Incumbent Latecomer Firms' Strategy During the Emergence of New Technology Trajectories: Four Cases from China

Xiao, Yangao (1); Liu, Jiajia (2); Tylecote, Andrew (3)

1: University of Electronic Science and Technology of China, China, People's Republic of; 2: University of Manchester, UK; 3: University of Sheffield, UK

Abstract: How do successful ('incumbent') latecomer firms in large developing countries compete during the emergence of new technology trajectories? What choices of technology strategy are available to them, and what factors shape their choice and performance outcome? Drawing upon Freeman's technology strategy framework and Whitley's theory of institutional conditioning of technological innovation, we extended existing theoretical insights into latecomer firms' strategy in radically changing environments. By conducting comparative firm-level case study in four firms in different sectors during emergence of technology trajectory change in China, we found that the performance of incumbent latecomer firms during the emergence of new technology trajectories is primarily shaped by: speed of trajectory change, availability of new knowledge and associated intellectual property blockade, corporate governance of the firm and its access to finance, and the role of the state. We developed a framework to understand how the four influential factors interact with each other and how they shape incumbent latecomers' strategy.

Key words: Strategy, Technology Trajectory, Developing Country, Incumbent Latecomer firms, Catch-up

1. Introduction

This paper makes its primary original contribution to the latecomer literatures (Hobday, 1995; Lee&Lim, 2001; Gao, 2003; Matthews, 2006) by proposing a theoretical framework to analyse *incumbent latecomer* firms (ILCFs) – their technological strategies and innovation outcomes - during emergence of new technology trajectories.These are firms which can still be classed as latecomers in developing countries (Hobday, 1995; Matthews, 2006), but have effectively caught up with the international leaders at least in production capacity in the established technological trajectory.

Dosi (1982, 1988) proposes that radical technical change is an outcome of competition between emerging and existing technology trajectories - the path or established pattern of 'routinized' problem-solving activity (i.e. of 'progress'). Emerging new technology trajectory brings about disruption to incumbent firms. It could induce high level of uncertainty due to emerging technologies (Day and Schoemaker, 2000); radical shift of knowledge set may destroy the usefulness of knowledge of established firms (Henderson and Clark, 1990); radically new products

or services also disrupt the market and jeopardise the position and revenue stream of incumbent firms (Bower and Christensen, 1995). On the other hand, research on the impact of trajectory change on Asia-Pacific latecomers emphasized the opportunities presented by the disruption - without prior deep commitment to the old trajectory, there is little embeddedness for latecomers to overcome, hence creating more opportunities for them to skip stages of development or even achieve leapfrogging (Cho *et al*., 1998; Lee and Lim, 2001; Mathews, 2006; Xiao et al., 2013; Lee and Ki, 2017).

However there remains ambiguity regarding incumbent latecomers. What opportunities and difficulties do they perceive in the wake of new technology trajectories? What strategic choices do they have to make, and what are the key influential factors during times of radical technical and market shift?

Our research incorporates appreciative theorising (Nelson, 1995) and investigated the above issues through multiple firm-level studies in four chosen industries during corresponding times of technology trajectory emergence between 2002 and 2017. While the (ICT) sector is well represented in the latecomer literature, the impact of technological change in other sectors is understudied. We thereby chose our firms from 4 different sectors, namely, Grace in man-made textile using natural fibres, Changhong in TV display, Midea in microwave oven, and Huawei in mobile telecommunication solutions. Each case represents a distinctive set of firm and sectoral level characteristics; each case firm experienced at least one technological trajectory shift; and they have had varied innovation performance outcome. These variations allow cross-case comparison and our theoretical framework to be illustrated in rather broad settings.

Our contribution is twofold. Theoretically we developed a framework to systematically understand incumbent latecomer firms' strategy during emergence of new technology trajectories, thereby strengthen the theoretical rigor and relevance of both strands of literature. By conducting empirical research in a variety of sectors and firms with contrasting technological regime and business contexts, we are able to draw conclusions in a variety of contexts. Empirically, the findings from our cross-sectoral and longitudinal study confirmed the robustness of our framework, and shows the framework to be applicable to analysing other emerging market economies with ambitions to compete internationally, in a variety of industries. The article does not claim that other factors beyond firms' institutional context and technology strategies do not matter. Obviously, many other strategies and firm-level decisions may influence technological development, but these are outside the scope of the current paper.

We review the existing research on the above matters in section 2 and propose an integrated analytical framework. We then articulate our research design and methods in Section 3, followed by the case analysis and discussion in Section 4 and conclusion in Section 5.

2. Theoretical building blocks and analytical framework

2.1 Incumbents, latecomers and incumbent latecomers

In the context of technical changes, firms in different competitive positions face varied opportunities and risks, and thus contrasting choices of technology strategy and competitive outcome (Liberman and Montgomery, 1988; Chu, 2009). As opposed to incumbent firms with established competitive position and market power (Black et al., 2012), latecomers /new entrants tend to lag in terms of time of entry into the industry, technological capability and command of resources (Hobday, 1995). Latecomers from developing countries suffer additionally from limited technological capability, lack of power in advanced markets, but also enjoy low-cost advantage and strong motivation for catch-up (Mathews, 2002).

We propose a term to describe a subset of latecomer firms, incumbent latecomers. They are latecomers from developing economies which have succeeded in catch-up in the existing technology trajectory and market. These firms display strong technical competence in production and have combined this with their low labour costs to win a substantial international market share, even in developed economies. They may or may not have competences in technological development. What they definitely lack - through their location - is a secure domestic platform of links to a strong science base and collaborating and/or competing domestic firms, which will facilitate their technological development. How do such firms cope with trajectory shift?

2.2 Incumbent latecomer's supportive and inhibiting factors for innovation during emergence of new technology trajectory

Firms rarely fail because of an inability to master a new field of technology, but because they do not succeed in matching the firm's systems of coordination and control to the nature of the available technological opportunities (Pavitt, 1998). To understand the dynamics of incumbent latecomer strategy during technology trajectory emergence, an integrated framework that considers a multitude of technical, institutional and organisational aspects will prove to be necessary.

Existing research has identified an array of factors that can be perceived as supportive for incumbent firms in emerging technology trajectories. Leifer (2000) and Rothaermel (2001) found that technical knowledge accumulation, market reputation and utilisation of complementary assets (Wu *et al*, 2014) can enable incumbent firms to overcome market disruption brought about by radical technological innovation. Meanwhile, other scholars focus on potential inhibitors for incumbent firms, such as incentives orientation (Henderson and Clark, 1990, Kaplan, 2008), organisational inertia (Hill and Rothaermel, 2003, Cohen and Levinthal, 1990) and strategic rigidity (Christensen and Bower, 1996; Hillman et al, 2009).

On the other hand, following the fast growth of emerging market economies, especially those in East Asia, latecomer firms and their catchup has received much scholarly attention. A number of researchers argued that emergence of new technology trajectory creates unique opportunities for latecomers, and this is due to high level of uncertainty in the technology and market development, combined with limited sunk cost by latecomers in the existing trajectory, making them relatively light-foot (Freeman and Soete, 1997; Gao, 2006). Whilst new trajectories may open

windows of opportunities for latecomers to achieve catchup, they also present risks, i.e. the risk of choosing the appropriate technology to catch up with, and the risk of creating new market (Lee and Lim, 2001; Lee, 2005). Therefore, for emerging market latecomers, technology trajectory shift presents not only 'technical' but also 'business', 'organisational' and 'institutional' challenges (Wu and Lin, 2012). We discuss implications of the latter three factors in a new framework in the following subsection.

Drawing upon these two sub-strands of literature, we propose an integrated model to evaluate supportive and inhibiting factors for incumbent latecomers during new trajectory emergence. We argue that supportive and inhibiting factors for incumbent latecomers are not simple arithmetical sums of the above factors but are dynamic and interchangeable. For instance, what can be supportive factors for latecomer firms, such as sunk cost on existing trajectory, may become inhibiting factors for incumbent latecomers because of their long-term investment and success. Table 1summarizes these parameters.

Table 1 Supportive and inhibiting factors for incumbent latecomer firms during emergence of new technology trajectory

Supportive factors	**Inhibiting factors**
Accumulation of existing technical competences	Technological and market uncertainty
Existing market reputation	Sunk cost on existing trajectory
Complementary assets	Organisational inertia
	Strategic rigidity
	Technical leap of trajectory shift

Supportive factors：

We expect *'accumulation of existing technical competence'* to have a supportive, but not dominant effect on ILCF's strategic choice and implementation. This will be particularly true if the scientific principles of the new trajectory are significantly different from the old ones.

We expect non-technical competences, such as *existing market reputation and accumulated financial resources* to have a key influence. They can not only buffer these firms from technological change, but also influence both the magnitude and directions of which these resources can be deployed (Wu *et al.*, 2014).

Inhibiting factors:

The higher the *technological and market uncertainty*, the higher the risk of failure for the firms.

The higher the *sunk cost* (supply chain, infrastructure, R&D investment) the ILCF encountered in the existing trajectory, the more risk there is for them to forsake that and shift to a new trajectory.

From one point of view, we do not expect ILCFs to display strong organisational inertia - the process of catch-up has caused them to rapidly change their technology, markets and therefore organisational arrangements, and they will have had to scan and evaluate alternative technologies and associated opportunities. On the other hand, they are accustomed to take their lead from other firms rather than show independent

innovative capacity. We expect those firms in industries with *long product life cycles* to suffer from greater strategic rigidity, hence hindering their strategic manoeuver onto the new trajectory.

Finally, the greater the *technological leap*, and the less *standardised* the technology, the harder it will be for ILCFs to succeed on the new trajectory.

2.3 Technology strategies for incumbent latecomers during trajectory shift

Freeman and Soete (1997) and Xiao et al (2013) have set out four technology strategies, in order of novelty and innovative effort: offensive, defensive, imitative and dependent (Table 2).

Table 2 Technology Strategy and Capability Matrix

	Dependent Strategy	**Imitative Strategy**	**Defensive Strategy**	**Offensive Strategy**
Nature of technology strategy	Passive – typically buy/ rent a bundle of technologies from single provider	Reactive -- minimize dependence, by unbundling and reverse engineering	Active – lead in engineering, product design, or process innovation; strong R&D.	Proactive – be leaders in new products, thro' own R&D and/ or links with science base.
Potential for enhancing static capability	Limited by finance and FFF co-operation	Slow to achieve; limited by IPR	High	High
Potential for learning and requirement for dynamic capability	Low; low	High; medium	High; high	Very high; very high

Source: Xiao et al 2013.

An incumbent latecomer may have reached its incumbent status - completed its catch-up - through an imitative or through a defensive strategy. (The more high-technology the sector, and the stronger the IPR regime, the more difficulty in catching up through an imitative strategy, since the firm then does not have significant IP.) By definition, the lead in developing a new - emerging - trajectory must be taken through an offensive strategy. An effective offensive strategy must be very hard for an incumbent latecomer to achieve, since it has a particular requirement for strong research (Freeman and Soete 1997). This can be assumed to be more easily carried out in an advanced economy with a strong research base. To get entry early to an emerging trajectory, the incumbent latecomer must certainly follow a well-worked out, well-funded, defensive rather than imitative strategy, since there is not enough 'out there' to imitate.

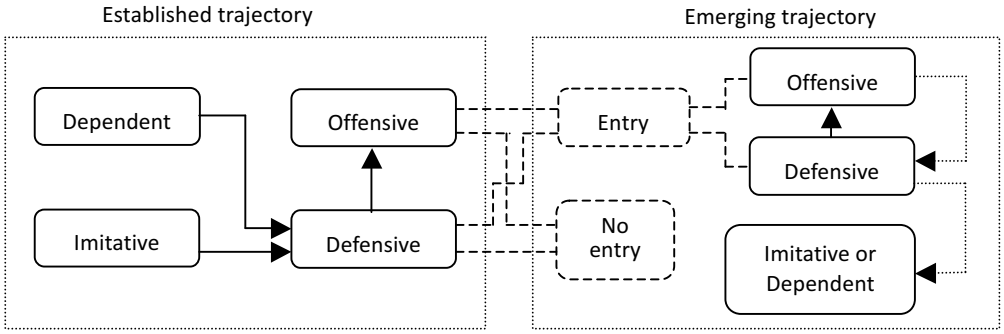

Figure 1. Incumbent latecomer firms' strategic choices and pathways in existing and emerging trajectory scenarios

2.4 Strategic factors for incumbent latecomers, a synthesis of analytical framework

Based on synthesis of business, organisational and institutional factors, we propose an analytical framework to theorise the impact of the above for ILCFs during trajectory change.

Table 3 Influential factors for incumbent latecomers during emergence of new technology trajectory - a synthesis of analytical frameworks

	Speed of trajectory change	Accessibility of external knowledge	Corporate governance and finance	Role of state (policy)
Impact on firm strategy	High speed - good for ILCF, contrary to Hill and Rothaermel, 2003	Stronger international IP protection - bad for ILCF (Xiao *et al.* 2013) Strong collaborative relationship with foreign firms - good (Malerba and Nelson 2011)	Engaged shareholders and capable CEOs - good (Cai and Tylecote, 2008; Xiao et al, 2013) Access to finance - good (Tylecote 2007)	Strong government support at the right time - good (Lee and Lim 2001) Inappropriate intervention of local government - bad (Krug and Hendrischke, 2008)

As Table 3 shows, the literature suggests that during the emergence of new technology trajectories, incumbent latecomers' choice of technology strategy are shaped by speed of trajectory change, accessibility of external knowledge, corporate governance and finance, and state policy. Specifically,

- The slower the speed of trajectory replacement, the more likely that ILCF has invested resources and time on the old trajectory and thus suffer from high sunk cost and switch cost. This tends to be the case for medium-low or low technology industries; alternatively, the faster the speed of trajectory shift in the industry, the greater the pressure for ILCF to decamp from the old trajectory and deploy defensive strategy, and we expect this to be applicable to industries with higher technology intensity and shorter product life cycle.
- Whilst in-house R&D may be the key sources of innovation when firms are catching up on the existing technology trajectory, accessing external knowledge to bridge over to a new trajectory is crucial for ILCFs. Meanwhile, comparing between the beginning of a new trajectory and the mature stage of an existing trajectory, we expect ICLFs to experience higher intellectual property barriers in

the former, primarily from foreign frontier firms (FFFs). ICLF may overcome such barriers through joint development, acquisition etc., with domestic and international organisations not in direct competition with them, such as universities, research institutes or industry suppliers.

- Chinese private-owned enterprises may have a strong position in terms of corporate governance because they generally have no agency problem: the top management own the firm and so there is no asymmetry of information or mis-alignment of incentives between management (agent) and owners (principal) (Tylecote and Visintin 2008). This should give them a longer time horizon and make them more willing to look ahead to the emergence of a new trajectory. In Chinese state-owned enterprises (SOEs), there is every opportunity for agency problems since the management are not the principal, nor is there a principal in direct contact with management (Cai and Tylecote, 2008). On the other hand, SOEs have much better access than POEs to external financial resources needed for defensive strategy (Xiao *et al*., 2013).
- There is evidence from Korea in particular that during the emergence of a new technology trajectory, firms are more likely to succeed, if the national government explicitly supports its firms to switch and change to the new trajectory (Kim, 1997). On the other hand there is a general consensus of economists (Grant, 1982; Wallsten, 2000; Hausmann and Rodrik, 2003; Shane, 2009) that governments are poorly equipped to 'pick winners'.

3. Research design and methods

Case studies have shown to be highly effective in addressing the 'how' and 'why' questions in strategic and innovation management research (Eisenhardt,1989; Yin, 2008). We adopted a design based on time-ordered matrix (Gerring, 2004), and followed historical events taking place within four firms in four sectors. They are: 1) Grace in man-made textile industry, with trajectory changing from viscose methods to advanced solvent methods; 2) Changhong in TV and display screen industry, with trajectory of display technology changing from CRT to LCD/LED and PDP (plasma). 3) Midea in home appliances industry, with trajectory of microwave technology changing from electro-magnetic to solid-state semiconductor technology; 4) Huawei in telecommunication industry, with trajectory of telecommunication changing from fixed-line and analog cellular, to cellular (mobile) telecommunication technology.

Formal empirical research took place between 2004 and 2016. We gathered multiple data sources, including 37 semi-structured interviews with each firm's CEOs and senior executives and employees. Each interview lasted between 1-3 hours, and questions covered the case firm's catch-up behaviour and strategy on the existing and new technology trajectories, considerations of strategic choices, and perceived influential factors for their success. We triangulated the data by interviewing senior executives from different functional departments (strategy, technical, legal, marketing and subsidiary), and by interviewing external experts in each case study firm's technology area. We also conducted three additional interviews with academic researchers on innovation in China and policy makers and regulators from Ministry of

Industry and Information Technology and local government officials. These interviews provided us with a significant understanding of how institutions interact with firms during emergence of trajectory change.

We also supplemented interviews with additional data. We collected these data through 3 main sources. 1) Official data, such as databases and websites of industry associations and international organisations, i.e. USPTO, SIPO and WIPO; key events, newsletters and annual reports from case study firms' websites; 2) site visits and observations. Between 2004 and 2016, two of the researchers made multiple visits to all of the four case study firms, observing the functional routines of the R&D, marketing and sales, and manufacturing departments; 3) other sources, such as business and chronology reports compiled by reputable international technology consultancies and open source platforms; research articles in the related technology areas, and news reports.

Our analyses were supported by Nvivo data analysis (Gibbs, 2002). Through interview coding, we categorised the technical and commercial challenges that the ILCFs had perceived during trajectory changes, how they scanned and processed information about new trajectories and weighed up different strategic options and how they went about them, how tensions between the firms and their stakeholders were addressed, and the impact this had on the strategic decisions. To reconstruct with as much accuracy as possible the processes that interviewees described, the interview content was triangulated with the other data sources. From documents that covered on average a 15-year period, we extracted factual information that described: the evolution of the new trajectories and their global commercial performances; leading FFFs' performance on the new trajectories before and during the observation periods; the business goals and strategies of the ILCFs; their technology activities and priorities; their financial, human and technology resources; and their interactions with the industrial and institutional environments. This information was used to create detailed time-ordered matrices, which enable condensing a large amount of data (Miles and Huberman, 1994).

Then, by iteratively condensing the content of the time-ordered matrices, we synthesized what was happening during the different stages of trajectory change and why certain decisions were made by each firm (intra-case analysis), and then identified similarities and differences across the four firms (inter-case analysis). Applying a 'constant comparative' method of analysis (Gibbert and Ruigrok, 2010), we actively searched for evidence that would contradict our emerging analytical insights (Ferlie *et al*., 2005). For instance, we asked leading experts in each technology field and key technical staff from each firm to answer our '*what if'* questions, i.e. What would have happened to the firm's strategic decisions and subsequent performance if certain emerging influential factors were different (i.e. timing of industrial policy, provision of training, linkages with other firms, etc). By doing so we managed to increase as much as possible the fit between our emerging observations and the empirical material. In the next section, the periods are used as empirical windows for zooming in on the subtle linkages between trajectory change, firm strategy and the corresponding institutions.

4. Case study

4.1. Grace: 'entrenchment' in the regenerated cellulose fibre (rayon) industry

4.1.1 Grace as the incumbent of Viscose fibre industry

Owned by the city government of Yibing, Sichuan province of China, Grace is a man-made textile producer incorporated in 1984. Grace's Viscose fibre process (R535A[B]) was initially imported alongside equipment from East Germany in 1950. In 2000, an in-house innovation of the viscose production process, patented in China as '2S process' boosted Grace's production capacity from 18,000 to 70,000 tonne per year, at a cost $650/tonne lower than Chinese national average (China was the world's cost leader in viscose fibre production). Thus, Grace became an incumbent latecomer (Xiao *et al*, 2013). As of 2016, Grace's sales revenue was US$ 2.5b, with over 50% from export. Its share was 33% and 25% of domestic and international markets respectively.

4.1.2 Grace's technology strategy choices during new trajectory emergence

The new trajectory, compared to the viscose method which relied on heavy use of alkalis and acids, is one that produces little or no chemical waste, and uses a patented solvent to break down natural cellulose fibres for spinning (Zhao, 2009). The firms which succeeded in developing and patenting the solvent are considered incumbent in the new trajectory. Emergence of this trajectory was symbolised by the invention of NMMO solvent (patent No. US3447939) in 1969 by Kodak. As of 1997, there were only two incumbent firms capable of mass-producing the new Lyocell fibre using NMMO solvent: Lenzing of Austria and Courtaulds of UK (acquired by Lenzing in 2002).

Meanwhile, in December 1997 Grace was actually granted a Chinese patent for a method very similar to the new solvent production method as the result of joint research with Sichuan University. According to industrial and patent experts this patent contains technology that could lead to 'inventing around' the NMMO patent blockade, and had good commercial potential. However, the solvent recovery rate as patented was 95%, and Grace was not able to profit from the method without a recovery rate of at least 99.5%. The senior management team at the time had to choose, between the new trajectory and the old. The former means increasing solvent recovery rate without Sichuan University's collaboration – the structures of control of universities don't provide them with an incentive to take an active part in the commercial development of technology. The latter means investing in the relatively cheaper and more certain process innovation on the old trajectory (2S). Grace as an under-financed local SOE could not afford to take high and expensive risks, and without policy support for government subsidies, it chose the latter. The following 15 years saw Grace continuing to defend its incumbent status on the viscose trajectory, receiving more than 700 Chinese invention patents. Its innovations on the viscose trajectory also significantly reduced the level of chemical waste pollution.

On the other hand, the market for NMMO trajectory started to consolidate during the same period of time. Since 2010, the NMMO method has been widely predicted to

be replacing Viscose methods as the mainstream production method in the industry. According to the industrial leader Lenzing's annual report, its Lyocell capacity has reached 150,000 tonne per year in 2012, overtaking its viscose capacity. In addition to Lenzing's international expansion of NMMO method production facility, other Chinese firms have also been developing NMMO capacity, using licensed technology from chemical firms such as BASF. Grace's senior managers felt that their predecessors had picked the wrong horse to back and the firm was entrenched in the old trajectory.

4.2. Changhong: 'retreat' in the flat screen display industry

4.2.1 Changhong as the incumbent of CRT TV

Changhong is a sub-national SOE consumer electronics manufacturer incorporated in 1958 in Mianyang city, Sichuang Province. Changhong imported from Panasonic a colour TV production line of 1,000 capacity in 1986, and started producing CRT (Cathode Ray Tube) TVs. Through in-house R&D, Changhong made continuous improvements and innovation on the CRT TV technology, becoming market leader in China in 1989 in terms of CRT TV and cost. Between 1989 and 1996, Changhong initiated a CRT TV price war in China, attempting to squeeze out international competitors. Its domestic market share shot up from 20.5% in 1996 to 25% in 1997 (Xie and Wu, 2003).

Meanwhile, since the early 1970s leading international TV producers had been exploring a number of new alternative display technologies which could offer higher performance with less bulk, including rear projection (a transitional technology), PDP (plasma), LCD (liquid crystal display). LCD established itself early for small and technically undemanding flat screen displays (pocket calculators, and later laptops) with low demand for power. In 1988, Sharp introduced the first commercial LCD television. But by that time plasma displays were far in advance of LCDs in performance, giving higher resolution in particular, and by the mid-1990s the plasma display was the only real offering in the high resolution space. Meanwhile LCD had the advantage of fast-growing sales at the lower end of the market which moved it along the experience curve.

4.2.2 Changhong's technology strategy choice and performance during trajectory emergence

It was in this period that the senior management of Changhong first began to examine alternative technologies seriously. Between May 1998 and August 1999, Changhong's board of directors met 12 times to discuss their strategy - and came to the conclusion that rear projection was most likely to be the next mainstream product. Changhong implemented imitative strategy, focusing on reverse engineering of optical system, processor and product design, and at the same time collaborating with a technology firm run by ethnic Chinese in Silicon Valley and Philips on resolution technology. Changhong soon mastered rear projection technology and its sales reached 200,000 sets by 2002, with domestic market share 20%. Between 2000 and 2004, Changhong's rear projection TV was regarded as a great success and main source of profit.

However, in 2004 PDP overtook rear projection worldwide. In 2005 LCD (including LED) reached rough parity with PDP in world market shares.

At this point Changhong decided that it needed to look beyond rear projection. It hired an American patent law firm to conduct patent intelligence search and consultancy. The search showed that a patent race was taking place amongst top firms such as Sharp, Hitachi, Canon, Samsung and Philips. As of 2004, the world's top 20 LCD display producers had received over 6,500 invention patents. On the other hand, although PDP display patents are also being registered by firms such as Panasonic, Fujitsu, NEC, LG and Samsung, the stock and growth rate of PDP patents were much lower. Technologically, although PDP display had a 'shadow image' problem and higher energy consumption, LCD technology also had a major problem in producing the larger-size screens. Changhong decided in 2006 that it was safer to choose PDP. It was precisely in this year that LCD prices started falling rapidly while their screen sizes were increasing rapidly. By late 2006, several vendors were offering 42" LCDs, attacking plasma head on. They were more expensive but offered higher resolution, at 1080 pixels, while plasma was stuck on 720 pixels. Changhong entered a joint venture with 5 other Chinese TV producers to set up a 6th generation LCD production line but it was cancelled due to disagreement on collaboration and investment terms.

Nonetheless Changhong kept faith in plasma. In April 2007, it launched a 3-term project to develop and produce PDP screens. The first term had a capacity of producing 600 million PDP modules, involved US$ 657m investment and was expected to be ready in July 2008. However, in 2008 Pioneer and Hitachi announced that they would seize production of PDP due to gloomy market projection.

In 2008, Changhong's suppliers of large CRT screens DNP and KURARAY in Japan had announced that they would stop production of CRT screens, which effectively ended Changhong's rear projection project.

In December 2012, Changhong acquired Korea's 3rd largest PDP producer Orion with US$ 100m, thus receiving the firm's 353 patents, including 12 PDP invention patents licensed to other PDP producers. This allowed Changhong to enter the world's PDP patent club and use cross-licensing. Once again the timing was not ideal. In 2013, Panasonic announced retreat from PDP, signaling failure of the trajectory. Changhong incurred huge financial loss: US$ 150 m and US$ 70 m in 2012 and 2013 (sales revenue US$ 280 m and US$ 300 m) respectively. Under pressure to cut losses, Changhong sold off its PDP subsidiary to a state-owned asset management company in Mianyang in 2014.

After failing to establish competitive position at two attempts, Changhong no longer has the financial resources, nor the credibility to leverage external resources to compete with international incumbents in the display technology. It could not even follow domestic strong players such as Hisense and TCL.

4.3 Midea: 'slow advance' in the solid-state microwave oven industry

4.3.1 The incumbent latecomer on magnetron microwave technology trajectory

Midea was incorporated in 1968 as a collective enterprise in Foshan city, Guangdong province. It was bought out by the CEO in 1984 and listed in the Shenzhen stock

exchange since 2001. It started producing microwave ovens in 1999. By that time microwave oven had been a home appliance for over 50 years and still used mature magnetron technology. Competition was cost-focused and China was replacing South Korea to be the world's microwave production base. Since 2002, Midea had implemented a business strategy for 'product differentiation with general cost leadership', striving to become incumbent in this sector. In terms of technology input, it hired over 60 microwave and food industry experts internationally, including LG's industrial design director, and conduct joint research with domestic universities, setting up 'Electro-Magnetic Wave Technology and Application Research Centre' with the University of Electronic Science and Technology of China. In terms of output, since 2003, Midea has introduced a number of functional innovations in microwave ovens, such as the patented 'sterilising function using multi-wavelength lights' technology. By 2013, Midea's annual microwave sales had reached 27 million, overtaking the market leader Galanz. In 2014, Midea received 215 WIPO patents for microwave technology (LG had 2583 and Galanz 75). In 2016, Thomson Reuters ranked Midea as Asia's No. 1 innovator in kitchen appliances[*], thus confirming Midea's incumbent status in magnetron microwave technology.

4.3.2 Midea's technology strategy and performance during emergence of solid-state semiconductor trajectory

At the time of Midea's ascent in magnetron, a new trajectory using semiconductor technology started to emerge in the US. Already widely used in telecommunication and industrial heating, it showed great potential to replacing magnetron technology. Compared to a magnetron microwave, a semi-conductor one uses low-voltage electric current; has evenly distributed heating mechanism and low microwave leakage; and is light-weight and portable. Meanwhile, due to its wide applications in other high-tech industries, the speed of technical advancement in semi-conductors has been fast - its heat conversion rate was quickly approaching the microwave oven industrial standard of ≥56% (Tang *et al* 2013).

The spread of semi-conductor technology to microwave ovens has been led by semi-conductor producers such as Freescale and NXP. They started to recommend the solution to major microwave oven producers in 2001, and in 2002, Panasonic started its own R&D in this technology, followed quickly by Samsung, Whirlpool, LG and Toshiba, then by Chinese firms such as Haier and Galanz. In July 2010, Freescale approached Midea, offering it technology details, samples and heater prototypes for joint development. While Freescale retained its original IP, each party would receive patents for new IPs based on level of input and contribution. Midea considered the risks of becoming dependent on Freescale's supply of technology and opted for defensive strategy - it started independent research activity to develop semiconductor microwave technology, employing doctoral researchers from Chinese universities to lead the project; it also used semi-conductor CPU suppliers from multiple sources. In April 2012, Midea became the first firm in the world to introduce a semi-conductor

[*]http://www.prnewswire.com/news-releases/thomson-reuters-2016-state-of-innovation-study-finds-double-digit-increases-in-global-innovation-300266626.html

microwave oven prototype with its own USPTO patents. However, this was as far as Midea got in terms of commercialisation. There were three main obstacles. Technically, the heat conversion rate of a core component, LDMOS, remained below the national standard for microwave ovens, preventing it to be marketed as kitchen microwave. Additionally, the cost of main component, the semi-conductor chips remained around 5 times of magnetron tubes, making the final product much more expensive and created uncertainty about market reaction. Finally, currently most major firms with semi-conductor microwave technology have all been holding fire for fearing of bearing the disadvantages of first mover. Midea's journey hence continues.

4.4 Huawei: 'triumphant arrival' in the mobile telecommunication industry

4.4.1 The incumbent on fixed-line telecom technology

Huawei Technologies Co., Ltd is a telecommunications company headquartered in Shenzhen, Guangdong. As of July 2015, it employs over 150,000 people; 45% of them are R&D staff in 16 research centres internationally. Huawei is officially owned by Huawei Holdings Ltd., shared between founder Ren Zhengfei (1.4%), other senior executives and 84,187 employees.

In 1992, through imitative strategy, Huawei reverse-engineered the C&C08 fixed-line telephone switch and achieved initial financial success in the domestic Chinese rural market. In 1993, through using innovative optic fibre through own research (more advanced than dominant design at the time, according to an independent industrial expert), Huawei developed its own branded switch with 10k portals, followed a series of improved models in the following 10 years. In 2012, Huawei overtook Ericsson to become No. 1 provider of internet access network and fibre optic network solutions. Its 2014 turnover was US$46.5bn. Its R&D intensity has been consistently higher than the international average of 10%.

4.4.2 Huawei's technology strategy and performance on the mobile telecom technology trajectory

While fixed-line telephone and internet network share similar technology principals, mobile telecommunication denotes significant differences. Cellular mobile telecommunication uses cellular wireless networks to connect between internet equipments and end devices to transport high volumes of data, including voice, texts and audio/video data. China announced its strategy to adopt GSM (Global System for Mobile Communications) standards for mobile phone communication in October 1994, and Huawei was one of the first Chinese firms to invest heavily to develop the initial GSM technology. By 1997, Huawei was offering complete GSM systems and Ethernet switchboard networks in China. By then its gap with incumbents on such technology had narrowed to 6 years. In 1998 when Huawei began to enter into the 2G (2^{nd} generation) mobile network, it realised that all major international markets have been occupied by major producers at the time, such as Nokia, Ericsson, Siemens. Huawei's CEO Ren Zhengfei decided to skip the 2G and focus on the 3G technology, 4 years *before* its commercial introduction. Reverse engineering here was clearly impossible, requiring defensive strategy.

Huawei's innovative activities have been focused on three areas. 1) Whole-system 3G+ business systems. Between 1998 and 2003, Huawei invested a total of $400 m and deployed 3,500 R&D staff on the 3G technology. It joined other world-leading producers to set 3G and 4G standards, contributing 25% (665) of 3GPP LTE core standard items, ranking world No. 1. Huawei started work on 5G in 2009, and planned to launch pilot commercial 5G network with its international collaborators. 2) Developing distributed base station. In order to break into highly competitive European 3G market, through deep negotiations with major mobile network operators, Huawei initiated an innovative 'distributed base stations'. Through separating Remote Radio Unit and Base Band Unit, Huawei's base stations have two components enabling flexible installation, easy site deployment, low power consumption and lower unit cost. 3) Diversification into handsets. Huawei had been manufacturing handsets since mid 2000s, and from 2011, it started to market its own branded handsets, deploying its own-developed 'Kirin' IC chips and dual-camera lens developed with Leica, by 2015 Huawei had become world's 3rd largest handset producers with a shipment of over 100 million.

As of end of 2016, Huawei has received 62,519 patents worldwide (39,613 from outside of China and 90% invention patents). It ranked also first for the second year with 3,898 applications to WIPO in 2015, followed by Qualcomm with 2442 applications.

5. Discussion

This section populates proposed models in section 2, comparing and contrasting the constructs and empirical findings in the 4 cases.

We can usefully distinguish the four firms by level of technology and thus rate of change. Changhong and Huawei both operate in ICT sectors with a high level of technology and R&D intensity among the global leaders. Fast change is normal. On the other hand, the TV sector had been slow-moving during the period in which Changhong became an incumbent: Changhong flourished in the 1990s using rather old technologies like CRT, acquired using an imitative strategy. It seems to have assumed that imitative strategy would continue to work, indefinitely, and tried far too late to switch to a defensive strategy, when the leaders had been pursuing the emerging technologies for decades. Huawei by contrast caught up while a disruptive new technology trajectory was manifestly getting under way: its organisational ethos developed at a time when change was clearly fast and going to remain that way. In terms of innovation opportunities on the new technology trajectory for ILCFs, from Huawei's fix-line and mobile telecommunication competences were to some extent transferrable and transferred. Huawei also hired up to 5,000 university IT graduates each year, since the late 1990s, to staff its research centres, internationally, in order to keep its knowledge stock up to date. But for Changhong, their accumulated knowledge and competences, easily adapted from basic CRT to rear projection, had little supportive impact when they tried to switch to one of the genuinely new trajectories. This is mainly due to a more significant shift in the scientific principles to firms with latecomer resources to bridge over with; and partly because Changhong

had been following imitative technology strategy, and did not really build up strong enough competences to conduct R&D in novel fields. It only began to carry out substantial R&D in 2004-5, when it was already hopelessly behind the field.

Grace and Midea are on the other hand in sectors with low to medium technology and generally moderate R&D intensity. Fast change is not normal; and indeed in rayon, a low technology sector, it did not happen. The crucial invention was made decades ago, and only gradually commercialised. We cannot say that Grace was accustomed to imitative technology strategy, like Changhong, because it very successfully carried on an offensive strategy with high R&D intensity with 2S. However, Grace made its 2S innovation within the old technological trajectory, as a response to crisis. It was not prepared - or those funding it were not prepared - to spend heavily in 'normal times' on catching up through defensive strategy with those advancing in the new technological trajectory. How useful its accumulated competences and knowledge might have been in such a strategy, it never found out. Midea is in a medium-technology sector in which it has carried on a moderate R&D intensity for a considerable time, in spite of the maturity of its established trajectory, and it was thus reasonably well prepared for the arrival of the new technology. Unlike the other three, it had a market reputation in the global market, which helped it to get Freescale as partner.

We must note that the two firms which clearly failed, Changhong and Grace, were and are sub-national SOEs, while the two which succeeded (Huawei) or have not yet failed (Midea), are privately owned. It does seem that the corporate governance disadvantages of state ownership outweigh the financial advantages -which are at any rate modest for sub-national firms. Moreover there is no evidence from our four cases that the state was wise enough to 'pick winners' and encourage and support firms in the right direction.

One clear implication of our studies is that one should not regard the experience of Taiwan and South Korea in taking advantage of a change in technological trajectory to leapfrog incumbents elsewhere, as easily repeatable. The technologies on which the new trajectory is to be built are likely to be much better known in advanced economies (in firms and in universities) than in developing economies. (Taiwan and Korea are small outward-facing economies with very close connections to the US). The 'incumbent latecomer' may well have the faults of the typical incumbent - attachment to the old trajectory - without its advantages: strong R&D and good connections to an advanced science base. And thus it is all too likely that a change of trajectory leads to the loss of incumbency of a latecomer, as it seems to have done with Grace and Changhong. It is too soon to say what the effect of the change of microwave trajectory will have on our incumbent latecomer, Midea - but it is clearly still vulnerable. That leaves Huawei, with its 'triumphant arrival' at the head of the new telecoms trajectory. But Huawei is by common consent the most successful firm in a country of 1.3 billion people. Let us not rest too much on its shoulders.

Table 4 Institutional impacts on each case study firm's technology strategy during trajectory emergence

Factor / Firm	Speed of trajectory shift	Accessabilityof external knowledge	Corporate governance and Finance	Role of state (policy)
Grace	Old and new trajectories co-existed for >2 decades, each serving mass and niche markets.	FFF set up patent blockade internationally, so the advanced solvent was not legally useable, but technology was known to Grace.	Local SOE, poor governance, under-financed, and later pressured to diversify	Central government took no interest in this industry and offered no support for innovation (low-tech.).
Changhong	CRT trajectory was quite suddenly superseded in TVs, but writing had been on the wall for decades.	Massive prior patents by Japanese and Korean firms; result as Grace.	As Grace, except that finance became more available later in the case period.	Central government showed little interest in this industry initially, moderate interest later.
Midea	Speed of shift and replacement predicted to be quick and comprehensive, but has proved subject to technical and cost bottleneck	Technology controlled not by own industrial incumbents but semi-conductor producers, who intend to monopolise the upstream supply chain; acquisition of semi-conductor firms may give access, but expensive for first-movers	POEs capable of fast decision making, responding to technical and market change; large size and diversification enabled better access to finance for R&D.	Central government not involved in semi-conductor microwave technology.
Huawei	Very fast change to mobile telecom dominance and succession of 'G' stages within it, but quite predictable. Somewhat slower in China initially.	Reverse engineering gave early access for catch-up but soon the only way to access advanced technology was 'inventing round'.	POE with CEO who is industrial expert - ideal for governance; large finance raised internally through selling shares to employees to support early R&D (otherwise difficult for POEs).	Central government ignored Huawei until it was successful internationally, then supported it as state champion. Huawei largely ignored government's attempt to develop own standard (TD-SCDMA).

6. Conclusion

Through cross-sectoral comparative study of 4 longitudinal cases, we developed and populated a framework to systematically understand incumbent latecomer firms' strategy during emergence of new technology trajectories. We thereby strengthen the theoretical rigor and relevance of both strands of literature.

Specifically, we confirmed that incumbent latecomer's strategy is particularly influenced by: 1) speed of technological and market shift; 2) access to external scientific knowledge and associated intellectual property barriers; 3) appropriateness of corporate governance and finance, and 4) the role of the state. We also found that early participation in standard-setting helps these firms lower the risk of entering into the new trajectory.

Empirically, the findings from our cross-sectoral and longitudinal study confirmed the robustness of our framework, and shows the framework to be applicable to analysing other emerging market economies with ambitions to compete internationally, in a variety of industries.

Acknowledgement

Thanks to the program "Research on the mechanism, influence and coping strategy of patent holdup from the LCF's perspective" funded by The National Social Science Fund of China (Grants No. 13BGL029) and the program "How does innovation open: based on organization control" funded by The National Natural Science Foundation of China (Granted No.71472023). Many thanks to the anonymous reviewers for their useful comments.

References

[1] Black, J., N. Hashimzade, Gareth Myles. Oxford dictionary of economics (4th ed.) . Oxford: Oxford University Press, 2012.
[2] Bower, J.L., C.M. Christensen. Disruptive technologies: Catching the wave. Harvard Business Review. 1995, January-February: 43-53.
[3] Cai, J., Tylecote, A.. Corporate governance and technological dynamism of Chinese firms in mobile telecommunications: a quantitative study. Research Policy, 2008, 37(10): 1790–1811.
[4] Christensen, C.M., J.L. Bower. Customer power, strategic investment, and the failure of leading firms. Strategic Management Journal, 1996, 17(3):197-218.
[5] Christensen, C.M., M. Overdorf. Meeting the challenge of disruptive change. Harvard Business Review, 2000, 78(2):66-76.
[6] Chu, W.W. Can Taiwan's second movers upgrade via branding. Research Policy, 2009, 38(6): 1054-1065.
[7] Cohen, W. M., D. A. Levinthal. Absorptive capacity: A new perspective on learning and innovation. Administrative Science Quarterly, 1990, 35(1): 128-152.
[8] Cooper, A.C., D. Schendel. Strategic responses to technological threats. Business Horizons, 1976, 19(1): 61-69.
[9] Dosi, G. Technological paradigm and technological trajectories. Research Policy. 1982(11): 147-162.

[10] Dosi, G. Sources, procedures, and microeconomic effects of innovation. Journal of Economic Literature, 1988, 26(3): 1120-1171.
[11] Day, G.S., P.J.H. Schoemaker. Avoiding the pitfalls of emerging technologies. California Management Review, 2000, 42(2):8-33.
[12] Eisenhardt, K.M. Building theories from case study research. Academy of Management Review , 1989,14(4): 532–550.
[13] Ferlie E, Fitzgerald L, Wood M, Hawkins C. The nonspread of innovations: the mediating role of professionals. Academy of management journal. 2005 Feb 1;48(1):117-34.
[14] Freeman, C. Soete, L. Development and the diffusion of technology. in Freeman, C. and Soete,L. (eds.), The economics of industrial innovation.London: Pinter Publishers, 1997.
[15] Gao, X.D. Technological capabilities catching up: following the normal way or deviate. MIT Sloan School of Management, 2003.
[16] Gao, X.D. Theory of indigenous technological innovation. Management of Innovation and Entrepreneurship. Beijing: Tsinghua University Press,2006,2:12-29.
[17] Gans, J. S., S. Stern. When does funding research by smaller firms bear fruit: evidence from the SBIR program, Economics of new Technology and Innovation, 2003, 12(4): 361-384.
[18] Gary, M.S. Implementation strategy and performance outcomes in related diversification. Strategic Management Journal, 2005, 26(7): 643–664.
[19] Gerring, J.. What is a case study and what is it good for. American Political Science Review, 2004,98(2):341-354.
[20] Gibbert M, Ruigrok W. The ‘‘what’’and ‘‘how’’of case study rigor: Three strategies based on published work. Organizational research methods. 2010, 13(4):710-37.
[21] Gibbs GR. Qualitative data analysis: Explorations with NVivo. Open University; 2002.
[22] Grant, R. M. Government cannot pick winners. Economic Affairs, 1982, 3(1): 29–32.
[23] Guan, J.C., R.C.M. Yam, E.P.Y. Tang, A.K.W. Lau. Innovation strategy and performance during economic transition: Evidence in Beijing, China. Research Policy, 2009,38(5): 802-812.
[24] Hausmann, R., D. Rodrik. Economic Development as Self-Discovery. Journal of Development Economics2003, 72 (2): 603-633: .
[25] Henderson, R.M., Kim B.C.. Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. Administrative Science Quarterly, 1990,35(1):9-30.
[26] Hill, C.W. L., F.T. Rothaermel. The performance of incumbent firms in the face of radical technological innovation. Academy of Management Review, 2003, 28(2): 257-274.
[27] Hillman, A.J., M.C. Withers, B.J. Collins. Resource dependence theory: A Review. Journal of Management, 2009, 35(6): 1403-1427.
[28] Hobday, M.. East Asian latecomer firms: Learning the technology of electronics.World Development, 1995,23(7):1171-1193.
[29] Kaplan S. Cognition, capabilities, and incentives: Assessing firm response to the fiber-optic revolution. Academy of Management Journal. 2008 Aug 1;51(4):672-95.
[30] Kim, L. The dynamics of Samsung's technological learning in semiconductors.

California Management Review. 1997, 39(3): 86-100.
[31] Kim, L. Building technological capability for industrialization: Analytical frameworks and Korea's experience. Industrial and Corporate Change.1999, 8(1): 111-136.
[32] Krug B, Hendrischke H. Framing China: Transformation and Institutional Change through Co-evolution. Management and Organization Review. 2008 Mar 1;4(1):81-108.
[33] Lee, K. Making a technological catch-up: Barriers and opportunities. Asian Journal of Technology Innovation, 2005, 13(2):97-131.
[34] Lee, K., J.H. Ki. Rise of latecomers and catch-up cycles in the world steel industry. Research Policy, 2017, 46(2):365-375.
[35] Lee, K., C. Lim. Technological regimes, catching-up and leapfrogging: findings from the Korean industries. Research Policy, 2001,30(3):459–483.
[36] Lerner, J. When Bureaucrats Meet Entrepreneurs: The Design Of Effective 'Public Venture Capital' Programmes, The Economic Journal, 2002,112: 73-84.
[37] Lieberman, M.B., D.B. Montgomery. First-mover advantages. Strategic Management Journal, 1988,9(1): 41-58.
[38] Leifer, R., C. M. McDermott, , G. C. O'Conner, L. S. Peters, M. Rice, R. W. Veryzer. 2000. Radical innovation; How mature companies can outsmart upstarts. Boston: Harvard Business School Press.
[39] Liu, J., Tylecote, A. Corporate governance and technological capability development: three case studies in the Chinese Auto industry. Industry and Innovation 2009,16 (4–5):525–544.
[40] Lv, A., L.N. Zhang. 1. Advancement of new solvent for cellulose fiber. Acta Polymerica Sinica,2007(10):937-944.
[41] Malerba, F., R. Nelson. Learning and catching up in different sectoral systems: Evidence from six industries. Industrial and Corporate Change, 2011, 20(6): 1645-1675.
[42] Mathews, John A. Competitive advantages of the latecomer firm: A resource-based account of industrial catch-up strategies. Asia Pacific Journal of Management, 2002(19): 467-488.
[43] Mathews, J.A. Catch-up strategies and the latecomer effect in industrial development. New Political Economy, 2006, 11(3):313-335.
[44] Miles MB, Huberman AM. Qualitative data analysis: An expanded sourcebook. sage; 1994 Jan 12.
[45] Mu, Q., K. Lee. Knowledge diffusion, market segmentation and technological catch-up: The case of the telecommunication industry in China.Research Policy,2005, 34(6):759-783.
[46] Nelson RR. Recent evolutionary theorizing about economic change. Journal of economic literature. 1995 Mar 1;33(1):48-90.
[47] Poon, J.P.H., A. MacPherson. Innovation strategies of Asian firms in the United States. Journal of Engineering and Technology Management, 2005, 22(4): 255–273.
[48] Rothaermel, F. T. Incumbent's advantage through exploiting complementary assets via interfirm cooperation. Strategic Management Journal, 2001, 22(6-7): 687-699.
[49] Shane, S. Why encouraging more people to become entrepreneurs is bad public policy. Small business economics, 2009, 33(2): 141-149.
[50] Song, M., C. Droge, S. Hanvanich, R. Calantone. Marketing and technology resource complementarity: An analysis of their interaction effect in two

environmental contexts. Strategic Management Journal, 2005, 26(3): 259–276.
[51] Tang, X.W., J.H. Ou, X. Wang, X.Y. Li, C.H. Liang. Research on the applications of semiconductor technology in superpower microwave heating. Vacuum Electronics, 2013(6):8-11.
[52] Tylecote A. The role of finance and corporate governance in national systems of innovation. Organization studies. 2007 Oct; 28(10):1461-81.
[53] Tylecote A., Visintin F. Corporate governance, finance and the technological advantage of nations. Routledge; 2008 Dec.
[54] Wallsten, S. J. The effects of government-industry R&D programs on private R&D: the case of small business innovation research programs. Rand Journal of Economics.2000, 31: 82-100.
[55] Wu B, Wan Z, Levinthal DA. Complementary assets as pipes and prisms: Innovation incentives and trajectory choices. Strategic Management Journal. 2014 Sep 1;35(9):1257-78.
[56] Wu, G.S., M. Lin. Discussion on Generalized trajectory theory. Technology Economics, 2012,31(2):1-5,35.
[57] Wu, X.B.,Q.R. Xu. A Competitive model of secondary innovation for later-comer's advantage analysis. Journal of Industrial Engineering and Engineering Management, 1995,9(1): 7-15.
[58] Xiao, Y.G., H.C. Zhang, W. Liu. Catching-up opportunity and strategy of latecomer in the context of different industrial technologies: Case from Grace. Beijing: Tsinghua University Press,2013,9: 75-89.
[59] Xiao, Y.G., A. Tylecote, J.J. Liu. Why not greater catch-up by Chinese firms? The impact of IPR, corporate governance and technology intensity on late-comer strategies. Research Policy, 2013,42:749-764.
[60] Xie, W., G. Wu. Differences between learning processes in small tigers and large dragons: Learning processes of two color TV (CTV) firms within China. Research Policy, 2003,32(8):1463-1479.
[61] Yin, R.K. Case Study Research: Design and methods(4th ed.) . London: Sage,2008.
[62] Zhao, Q.Z. Research on the industrialization of new Lyocell. China Textile Leader, 2009(10):72-74.