# Is China transmuting to fast overtake the USA in innovation?

## R&D case-studies in advanced technology manufacturing

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### Abstract

**Purpose** – This paper aims to argue for a China transmuting to fast overtake USA in innovation based on the extrapolation of past statistical trend. Case studies in self and co-innovation are provided so that the documentation of the dynamics of knowledge flows and a brain-linguistic explanation is given as to why, in the future, the Chinese are likely to lead in innovation.

**Design/methodology/approach** – This paper illustrates a multi-method approach in research for *Chinese Management Studies*. First, the sociological background of China is highlighted (Mao Zedong's aphorism). Second, insights from OECD patent database are utilized. Third, the use of comparative research and development case-studies: self-innovation (Chinese) and co-innovation (contrasting Japanese versus French cooperation with Chinese). Fourth, is the inter-disciplinarily approach wherein the assimilating of knowledge is related to recent advances in brain research. Fifth, emphasizing the different levels in organizing for innovation: national (China), organizational (SOE), group processes and person-to-person, synapses within individual brains.

**Findings** – Statistical trend suggests that China is transforming and is on the path toward overtaking the USA in innovation. When will this happen? Using extrapolation as an indication, China may surpass the USA by the 50 per cent mark within the next decade. Insights into the processes of self-innovation and co-innovation are provided. Authors argue for a brain-linguistic explanation (Hebb, 1949) for further understanding why China will eventually lead *ceteris paribus* innovation, a function of the human brain.

**Originality/value** – This paper highlights on the basis of statistical trends (using OECD database) a rising, innovative China that is poised to overtake the USA in the near future. A major contribution is in providing insights of interactional processes required to foster innovation: self and co-innovation (comparing Japanese and French). The critical brain-linguistic role as the rationale as to why the Chinese are given a greater, more developed brain power that will eventually surpass the West in innovation.

**Keywords** Innovation, China, Co-innovation, Self-innovation, Brain power

**Paper type** Research paper

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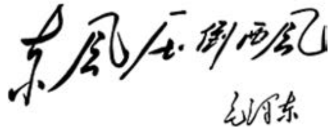


**The East Wind Prevails Over the West Wind**
**Mao Zedong, Moscow, 1957**

## Introduction

The advanced technology manufacturing industry plays a key role in the building of China's modern industrial structure. Advanced technology manufacturing contributes significantly to national defense in addition to the economy, and as the 16th CPC National Congress (11th Five-Year plan, 2006-2010) was convened with rigorous governmental support, there has been great progress made in China. By 2013, China had become one of the world's leading equipment manufacturers, accounting more than 30 per cent of global industrial output despite the perceivable gap in technology between national and international suppliers (Jin *et al.*, 2014). Thus, the key issue is in how China may *speedily* catch up with those who are the foremost in technology globally.

This race to be the first in technology has long been inspired by Mao Zedong (Moscow, 1957) who proclaimed 东风压倒西风 (in Pinyin: *dong feng ya dao xi feng*) to his Chinese students studying engineering and science in Russia. This aphorism is actually a citation by Mao Zedong from the Chinese novel, *Dream of the Red Chamber* (Chapter 82) and is often translated as "The East winds *prevailing* over the West". Yet the Chinese character 压 *ya* in context of a competitive race (Russian versus the USA "Space Race") ought to be better rendered as surpassing. This brings us to a key question for this research: Is China beginning to *surpass* the USA in the race to innovate?

From almost two decades of statistical data (Figure 1), the answer has been a resounding yes! In addition, China has been gaining ground consistently, in fact, in terms of the growth rate of patents filed in the USA versus China. What is most intriguing – and what sparked interest to embark upon this inquiry – is the presence of

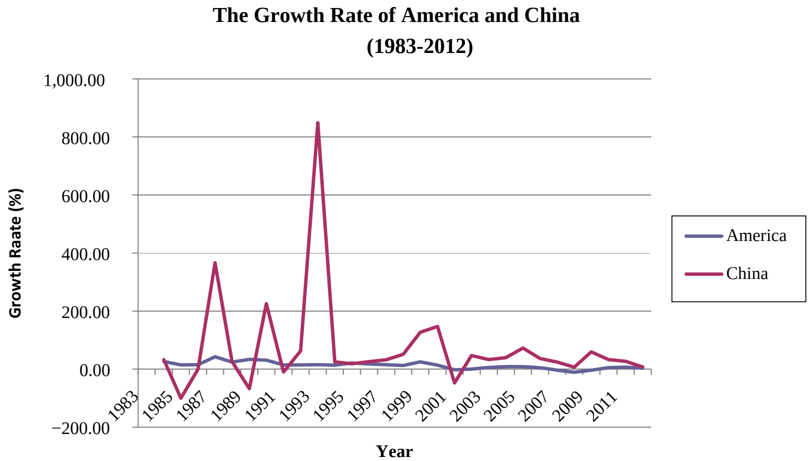



**Figure 1.**
The growth rate of patents filed in the USA and China (1983-2012)

a sharp peak exceeding 800 per cent. Compared to the USA, China as a nation is a latecomer to the global scene of patent filing, and the USA is the foremost forerunner.

Lee and Lim (2001) claimed that latecomers tried to catch up technologically by first assimilating and then adapting. Accordingly, a newly industrializing economy (NIE) first learns by imitating, much like the art of learning calligraphy, where one first imitates the master. Second, there is a much deeper involvement (Bell and Figueiredo, 2012): innovation. Besides this spectacular outburst of patent filing activity during the mid-1990s, has China been enhancing her innate capability in innovation?

As shown in Table I, it can be seen that China progressed consistently in the share of global patents from almost nothing in 1983 to 9.89 per cent in 2012. The super leap in global percentage share happened during 1992-1993 from 0.03 to 0.22 per cent, and the political complexity of China is embedded in this simple statistic. If patents are

**Table I.**
The patent number and percentage in America, China and the world (1983-2012)

| | Regions | | | | |
|---|---|---|---|---|---|
| | America | | China | | World |
| Year | No. | (%) | No. | (%) | No. |
| 1983 | 1,754.0000 | 41.59 | 1.0000 | 0.02 | 4,217.0000 |
| 1984 | 2,217.1389 | 38.22 | 1.3333 | 0.02 | 5,801.0000 |
| 1985 | 2,548.2238 | 36.58 | 0.0000 | 0.00 | 6,967.0000 |
| 1986 | 2,941.6929 | 37.54 | 0.7917 | 0.01 | 7,836.0000 |
| 1987 | 4,182.7567 | 39.81 | 3.6905 | 0.04 | 10,507.0000 |
| 1988 | 5,182.5288 | 40.40 | 4.6667 | 0.04 | 12,828.0000 |
| 1989 | 6,924.9333 | 39.70 | 1.5238 | 0.01 | 17,441.0000 |
| 1990 | 9,032.5706 | 42.95 | 4.9641 | 0.02 | 21,030.0000 |
| 1991 | 10,330.4640 | 44.27 | 4.4635 | 0.02 | 23,337.0000 |
| 1992 | 11,877.8790 | 43.77 | 7.2619 | 0.03 | 27,140.0000 |
| 1993 | 13,701.0350 | 43.22 | 68.9000 | 0.22 | 31,702.0000 |
| 1994 | 15,566.2660 | 42.24 | 86.0205 | 0.23 | 36,853.0000 |
| 1995 | 18,841.7880 | 42.62 | 101.5536 | 0.23 | 44,205.0000 |
| 1996 | 22,158.7930 | 41.48 | 127.9190 | 0.24 | 53,422.0000 |
| 1997 | 25,580.1940 | 41.18 | 168.7686 | 0.27 | 62,115.0000 |
| 1998 | 28,851.8230 | 40.61 | 255.1790 | 0.36 | 71,042.0000 |
| 1999 | 35,996.2052 | 40.76 | 578.4849 | 0.66 | 88,304.0000 |
| 2000 | 40,939.4122 | 39.86 | 1428.8145 | 1.39 | 10,2702.0000 |
| 2001 | 40,106.8998 | 38.30 | 750.3802 | 0.72 | 10,4708.0000 |
| 2002 | 39,993.2192 | 36.83 | 1,100.6931 | 1.01 | 10,8598.0000 |
| 2003 | 42,291.9291 | 35.66 | 1,459.6807 | 1.23 | 11,8600.0000 |
| 2004 | 45,633.9985 | 34.46 | 2,039.8083 | 1.54 | 13,2419.0000 |
| 2005 | 49,778.4292 | 34.36 | 3,521.0351 | 2.43 | 14,4885.0000 |
| 2006 | 52,068.3246 | 33.73 | 4,811.4131 | 3.12 | 15,4351.0000 |
| 2007 | 50,043.5446 | 31.30 | 5,980.4707 | 3.74 | 15,9890.0000 |
| 2008 | 44,654.0419 | 29.72 | 6,383.8217 | 4.25 | 15,0234.0000 |
| 2009 | 42,887.3643 | 27.39 | 10,186.1439 | 6.50 | 15,6599.0000 |
| 2010 | 45,232.1538 | 26.26 | 13,558.2742 | 7.87 | 17,2228.0000 |
| 2011 | 48,212.7688 | 26.06 | 17,247.9639 | 9.32 | 18,5036.0000 |
| 2012 | 50,150.7282 | 26.70 | 18,573.2557 | 9.89 | 18,7858.0000 |

**Source:** http://stats.oecd.org/viewhtml.aspx?datasetcode=PATS_IPC⟨=en#

reflective, then the post-Tiananmen period (1989-1992) is marked by China's transformation toward a greater innovative society. Does this statistical trend then hint that China is *fast* catching up in innovation? For the answer to this, we turn to the literature on how NIEs may technologically be catching up.

## Theory of catching up

Through globalization, some NIEs are able to narrow the technological gaps between themselves and developed countries, and successful catching up goes beyond the adoption of existing techniques to encompass innovation (Fagerberg and Godinho, 2005). There are variants in these approaches to innovation, primarily self-innovation (Fagerberg and Godinho, 2005; Hobday, 1995; Lee and Lim, 2001; Jacobs and Notteboom, 2011; Chuang, 2014) and co-innovation (Fagerberg and Godinho, 2005; Fan, 2006; Okamuro *et al.*, 2011; Lee *et al.*, 2014).

As shown in self-innovation literature, the key themes are technological capability, learning and knowledge spillover, path choice and windows of opportunities. Technology-oriented views focus on assimilation of technology (some obsolete) of developed countries. Consistent with product life cycle theory (PLC), technology is a cumulative, unidirectional process (Figueiredo, 2010, 2014; Shan and Jolly, 2012), and by undertaking different types of innovative activities, NIEs may not merely imitate (Bell and Figueiredo, 2012) but innovate as well. For this to happen, both the internal knowledge base and the accessibility to external knowledge are critical for catching up (Mathews, 2002; Park and Lee, 2006).

Internal knowledge enhances a latecomer's **learning** capability and enables knowledge **spillover** from external sources of advanced knowledge (Chuang, 2014). Once acquired and assimilated, external knowledge renews as well as accelerates a latecomer's building up of knowledge bases (Keller, 2004; Ernst and Kim, 2002; Chuang, 2014). Different **pathways** exist for latecomers, including "original equipment manufacturing (OEM) (Hobday, 2000), OEM evolving to own design and manufacturing (ODM) and, finally, through acquired strengths in technology, a latecomer's own brand manufacturing (OBM)". OEM-ODM-OBM is organizational innovation requiring facilitation of learning toward knowledge frontiers for latecomers.

Lee and Lim (2001) identified path-creating, path-skipping and path-following in catching up. The first two, path-creating and path-skipping, may be seen as "leapfrogging". In path-following, a latecomer takes the well-trodden path of forerunners but in much less time. A latecomer, as a stage-skipper, follows up on forerunner's path but may skip some stages. To be a path-creator, a latecomer has to seek their own pathway for new technology. Not all of these paths are as effective for catching up (Lee and Lim, 2001), and latecomers who are path-followers often experience setbacks despite their rapid catching up due to the continuing substantial gap in technological capabilities between the latecomer and forerunners. In stark contrast, the gap between path-creators or path-skippers and the world's best is constantly being reduced. A path-follower is unlikely to win in the catching-up game. To catch up, a latecomer has to be leapfrogging either by creating or skipping. Li and Kozhikode (2008) suggested another classification: latecomers as emulators or blind imitators. Emulators are flexible in their routines while blind imitators are far more rigid. For catching up with forerunners, emulators are far better positioned.

Other scholars (Perez and Soete, 1988; Archibugi and Pietrobelli, 2003; Niosi and Reid, 2007; Jacobs and Notteboom, 2011) emphasized windows of opportunity for latecomers in catching up. An emerging new techno-economic paradigm may be one such window of opportunity. Latecomers may leapfrog by *quickly* riding upon the new wave, thus overtaking forerunners locked into prevailing technologies. During the paradigm shift latecomers and (once) forerunners had to neural-*synapse* (Foo and Lee, 2002) upon new technology. It is an open game without entry barriers, and there is scope for co-innovation and for latecomers to potentially level up on technology with forerunners.

Damijan and Rojec (2007) argued that foreign direct investment (FDI) was needed for restructuring the manufacturing sector and productivity growth within central European countries (CECs). High foreign penetration has resulted in a negative impact on productivity growth across high and medium-high technological industries. Though FDI brought in forerunners, these tend to engage in the lower end of the technological spectrum, but there is still the requirement of raising domestically the technology absorption capacity in of CEC.

While external finance (Fagerberg and Godinho, 2005) has a potentially great role in enabling catching up, increased debt exposure have made countries vulnerable; for example, the financial crisis in South Korea toward the end of the 1990s where South Korea and Taiwan had to rely on subcontracting. Under OEM contracts, forerunners helped latecomers with the selection of equipment, training of managers, engineers and technicians, production, financing and management (Hobday *et al.*, 2004). Renewals in subcontracting enable latecomers to continue to update their knowledge, thus enhancing their technological capability.

R&D cooperation is yet another approach to catching up. Lee and Lim (2001) cited cooperation being effective in a latecomer leapfrogging in the case of a South Korean CDMA, a telecommunication corporation, enhanced their technological capabilities by co-developing with a USA-based venture company and proved successful as people-to-people interactions are critical for success in technology-based, cooperative arrangements. Strategies of catching-up are summarized in Table II (see above).

Enhancing technological capability is an arduous task wrought with uncertainty: a self-innovator may take decades to catch up and therefore co-innovation may be a better alternative process. Many Chinese and Indian corporations cooperate with advanced foreign corporations to gain access to advanced knowledge. Due to global patent systems, latecomers can never obtain the legal ownership of technology from forerunners. Understandably, forerunners are reluctant to render cooperative help in fields to a latecomer in a core technology. Yet the key to innovative success for China is whether people inside Chinese firms (Figure 2) are able to synapse (neural, brains) to new, emerging technology to generate outputs.

In the next section we turn to investigating empirical practices used in organizing for R&D through self-innovation and co-innovation.

## Research and development case studies: self and co-innovation

Through case study research, we gathered in-depth, plentiful data on latecomer-forerunner, R&D cooperation. The exploratory stage is for theory building (Yin, 2003), where we are uncovering areas for deepening research (Voss *et al.*, 2002), as little is known about R&D at the periphery of technology. Multi-case studies allow comparisons on similarities and differences in practices within differing contexts

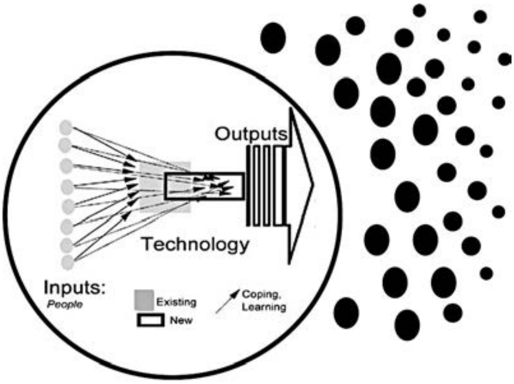
| Strategies | Themes | Authors | Key points |
| --- | --- | --- | --- |
| Self-innovation | Technological capability | Dutrenit, 2004; Fagerberg and Godinho, 2005; Mazzoleni and Nelson, 2007; Lee *et al.*, 2014 | The accumulation of technological capabilities, rather than physical capital, is the main factor supporting catching up; latecomers catch up with forerunners through assimilating and adapting the forerunners' advanced technology and increasing their own technological capabilities |
| | Learning and knowledge spillover | Hobday, 1995; Kim, 1997; Ernst and Kim, 2002; Mathews, 2002; Park and Lee, 2006; Chuang, 2014 | Learning from forerunners enables latecomers to acquire and assimilate advanced knowledge; knowledge spilled from external forerunners will renew and accelerate internal knowledge base and improve catching up process |
| | Path choice/path-ways | Hobday, 2000; Lee and Lim, 2001; Fagerberg and Godinho, 2005; Li and Kozhikode, 2008; Liu *et al.*, 2014 | Latecomers can catch up with forerunners through OEM-ODM-OBM; latecomers could choose leapfrogging strategy, including path-creating and path-skipping, to catch up; firms that choose emulation develop flexible routines are better positioned to catch up |
| | Window of opportunity | Perez and Soete, 1988; Archibugi and Pietrobelli, 2003; Niosi and Reid, 2007; Jacobs and Notteboom, 2011 | The time of techno-economic paradigm shift is an opportunity for latecomers to catch up, when everybody has a similar start with new technology and the entry barriers tend to be low |
| Co-innovation | FDI | Fagerberg and Godinho, 2005; Damijan and Rojec, 2007; Tang and Hussler, 2011 | FDI is an important vehicle of catching up through promoting manufacturing sector restructuring and productivity growth, but foreign investment mostly engages in lower end technological segments and will only change when the latecomers' absorption capacity upgrades; catching up heavily relied on FDI will make latecomers vulnerable and lead to the financial crisis |
| | Subcontract | Hobday, 2000; Fagerberg and Godinho, 2005; Fan, 2006; Rasiah *et al.*, 2012; Lee *et al.*, 2014 | Latecomers can get help from forerunners under a subcontract; Successful subcontracts can renew and update the latecomers' knowledge and increase their technological capabilities, and prepare the latecomers to catch up |
| | R&D cooperation | Lee and Lim, 2001; Fan, 2006; Okamuro *et al.*, 2011; Wang *et al.*, 2014 | Cooperating with an advanced company can improve the latecomer's technological capabilities by high frequency of interacting and collaboration, and increase the latecomer's chance to catch up |

**Table II.** The strategies of catching up, themes and corresponding authors

(Silverman, 2013), and generic insights may be discovered (Eisenhardt and Graebner, 2007). H and D are two leading, advanced technology state-owned enterprises (SOEs) in China (see Appendix 1 for background discussion). T and F are advanced manufacturing corporations in Japan and France, respectively. D was chosen for self-innovation with D and F, H and T for co-innovation. The conceptual framework that guides the implementation of the case studies are provided in Figure 3.

We chose these three cases for these reasons:

(1) D is a helicopter manufacturing corporation belonging to Aviation Industry Corporation of China. D is a key construction project for China's First Five-Year




Source: Adapted from Foo and Lee (2002)

**Figure 2.** Dots represent technology firms

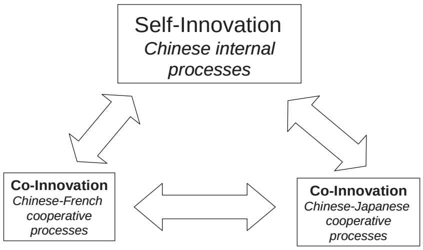



**Figure 3.** Self-innovation and co-innovation processes

Plan supported by the Ministry of National Defense. Through improvements in R&D, D now leads in turboprop engines.

(2) Co-innovation between D and F. D as latecomer was able to design the main gearbox of the Z9 helicopter but lagged in manufacturing. In contrast, F, a highly experienced developer of helicopters, had extensive experience in manufacturing the main gearbox, and insights may be gained on co-innovation processes in contrast to self-innovation processes.

(3) Co-innovation between H and T. For the past 20 years, H had been a large-scale SOE that made great strides on the development of nuclear turbines (design and manufacturing). However, H is weaker on aspects of test technology, and T is a Japanese semiconductor manufacturer that led the industry in nuclear power technology. Being Japanese, this co-innovation may be contrasted with both self-innovation and Chinese-French co-innovation (D-F).

## Self-innovation

WJ5 is D's turboprop engine (see Appendix 2 on technical aspects) used in civil airplanes, seaplanes and military transport aircrafts. The use of WJ5 was suspended in 1980, as it was found to be underpowered during take-off. In 1985, D began to develop a new model WJ5A by redesigning the turbine at takeoff to 100°C and 442kW, as the WJ5A could possibly withstand higher temperatures and was more pressure resistant. Despite several test flights, WJ5A failed the expected standards. D then changed WJ5A from one to a two-grade rotation speed, thus reducing the take-off power and the changed, more reliable and longer-lasting engine was re-designated WJ5A-I.

## Intra-firm communications of D

*Platform for communication*

- *Physical space such as conferencing, meeting and chatting*: D provided enough rooms for all types of communication. Meetings were held regularly or on an impromptu basis, and several chat rooms were availed for staff to chatting during and out of office hours, and they were able to use them to talk about work or their personal lives. Chat rooms provided a relaxed atmosphere and thus fostered a closer bonding among staff.
- *Information system and databases*: D built its own information system for staff with data on products and processes.
- *Management system*: D built a mature management system for promoting a freer flow of information which cuts across different organizational levels while documenting working procedures.

*Formal communication*

- *Conferences, meetings and seminars*: Conferences were organized every month for senior managers. Their purpose was to discuss the key issues about the development of the WJ5A and the WJ5A-I. Following such discussions, schedules were adjusted for the next stage.
- *Meetings*: Meetings were held for managers and technicians to solve any problems encountered during the development process. Often managers and technicians from different technological fields had to put their minds together to find solutions for complex problems that arose from the R&D processes.
- *Training*: Experts from the company gave technicians lectures on technologies and operating skills relevant for developing WJ5A and WJ5A-I, and D often invited famous experts from universities and research institutions who were requested to make presentations on the relevant and latest advances in technology.
- *Teamwork*: To technically increase the power of the W5J during take-off, a temporary, multi-disciplinary team was set up (technicians from aerodynamics, thermodynamics, mechanics and physics). Team members communicated through meetings and seminars. Departmental boundaries were set aside, as the team integrated its knowledge to realize the goal which was to find the most feasible way to improve the power of take-off.
- *Job rotation*: Similar to the structure of many Japanese corporations, managers and technicians in D are rotated in their jobs for a better understanding of the overall workflow. In the process, they master different sets of skills and enhance communications. D found, consequently, they were able to easily uncover and solve problems while improving an existing, or in the creation of a new, product.
- *Orders and reports*: Communication between superiors and subordinates continued to be embodied in orders and reports. Managers gave orders to technicians about their tasks, and technicians had to report back on what had

been done, including the management of problems. Orders and reports enabled managers to better control the schedule and orientation of the project.

*Informal communication*

- *Mentorship*: Mentorship was one of the basic relationships in D. As soon as a technician joined the company, they were led by an experienced technician (or manager), and in working together, the technician could learn the more intricate skills from the mentor that were widely used in developing the WJ5A and the WJ5A-I.
- *Chatting*: Technicians and managers usually met in chat rooms during off-hours, often talking about their work experiences, enlightening each other in a casual manner. Sometimes they talked about their personal lives and became friends outside of work.
- *Personal relationship*: Technicians and managers often visited each other on weekends and holidays. Corporate sponsored staff dinners, and parties were held three or four times every year to encourage socializing.

## Co-innovation (Chinese-French)

From 1992 to 1993, D cooperated with F to develop the Z9 carrier-based helicopter main gearbox. Under contract, D designed the main gearbox and F its manufacture. With this invention, D planned to break out of the bottleneck on manufacturing by mastering the F-related technology. The transmission systems in engines are crucial to a helicopter's function and reliability, and the gearbox is the core element keeping the engines working. Technicians of F worked in D's workshop, with D's technicians leading the way in manufacturing and assembling the gearbox, and the technical aspects included parameter setting, parts processing, cryogenic treatment, heat treatment and polishing.

## Communications between D and F

*Platforms for communication*

- *Seminar*: The main platform for teaching and discussing the relative manufacture technology of main gearbox between technicians from D and F was through seminars.
- *On-site communication*: To facilitate the transfer of practical skills in co-manufacturing, on-site communications were found to be more effective than classroom lessons. Thus, F sent several technicians to D to directly assist in the manufacture of main gearbox on-site.

*Formal communication*

- *Training*: Technicians from F introduced the engineering and technical staff of D the crafts of cutting, heat treatment, measurement and detection technology.
- *On-site guidance*: Technicians of F explained to the counterparts of D how to use the equipment. They demonstrated the process of testing, including the rationale behind the setting of parameters for cutting.

*Informal communication*

- *Friendship*: Through cooperation on technical areas, technicians of D and F became close friends. They grew to understand each other better and their ways of thinking and acting. Technicians of D began to appreciate not only the technical but also the design philosophy underlying the design of the helicopter main gearbox.

## Manufacturing specifics

- *Creating new knowledge*: Through both formal and informal communications with F's technicians, technicians of D acquired thorough new knowledge involving material cutting, heat treatment, component measurement and function detection. Many of the practical problems that were impossible to be explained in words were solved on the workshop floor. Technicians of D and F worked together to cast parts, operate machines and test prototypes. Besides operational learning, technicians of D assimilated and improved upon the skills gained from F. They tried to combine the global knowledge of F with their own, specific local knowledge. Consequently, they are able to create new local knowledge.
- *Setup of cutting parameters*: The main weaknesses of D in gearbox manufacturing were cutting and heat treatment. For example, setting cutting parameters was a big problem for D, and the production supervisor complained:

  > We don't know how to set the parameter when cutting the bevel gear. So we disassemble the cutting process into 40 sub-processes to avoid imprecise cutting. This undoubtedly results in a great waste of time, material and labor.

  Through cooperation with F, this supervisor learned how to set parameters and, thus, solved the cutting problem. He added:

  > With the help of F, we understood the principle behind parameter setting. The bevel gear can now be cut in just one process.

- *Adaptation of design*: Through training and on-site guidance, the prototype of the main gearbox was understood, and the original design of the main gearbox was improved. This accorded with the cutting parameters and heat treatment. From prototype manufacturing, the technicians of D found that the design of the gearbox created difficulties for manufacturing. Accumulated experiences enabled technicians of D to adapt the original design to different requirements.
- *Harbin Z9 helicopter*: In cooperation with F, D mastered the art of manufacturing gearboxes through further improvements to the original design. Through prototyping, the Z9 carrier-based helicopter was finalized in 1993, and D then built their production line. Now officially an SOE, D is the most advanced in China for manufacturing of helicopter transmission system. Since 1993, D began to design and manufacturing Harbin Z9 helicopters (Figure 4) which has since led to different versions even though all shared the same main gearbox. To cater to specific functional requirements, D is able to make incremental improvements as necessary.


**Figure 4.**
Harbin Z9 helicopter

**Source:** http://en.wikipedia.org/wiki/Harbin_Z-9

## Co-innovation (Chinese and Japanese)

In 2009, H and T decided to test-develop the X blade together. This led to the setting up of the H-T R&D department. Rights and duties were specified in contracts with scheduled goals, and from 2010 to 2013, H and T cooperated on developing the X blade. H worked on design and development; T focused on the testing of the prototype, and improvements to design and development were to be made by T after testing was completed. Following the updating of the design, a three-level simulation of turbine was to be conducted in T's factory. Three scaled-down models were tested for dynamic stress. The R&D of the X blade is a complex process, requiring contributions from diverse fields, including aerodynamics, material science, welding technology and astrometry. H and T formed a team with the best technicians from these fields, and the team was empowered to cut across corporate boundaries while platforms were created to foster formal and informal communications.

*Platforms for communication*

- *Face-to-face communications*: A special office was set up in H, and T's technicians were to report to it on a monthly basis to communicate with H's technicians. Face-to-face communications has been found to be critical for cooperative R&D to be effective.
- *Local area network*: A local area network (LAN) between H and T was built for real-time contact, and every team member was given a specific account to share information.

*Formal communication*

- *Meetings*: Regular meetings were organized within the team. Team leaders (managers from H and T) distributed specific tasks to team members, and team members reported on the progress of their tasks. Documents were shared on the meetings: blueprints, files about technical parameters, progress reports, test reports and related files. At the meetings, team leaders conventionally set the sub-goal for the following period.

- *Brainstorming sessions*: H's managers and technicians highlighted difficulties in developing the X blade and sought answers and advice from T. By brainstorming many ideas, suggestions were put forward and these resulted in practical solutions.
- *Real time*: With individual LAN accounts, team members easily and rapidly interacted with each other. Thus, information could be transferred without delay.
- *Visits of senior managers*: Throughout this period of cooperation, senior managers of H and T visited each other regularly and discussed key issues. As a result, timely decisions were able to be made.

*Informal communication*

- *Chatting*: Besides formal communication in workshops, managers of H paid more attention to the role of informal communication, and managers of H encouraged their staff to chat with T's staff after work. T's managers and technicians were often invited to tea parties and staff dinners. A manager from H commented:

> Being Eastern, Japan shares with China a similar wine culture. Therefore eating and chatting at dinner table became the channels for enabling staff of H to better understand the thinking of T.

*Testing and improvement*

In the initial phase of the X blade prototypes, the root sheared off and failed the test. Yet the results showed both the top and tie wire passed the dynamic stress testing. T made a suggestion to H on how to improve the design of the root and, while analyzing the parameters of the blade, H's technicians found that the loading capacity could not hold the dynamic stress. After repeatedly calculating and adjusting the loading capacity, H could not solve the problem, and it was investigated even after working hours by the technicians.

At a staff dinner, a technician of T told his story about how he found the defect in a component of the turbine. This simple conversation gave a technician of H an insight, and he re-checked the test data by comparing the initial values and found the solution. He was also able to correctly calculate the value of loading capacity, and the root of the blade finally passed the dynamic stress test.

In 2013, the X blade was developed in H, which promoted H to the leading technology ranks of domestic blade development. In addition, while relying on the skills and experience accumulated through the R&D cooperation with T, H built its first blade R&D system, which became the pioneer of blade R&D systems in China.

## Comparisons across contexts

Here we compare the innovation processes across these cases (Table III below). Formal and informal processes are part of knowledge sharing, and clearly knowledge sharing is essential for innovation. Intriguingly different types of knowledge were being shared in different ways in these cases. For self-innovation and co-innovation, explicit knowledge was shared formally through meetings, trainings and guidance, while informality is how tacit knowledge was conveyed as in mentorship, chatting, dinners and at parties.

**Table III.** Self- and co-innovation

| | Innovation process | |
|---|---|---|
| Innovation type | Formal communication | Informal communication |
| Self-innovation | Conferences, meetings and seminars | Mentorship |
| | Training | Chatting |
| | Teamwork | Personal visiting |
| | Job rotation | Staff dinner and parties |
| | Orders and reports | |
| Co-innovation with France | Training | Friendship |
| | On-side guiding | |
| Co-innovation with Japan | Visiting between senior managers | Chat |
| | Real-time contact | Tea party |
| | Meetings and brainstorm | Staff dinner |

In self-innovation, as staff members belong to the same organization, there is emphasis on order and in respecting hierarchical levels. Formality is featured strongly in the self-innovation process of D. In sharp contrast, even within D, informality appeared to be essential for co-innovation between D and F. A partial explanation is the knowledge involved: in the self-innovation process of D, knowledge about turboprop engines had to be gathered before being integrated to create new knowledge. This may lead to more formal communications between technicians and managers in the form of meetings, seminars and teamwork. The main role of informal communications in self-innovation is transmitting corporate culture and generating team spirit.

Co-innovation processes between China and France (Western) also differ from China and Japan (Eastern). In the co-innovation processes between D and F and H and T, the latecomers (D and H) were not able to obtain much explicit knowledge from forerunners (F and T) due to protective barriers. This left the latecomers needing to informally elicit tacit knowledge from forerunners. The frequent interpersonal contacts between latecomers and forerunners often led to a building of respect and trust for each other. In such a situation, the spillover of tacit knowledge is thus facilitated and this led to a highly successful co-innovation process.

On the other hand, the co-innovation between China and France was different from that of Japan. Culture may be the main reason for these differences as T, being a Japanese corporation, was rigorous and emphasized a planned and scheduled approach to work. For the Japanese work traditionally must be completed strictly on schedule. F, as a French corporation, was much more flexible, as there is enduring belief that work should be done creatively in French culture. Interestingly, there is a French philosophy about work that declares one could be innovating while at work. D preferred to communicate with technicians and engineers of F in the workshop, where they could then learn more practical skills. One feature of H-T co-innovation was in the discussion of control schemes between managers resulting, if necessary, in adjusting schedules. These differences between East (Japanese) and West (French) are consistent with prior research about corporations operating in Singapore (Foo, 1992), and China's advanced technology corporations may choose different methods in cooperating with Japanese and French corporations. Having studied Chinese organizing for innovation, we now focus on the Hebbian theory of organization.

## Brains in catching up

In his *The Organization of Behavior*, Hebb (1949) theorizes upon the neural basis of learning. Indeed, in addition to the usual empirical studies, scholars in management should themselves turn to the new, cutting-edge frontiers of the twenty-first century discoveries that have been found inside the human brain. Whether it is for self- or co-innovation brains (Chinese, Japanese and French), all interact in the search of knowledge. Their brains implicitly try to synapse onto knowledge as related to new technology.

Foo and Lee (2002) suggested a neural firm – groups of brains working together – paradigm for interpreting people–technology interactions. How, according to *Nature* (Koralek *et al.*, 2012), brains learn through the re-wirings of neuronal circuits even while learning (assimilating) abstract skills. Innovative breakthroughs require much more than just mere assimilative learning. So, in structuring such interactive, learning contexts (Figure 5 below) – whether self- or co-innovation – the focus should turn to conditions enabling *Aha* type insights. What happens inside the brain of a person struck by an inventive insight *Aha* is still very much a mystery within the study of neuroscience. Yet from above investigations, perhaps the French, more relaxed approach is more conducive for innovation.

*Is China transmuting and* fast *overtaking the USA in innovation?*

This question is best answered by looking at broad patterns – the past and statistical data (Figure 6). Undeniably, a trend seems to be emerging of China as East Wind, 东风 (Pinyin: *dong feng*) beginning to 压 (*ya*) on the USA, the West Wind, 西风, (*xi feng*). By

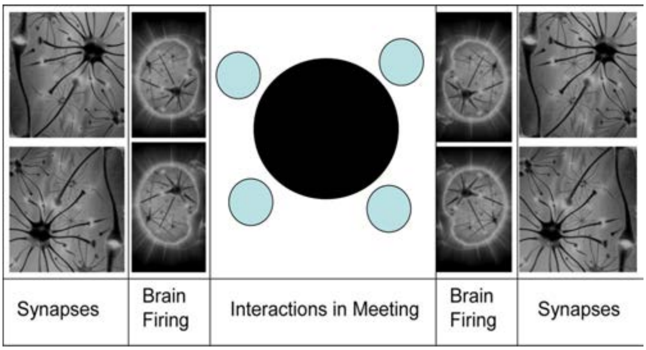



**Figure 5.** Interactions in meeting, brain firing and synapses (original montage)

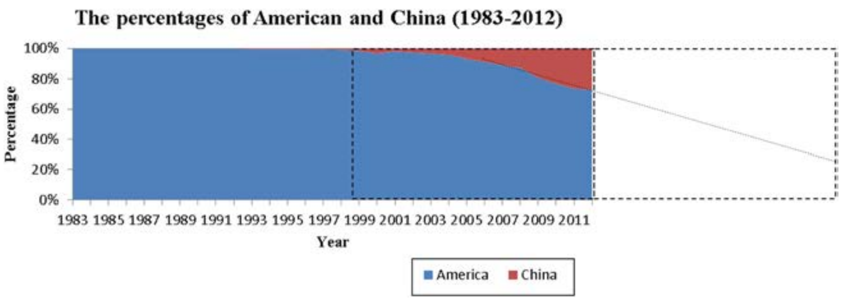



**Figure 6.** Extrapolating upon past trends of American (USA) and China's share of patents

simple extrapolation, China is indeed on such a path. If this projection holds, in the not too distant future, China will be surpassing the USA in the percentage share of patents. China will be at the crossover 50 per cent mark, according to the extrapolative indication, within the next decade. By then, the ancient Chinese civilization may be said to have been restored back to the status as a leading nation. This is also a logical development, given China's rapid ascendancy toward becoming the world's manufacturing powerhouse.

Scholars may debate about whether or not this will ever happen. Yet as the brain's firing and patterning is behind the assimilation of knowledge (learning), then one root explanation lies in the Chinese language. The Chinese, in mastering *putong hua*, actually develop more of their brains; the BBC argued that it takes more brain power to learn that language than it does to learn English ([1]). Speaking the Chinese language engages both the left and right sides of the brain while English only engages the left. A major contribution also lies in learning to write pictographic Chinese characters (Mao Zedong's calligraphy) for brain development.

Whether it is through self- or co-innovation, brain power matters. For innovation to happen, knowledge gained has to be "transmuted" for new uses. While it is technically feasible to model an artificial brain (neuronal processes) to perform the role of appreciating aesthetics (Foo *et al.*, 2009), it is improbable to create an artificial innovative brain. By writing this paper, the authors hope that other scholars will venture to undertake similar research about Chinese innovation and hopes to feature a series of papers in this journal that documents how China has come to lead globally in innovation.

## Note

1. http://asiasociety.org/education/chinese-language-initiatives/learning-chinese-pays-dividends-characters-and-cognition

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**Appendix 1. Background of companies**

D is a state-owned helicopter manufacturing corporation belongs to Aviation Industry Corporation of China, which one of the key construction projects during China's First Five-Year Plan. The main business of D company includes Aviation light power and its derivatives, helicopter transmission system, Aviation transmission parts and other mechanical processing products, industrial gas turbine generating set, aviation electro-mechanical products and aluminium magnesium alloy casting and mold products. WJ5 was once the D company's famous product, but was suspended operation in 1980 because of the underpower of take-off in the conditions of high temperature and high air pressure. In 1985, D company began to develop a new model of turboprop engine by itself based on WJ5, and developed WJ5A and WJ5A-I successfully. In 1992, Ministry of National Defense increased its order for military helicopter in consideration of reunification of Hong Kong with China. For this reason D started to develop and manufacture the Z9 carrier-based helicopter. D was able to design the main gearbox of Z9 helicopter as needed, but corresponding manufacturing ability still fell behind, so D cooperated with F from 1992 to 1993 to develop the Z9 carrier-based helicopter.

H is a large-scaled state-owned turbine manufacturing corporation, the main business of H company is the design and manufacture of large sized fossil turbine, nuclear turbine, industrial steam turbine, marine steam turbine and gas turbine. The annual production capacity of the Company is 30,000MW (equivalent), accounting for about 1/3 of the total annual output of home-made steam turbines for power generation in China. In 1990s, H participated in the construction of Qinshan nuclear power plant in the first, second and third phase, Guangdong Dayawan nuclear power plant and Lingao nuclear power plant, and made a breakthrough at the design and manufacture technology of nuclear turbine, but the test technology was relatively lower. In 2009, H began to develop the 1,500MW nuclear turbine (CAP1400), and X blade is the key component of this nuclear turbine. After a long period of development, H has accumulated rich experience in the blade design and development, but the test technology is beyond the reach of H itself. T holds the leading position in terms of nuclear power technology. With the advance technology in blade design, development, and test, whereas, T could not enter into China's turbine market without the Chinese government's permission. Joint venture or cooperation with native enterprises seems to be the only way available. But T avoided cooperating with H in its core technology in order to protect its competitiveness, but choose to cooperate in testing which don't directly relate to T's core technology.

## Appendix 2. Technical aspects of products

**Table AI.** The technical aspects of WJ5A and WJ5A-I

| Work conditions | Model | Angel of accelerator (a°) | Rotate speed (n) (rpm) | Oil consumption (Gr)kg/h | Equivalent power (Nd) hp | Temperature of exhaust (T4) °C | Continuous working time (min) |
|---|---|---|---|---|---|---|---|
| Take-off | WJ5A | 87-100 | 15,600 ± 150 | ≤822 | 3,150 ± 3% | 502 | 5 |
| | WJ5A-I | 100 ± 2 | 15,600 ± 150 | +10<br>754<br>−20 | 2,900 ± 3% | 481 | 5 |
| | | | 15,600 ± 150 | ≤755 | 2,790 | 493 | 5 |
| Max condition | WJ5A | 74 ± 2 | 15,600 ± 150 | ≤750 | 2,800 | – | 30 |
| | WJ5A-I | 79 ± 2 | 15,600 ± 150 | ≤715 | 2,600 | 476 | 60/5 |
| Rated condition | WJ5A | 65 ± 2 | 15,600 ± 150 | ≤715 | 2,585 ± 3% | 478 | 60 |
| | WJ5A-I | 65 ± 2 | 15,600 ± 150 | 642 ± 10 | 2,267 ± 3% | – | Not limit/60 |
| Flight idle speed | WJ5A | 18 | 15,600 ± 150 | Actual measurement | 730 ± 50 | 412 | 30 |
| | WJ5A-I | 18 | 15,600 ± 150 | Actual measurement | 730 ± 50 | 314 | Not limit |

**Source:** www.dongangroup.cn/product1.htm