to the ecosystems, but also shaping them by creating opportunities through innovation and collaboration.

On the other hand, in contrast to prior studies on dynamic capabilities which focus on an individual firm's behaviour of self-renewal, the ecosystem-based dynamic capability building process focuses on co-evolving competences dispersed across the entire ecosystem (Liu and Rong, 2015). This process can be facilitated based on regulating the access to an ecosystem-wide shared platform (Cusumano and Gawer, 2002), which provides a common communication structure and a formalised method of interaction to stimulate partners' involvement and orchestrate knowledge and ideas exchange regarding the design and development of CoPs (Liu and Rong, 2015) (see Figure 8).

Figure 8 Evolution of three dimensions at three stages (see online version for colours)



6 Conclusions

This research carries out an in-depth case study on CGN, which has gained a firm foothold in the global nuclear power industry as a latecomer by building an innovation ecosystem. With respect to the lifecycle model, we explore the evolutionary trajectory of an innovation ecosystem in terms of structure and interactions among players during different stages, and conclude with the underlying logic of competence gaining through evolution of three dimensions, i.e., technology, value and capability. This framework answers why organisations are willing to enter an ecosystem and how the network hub of the ecosystem manages its technological and organisational resources leveraging dynamic capabilities. We find that although the specific activities of building and managing an ecosystem are idiosyncratic depending on various CoPs projects and contexts, there exhibits a common ground. Therefore, we believe the case study of CGN provides further research directions in innovation ecosystem and useful implications for practitioners.

6.1 Theoretical contributions and implications

This research contributes to existing literature in three aspects. Firstly, the study extends traditional literature on industry-focused and resource-based theory (Porter, 2008; Prahalad and Hamel, 2006), and emphasises competence gaining based on the innovation ecosystem perspective. Secondly, on the basis of evidence from a CoPs firm, it enriches prior literature on mass-produced goods, whereby advantages of innovation ecosystem in delivering complex solutions while maintaining corporate focus are revealed (Willianson and De Meyer, 2012). Thirdly, breaking through the static and single dimension method commonly used in studying innovation ecosystem, we adopt a dynamic view to reflect the features of interdependency and co-evolution. It indicates that the formation of an ecosystem is the results of the interplays among various players and multi-dimensions.

The proposed framework is more comprehensive and integrative than other network-centric construct, such as the business network theory including dimensions of activities, actors and resources (Anderson et al., 1994).

The findings also offer valuable managerial implications for similar cases in China and other developing countries. Firstly, it shows that China fail in many emerging CoPs industries owing to incomplete ecosystem. Thus, it is vital for companies to have strategic vision which takes ecosystem as a new source of competence. Secondly, a successful ecosystem cannot emerge and evolve naturally, as it relies on effective management and interactions among players. Accordingly, for both focal firms like CGN, and complementary firms, it is crucial to recognise their own roles in the multi-level network and figure out specific environmental attributes within the ecosystem, so as to make proper strategic decision over time (Adner, 2006; Iansiti and Levien, 2004a). Last but not least, it is a fact that China used to focus on a single critical technology in catching up of emerging industries. However, this research shows that under the ecosystem context, some soft aspects, like value and capabilities, should go hand in hand with the technological development. Respectively, evolution of technology should be judged in a systematic manner, with integration of upstream and downstream technologies assumed to be vitally important; short-term indicator of firms' performance should be replaced by long-term one which emphasises shared vision and co-created value drawing the entire community towards a grander future; furthermore, dynamic perceptions on capabilities are highlighted to both react to the ever-changing environment and lead the future direction of the ecosystem. To achieve synergy of the three dimensions, tools and measures, such as platform and alliances are encouraged to be adopted.

6.2 Limitations and future research directions

Firstly, our data in this research cannot clarify a clear picture of how the three dimensions, i.e., technology, value and capability; connect with each other due to our research design. We will further refine the framework by unveiling the way of various dimensions respectively acting on the innovation ecosystem and interacting with one another

Secondly, this research explores the micro-foundation of the formation process of ecosystems from the view of a focal firm, CGN, and emphasises its intentional efforts related to the ecosystem. We hold the proposition that subject to scare resources, firms can only concentrate on several important tasks at a specific stage. Therefore, the framework and ecosystem structure we set up is oversimplified to comprise key actors and activities around the focal firm, while regarding other factors as part of the context (as it shows in Figures 4 to 6). For instance, the civilian nuclear power program in China is with aggressive government intervention. However, we simply give a brief introduction of the development of the whole industry as the context, with the government as an exogenous variable. Future researches will explore how other ecosystem players, such as the government, users and complementary firms affect the evolution of the ecosystem, and at the same time give a deep understanding of the full meaning of the contexts.

Lastly, to overcome the limitations of the single case study, we will further extend our research to other industries, such as the automotive industry in China, which is also typical CoPs but has different product features, industrial structure, and institutional and social contexts in which technologies compete and evolve. It would also be well worth comparing the case of CGN with that of other emerging countries, which share similar characteristics with China. Another key point is that, as Abernathy and Utterback (1978) postulate, the technology trajectory in advanced countries are quite different from that in catching-up countries. However, there are some common grounds when discussing an emerging technology in catching up countries and a mature technology in the transition stage in advanced countries (Kim, 1997). Therefore, our framework will surely to some extent provide implications to understand technological change in advanced countries.

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Notes

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