

**From learning to earning:  
the transition from manufacturing catch-up to  
competitiveness at the global business frontier, as  
pursued in China's energy equipment sector**

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## **Declaration**

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## **Summary**

### **From learning to earning: the transition from manufacturing catch-up to competitiveness at the global business frontier, as pursued in China's energy equipment sector**

RF Joe Studwell

Most studies of industrial policy in Japan, South Korea, Taiwan and China have been concerned with the state's role in framing industrial policy, and have taken a cross-sectional approach, limited in time. This thesis explores industrial policy longitudinally, as a dynamic, evolving relationship between the state and firms, one in which the positive contribution of the state tends to diminish as capabilities in the wider economy increase. It does so through an examination of the development of firms in China's electricity-generating equipment industry since 1978, based on more than 70 case study interviews. Three sub-sectors – thermal power equipment, wind turbines, and photovoltaics – are examined in order to track state industrial policy development and the evolution of firm-level capabilities and strategies over four decades. A multi-disciplinary theoretical foundation is constructed from development economics studies and economic and strategic management theory. The findings point to inevitable tension between the early-stage, centralising support for technological learning by a strong developmental state and the more fluid, dynamic and disruptive capabilities that define successful firms' strategies once basic manufacturing skills are acquired. While the developmental state's strengths are reflected in the steady, conservative nurturing of manufacturing capabilities, successful firm strategy increasingly requires dynamic capabilities reflected in systems integration, and strategic risk taking in the choice of activities in the business chain and technology sourcing, in turn favouring private ownership. The thesis findings recommend policies that explicitly recognise the need for transitions from state-led development to decentralised, entrepreneurial and market-led growth. It is concluded that strategic management research could contribute significantly to our understanding of economic development if researchers focused attention on political economy transitions in developmental-state-led economies.

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## Company names and abbreviations

### Case study firms

Formal firm name	Sector	Abbreviation
Shanghai Electric Group Co.	Thermal, Wind	Shanghai
Xinjiang Goldwind Science and Technology Co.	Wind	Goldwind
China Mingyang Wind Power Group	Wind	Mingyang
Envision Energy Co.	Wind	Envision
Suntech Power Holdings	PV	Suntech
Canadian Solar Inc.	PV	Canadian Solar
GCL-Poly Energy Holdings	PV	GCL

### Other firms

Formal firm name	Sector	Abbreviation
Harbin Electric Co.	Thermal, Wind	Harbin
Dongfang Electric Co.	Thermal, Wind	Dongfang
Sinovel Wind Group Co.	Wind	Sinovel
Guodian United Power Technology Co.	Wind	United Power
Trina Solar	Solar	Trina
Yingli Green Energy Holding Co.	Solar	Yingli
JinkoSolar Holding Co.	Solar	Jinko
JA Solar Holdings Co.	Solar	JA Solar
Longi Green Energy Technology Co.	Solar	Longi

## Other abbreviations

AMSC	American Superconductor Corp.
ATS	Automation Tooling Systems
BIPV	Built-In Photovoltaic
BBC	Brown, Boveri & Cie.
BNEF	Bloomberg New Energy Finance
BOT	Build Operate Transfer
CAS	Chinese Academy of Sciences
CDB	China Development Bank
CECA	China Energy Conservation Association
CFB	Circulating Fluidised Bed
CPC	Communist Party of China
CPIA	China Photovoltaics Industry Association
CREIA	China Renewable Energy Industry Association
CSRC	China Securities Regulatory Commission
CWEA	China Wind Energy Association
DDPM	Direct Drive Permanent Magnet
DG	Distributed Generation
DRI	Direct Reduced Iron
DTU	Technical University of Denmark
EGT	Endogenous Growth Theory
EPB	Economic Planning Board (South Korea)
EPC	Engineering, Procurement and Construction
ERI	Energy Research Institute
ERSO	Electronics Research and Service Organisation
EC	European Commission
EU	European Union
FBR	Fluidised Bed Reactor
FDC	Fast Developing Country
FDI	Foreign Direct Investment

FIT	Feed-In Tariff
FMMB	First Ministry of Machine Building
GCLNE	GCL New Energy
GCLSIT	GCL System Integration Technology
GE	General Electric
GRINM	General Research Institute for Non-Ferrous Metals
GSF	Global Solar Fund
HGPP	Hot Gas Path Parts
ICBC	Industrial and Commercial Bank of China
IDB	Industrial Development Board (Taiwan)
IEA	International Energy Agency
IPO	Initial Public Offering
IPP	Independent Power Producer
IPR	Intellectual Property Rights
ISI	Import Substitution Industrialisation
ITRI	Industrial Technology Research Institute
LGT	Large Gas Turbine
MEP	Ministry of Electric Power
MHI	Mitsubishi Heavy Industries
MITI	Ministry of International Trade and Investment (Japan)
MMB	Ministry of Machine Building
NCCCS	National Centre for Climate Change Strategy
NDRC	National Development and Reform Commission
NEC	National Energy Commission
NIS	National Innovation Systems
NSC	National Science Council
NYSE	New York Stock Exchange
O&M	Operations and Maintenance
ODM	Original Design Manufacture
OECD	Organisation for Economic Cooperation and Development
OEM	Original Equipment Manufacture
PECVD	Plasma Enhanced Chemical Vapour Deposition

PLA	People's Liberation Army
PPA	Power Purchase Agreement
R&D	Research and Development
REC	Renewable Energy Corp.
REL	Renewable Energy Law
S&T	Science and Technology
SAIC	Shanghai Automotive Industry Corp.
SAMI	State Administration of Machinery Industry
SCD	Super-Compact Drive
SDPC	State Development and Planning Commission
SETC	State Economic and Trade Commission
SQE	Supply Quality Engineer
TCE	Transaction Cost Economics
TCS	Trichlorosilane
UHV	Ultra-High Voltage
UNSW	University of New South Wales
USC	Ultra Super-Critical
XWEC	Xinjiang Wind Energy Co.

## Introduction

It could be argued that no industrial sector has been more central to the Chinese government's ambitions for economic development than power generation. One year after Deng Xiaoping established leadership over China's 'reform and opening' strategy at the Third Plenum of the 11<sup>th</sup> Central Committee of the Communist Party of China (CPC) in December 1978, China's State Council approved the allocation of US\$250m of scarce foreign exchange for licences and training required for the importation of technology for the manufacture of 300 and 600 megawatt steam turbines and boilers for coal-fired power stations.<sup>1</sup> Contracts with the American firms Westinghouse and Combustion Engineering were signed in September and November 1980, and formally approved by the Chinese and US governments in early 1981.<sup>2</sup>

The technology transfer process did not begin well. In the early 1980s, Westinghouse hosted more than 500 Chinese engineers for technical training courses in Florida. It was planned that the technicians would return to China and train other technicians. When Westinghouse supervisors re-located to China to oversee turbine construction at three newly-built factories in Shanghai, Wuhan and Harbin, however, they discovered that the content of their training modules had not been imparted to other workers. Westinghouse managers began to have

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<sup>1</sup> In response to the January 1979 'Report on Speeding Up the Development of the [Power] Machinery Industry By Learning From Foreign Experience' (关于借鉴国外经验, 加快机械工业发展的报告), submitted to the State Council. The report was the result of two 1978 inspection missions, to Europe and Japan.

<sup>2</sup> Source: Shi Yan (史言), 'Development of large-scale, complete power equipment sets' (大型火电成套设备研制), *Equipment Manufacturing* magazine (装备制造), 15 August 2013.



doubts that China would absorb the technology its Ministry of Machine Building Industry had contracted to receive.<sup>3</sup>

Progress in technical absorption in the early 1980s was painfully slow. Yet with the benefit of 35 years' hindsight, China not only absorbed the original steam turbine technology, but also went on to digest that for subsequent 'super-critical' and 'ultra-supercritical' generations of turbine design. Through a combination of licensing arrangements and joint ventures with multinational technology providers, and steady improvement in product quality under supply contracts to domestic power generation facilities, Chinese state companies mastered increasingly complex technologies and eventually progressed to export markets.

In recent years, there has been evidence of Chinese firms developing technological capacity independent of multinational providers, with companies controlling their own global networks of research and development, design and production facilities. In the renewable energy sector, the largest crowd at the China Wind Power trade show in Beijing in October 2014 was drawn by Envision, a private equity-backed wind turbine firm started by a Chinese former energy analyst for Total, and investment banker. Envision operates 'lean' wind turbine production facilities in China run by a combination of former managers from GE Wind with operations specialists from multinational automotive firms, recruited to bring new process skills to wind turbine manufacturing. Envision has turbine design and testing facilities located in Denmark, a

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<sup>3</sup> Th1, 9 June 2014.

blade development centre in Boulder, Colorado, software development centres in California in the United States and an energy management services division based in Houston, Texas. At the Beijing show, the firm launched Greenwich, a software application for design and optimisation of wind and solar farms that marries Chinese state supercomputing capacity in Jinan and Guangzhou with a low-cost software platform based on Google Maps and Amazon cloud hosting services. In seven years, Envision became a renewable energy systems integrator that ranked as the third biggest wind turbine supplier in China in 2015, and the eighth biggest in the world.<sup>4</sup>

This thesis explores China's transition from being a learning laggard to a global challenger – though not yet a global leader – in the power equipment sector. The thesis considers, on the one hand, the extent to which the transition should be understood in terms of top-down management by a successful developmental state and, on the other, it examines the extent to which China's entrepreneurs should be given credit for the bottom-up development of capabilities. In view of doubts about the global competitiveness of Chinese firms (Nolan 2002, 2014, Nolan and Zhang, 2002, Nolan et al., 2008, Abrami et al., 2014)<sup>5</sup>, the thesis also contextualises China's four-decade experience of trying to

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<sup>4</sup> Bloomberg New Energy Finance (BNEF) and FTI Consulting data for 2015, accessed 4 July 2016 at <http://nawindpower.com/top-10-wind-turbine-makers-for-2015-the-year-of-china>

<sup>5</sup> Nolan's long-running doubts about the competitiveness of large-scale Chinese industry are repeated in Nolan (2014:xvii): 'China is unique among large latecomer developing countries in... lacking a substantial group of globally competitive firms.' However, China has no obvious comparators in terms of 'large latecomer developing countries'. Only South Korea and Taiwan, both much smaller economies, are in any way comparable in terms of the structure and pace of their economic development. Of these two, South Korea is defined by branded multinational businesses, Taiwan is not. Moreover, South Korean corporates like Hyundai and Samsung were only recognized as globally competitive players in the 1990s, after more than three decades of development and at a level of GNI-per-capita, controlled for inflation, that China is only now approaching.

create globally competitive firms in terms of the historic industrialisation performance of Asian peers Japan, South Korea and Taiwan.

The three central research questions of this thesis are: 1. *What have been the common success strategies of firms transitioning from learning laggards to being globally competitive?* 2. *What have been the most successful developmental state policies that have facilitated this transition?* 3. *How have the most successful firm strategies and most successful developmental state policies evolved over time?* The central research questions are deliberately broad because the research construct is inductive, with no *a priori* assumptions (Zott and Huy, 2007, Hargadon and Sutton, 1997).

This thesis seeks to shift the debate about the developmental state away from its traditional focus on cross-sectional analysis of different countries (for instance: Wade, 1990, Evans, 1995, Amsden, 1989) towards a longitudinal focus on how the relationship between the state, the entrepreneurial firm, and decentralised arm's length markets evolved, or might optimally evolve, under the sort of successful industrial policy associated with the 'north-east Asian' economies of Japan, South Korea, Taiwan and China. I call such economies Fast Developing Countries (FDCs); they are characterised by average GDP growth of 8-10 percent per annum over more than 25 years (Spence, 2008, Studwell, 2013). Rather than add to a voluminous literature on east Asia that demonstrates that industrial policy contributes to accelerated economic transformation and accumulation (Amsden 1989, 2001, Chang, 1994, Johnson, 1982, Lall, 1996, Naughton, 1995, 2007,

Woo, 1991), this thesis seeks to tease out more detail about how industrial policy contributes, what its limitations are, and what are the evolving, longitudinal contributions of private sector entrepreneurs and markets that the developmental state must cede economic space to.

Empirically, the thesis deals with the power equipment manufacturing industry in China since 1978. Making cheap electricity is fundamental to accelerated economic development, because accelerated development involves heavy dependence on manufacturing (Kaldor, 1966, 1967, 1968, Studwell, 2013). China's attention to the power generation sector has been acute. This thesis looks at China's original, post-1978 programme to master technology for coal-fired thermal power generating equipment, the same fundamental technology that has been pursued by emerging countries and their leading engineering firms for more than one hundred years. The thesis then moves on to consider the acquisition of capabilities in two newer, renewable power generating technologies: wind turbines and crystalline photovoltaics.

The logic of this three sub-sector comparison is to allow for three different perspectives on the evolving state-firm relationship over time, and to track 'resets' as the developmental state and its firms tackle new technological challenges with constantly rising capabilities. In this thesis I use the term resets to refer to the launch of a new product category within the broad industrial sector that manufactures equipment used to generate electricity. Resets occur both within existing firms as they evolve longitudinally, and in new firms that are formed in the context of rising, economy-wide capabilities that encourage entrepreneurs to

launch start-ups. In technological terms, there are three resets that are considered: when the original 'big three' state-owned power equipment firms set out to make large gas turbines (LGTs) (a within-firm reset); when old state-owned firms, new state-owned firms, new hybrid state-private firms, and new private firms set out to make wind turbines (a within-firm and new-firm reset); and when mostly private firms set out to make solar photovoltaic power generating equipment (a within-firm and new-firm reset overwhelmingly skewed to new firms).

It is important to note that in developmental states resets may be heavily influenced by, or even determined by, government industrial policy, which aims to set priorities for technological catch-up at the firm level (Amsden, 1989, Johnson, 1982, Wade, 1990). This is particularly so in the early stages of catch-up because, at the outset, the developmental state has, almost by definition, greater capabilities in the planning, execution and coordination of technology acquisition than firms, which are characterised by low capabilities (Chang, 1994). The three sub-industry structure of the thesis attempts to capture the dynamic nature of the economic catch-up (Abramovitz, 1986, Gerschenkron, 1962) experience, at both government and firm levels, over four decades.

In the case of China, a thesis structure that also highlights intra-firm, technology-based resets in terms of state-firm relations is necessary because as Kroeber (2016) notes, China since 1978 engaged in not one but *two* reform processes. The first was the introduction of developmental state policies based around international trade and flows of technology similar to those familiar from Japan, South Korea and

Taiwan (Studwell, 2013). The second reform process, not seen in the other economies, was a transition away from a centrally-planned, non-market economy in which almost all activity, as of 1978, was undertaken by state work units not subject to price signals. The manner in which this wrenching second transition occurred can only be fully accounted for by investigating businesses that began operations at different points during the transition process, reflecting changing government industrial management- and firm-ownership regimes that obtained in different periods.

It is also helpful in answering the research questions of this thesis that the longitudinal structure allows us to compare the performance of state-owned firms with hybrid state-private firms and private firms, as they were successively permitted to participate in different power equipment businesses. In addition, the structure allows us to compare the thermal power equipment and wind turbine industries which were given full state industrial policy support from an early stage, and the photovoltaics sector where firms were left for many years to operate without an industrial policy commitment to a subsidised domestic market. These multiple perspectives are essential to the conclusions set out in Chapter 6.<sup>6</sup>

When we look chronologically at the resets examined in this thesis, we see the state-firm relationship in thermal power equipment as it was originally configured in 1978; the manner in which it evolved in the 1980s and 1990s as state control over state firms gradually loosened;

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<sup>6</sup> To be clear, a transition from more central control to less, or more planning to less, is a stylised fact of all Asian FDCs: Japan, South Korea, Taiwan, China. China is the most extreme case.

how the relationship was reset when the wind and photovoltaics businesses scaled up in the late 1990s and early 2000s, and private firms were allowed into the sectors to compete on a more or less equal footing with state firms; and what happened when state industrial policy focused the big three state-owned thermal firms on LGTs, initially in 2003, but more aggressively beginning with China's 12<sup>th</sup> Five Year Plan (2011-15).

As noted, throughout this longitudinal evolution, government industrial policymakers adjusted their strategies for technology acquisition and were confronted with new policy choices. At the firm level, managers and entrepreneurs addressed a rapidly evolving competitive landscape, one that made possible previously impossible entry strategies. Within firms, adaptability to technological resets was critical to commercial success. In this respect, an important contribution of this thesis is to highlight the changing role of firm strategy in catch-up. In the electricity-generating equipment industry, thermal firms set out in the 1980s to acquire basic manufacturing capabilities and a gradual, step-by-step approach to this process led to success. However, in both the thermal sub-sector and subsequent renewables sub-sectors, manufacturing capabilities alone did not provide a route to global competitiveness. Firm strategy in terms of different activities in a given business chain and technology sourcing became the keys to better margins and hence superior competitive performance. These were capabilities generated within firms, not capabilities that the developmental state could plan and direct.

In addressing the evolution of the state-firm relationship, this thesis concentrates considerable attention on questions of vertical scope of firm activity and on firms' unfolding value chain strategies. The approach reflects a substantial theoretical literature in economics and strategic management studies, set out in Chapter 1, that points to a tension between vertical integration as a means to acquiring capabilities at the firm level, and vertical disintegration as a route to greater profitability, most directly via reduced capital intensity. While the theoretical literature is substantial, it has not usually been applied to case studies of accelerated firm-level development under state industrial policy. In the development economics and economic history literature, examinations of the role of vertical integration as a tool of learning, and subsequent vertical disintegration, are to be found mostly in empirical studies (for instance: Thun, 2006, Cusumano, 1985, Gregory, 1985, Chandler, 1988 (1959), 1990 (1962), 1977). This thesis therefore seeks to connect theoretical insights from economics and strategic management scholarship focused primarily on developed countries with the experiences of firms in developing countries under developmental state leadership.

Chapter 1 sets out the theoretical and empirical context in which the thesis is written. It brings together different strands of literature in economic and strategic management theory, development economics studies, and economic and business history. The chapter also sets out the 'north-east Asian' developmental context into which China fits. A critical aim of Chapter 1 is to establish that there is a theoretical gap in the extant literature that justifies the theory building undertaken in this



thesis (Eisenhardt and Graebner, 2007). Chapter 2 presents the methodology and research design, as well as a brief discussion of the interplay of national and local governance in China that poses a particular challenge to a research construct concerned, in part, with 'government' industrial policy. Chapter 3 examines the development of the thermal power equipment sector after 1978 and the efforts of incumbent state-owned firms to react to the rise of renewables from the late 1990s. A discussion at the end of Chapter 3 reflects on the apparent successes and limitations of the original state firm development model. Chapter 4 considers the wind turbine business, where the central government decided in the early 2000s to use supply- and demand-side industrial policy to back the development of an industry in which firms of all domestic ownership types were encouraged to participate. Chapter 5 examines the solar photovoltaics sector, where the central government determined not to provide demand-side industrial policy support in the early 2000s. Emergent firms relied instead on limited, supply-side science and technology (S&T) policy support and on local government support, until a period of crisis in the industry saw the central government step in to create a subsidised domestic market similar to that in the wind sector. Chapter 6 presents integrated findings, discussion and scope for further research.

## **Chapter 1**

### **Theoretical and empirical context**

#### **1.1. Motivation**

Broadly, China has followed the industrialisation trajectory pioneered in east Asia by Japan, South Korea, and Taiwan (Studwell, 2013). The classic texts of accelerated industrial development in those economies were written in the 1980s and described industrialisation overwhelmingly from the perspective of government policy. According to the key country studies, it was the provision of support, subsidy and protection to nurture the development of ‘infant industries’ that defined the most rapid industrialisation processes the world had yet seen.

Amsden (1989) was the most strident in designating government planning as the decisive force in successful industrialisation, in a study of South Korea’s development. In her analysis, the state’s dominant role meant that: ‘the protagonist of industrialization is not so much the entrepreneur today as the salaried engineer’ (1989:9). According to Amsden’s paradigm, the state planned, and the engineer rather than the entrepreneur delivered on a plan that was driven by the state’s application of an extensive range of direct and indirect subsidies: ‘The allocation of subsidies has rendered the government not merely a banker, as Gerschenkron (1962) conceived it, but an entrepreneur, using the subsidy to decide what, when and how much to produce’ (1989:144).<sup>7</sup>

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<sup>7</sup> Amsden (1989) did not consider how the relationship between the state and the entrepreneur was adjusting, and would in future adjust, as the state began to reduce its involvement in industrial policy-making, even though this started to happen under the presidency of Chun Doo Hwan from 1980, in

Johnson (1982), author of the earliest of the seminal single-country studies, about Japan, identified a more mutually inter-dependent relationship between state and firm. He placed Japan's post-Second World War planning agency, the Ministry of International Trade and Investment (MITI), at the centre of industrial development, describing the defining characteristic of accelerated development as its 'plan-rational' nature (1982:chapter 1). The plan, however, had to complement rather than replace the contribution of the entrepreneur: 'the fundamental political problem of the state-guided high-growth system,' wrote Johnson, 'is that of the relationship between the state and privately owned business... If this relationship is overbalanced in favour of one side or the other, it will result in either the loss of the benefits of competition or the dilution of the state's priorities.' (1982:195).

Nonetheless, despite Johnson's assertion of this central tension, he included almost no firm-level examination of the state-firm relationship in his study. Equally, while Johnson recognised the emergence of key Japanese firms *outside* MITI's plans -- including Sony, Matsushita and Honda -- he did not provide an explanation as to why such successful firms should turn out to be 'unplanned'.<sup>8</sup>

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the period when she was conducting her research. Amsden's later work on the relationship between state and entrepreneur is discussed below.

<sup>8</sup> In a similar vein Johnson (1982:chapter 3) notes that it was the sale of publicly-owned 'pilot' factories to private entrepreneurs in Meiji Japan in the 1880s that coincided with the development of the first really successful Japanese firms. But there is no detailed analysis of what entrepreneurs were able to do that the state had not delivered.

Wade (1990), in dealing with the development of Taiwan, was largely consistent with Johnson. His 'governed markets' theory centred on three elements of effective state infant industry policy: very high investment to accelerate transfer of technology; more investment in certain industries than would occur otherwise; and exposure of many industries to international competition (1990:26pp). Firms and entrepreneurs were acknowledged, but existed in the background of Wade's state policy-driven development analysis. There was little direct consideration given to a firm-level or entrepreneurial perspective.

The emphasis on the contribution of state industrial policy in these country studies provided an important riposte to neo-liberal claims in the 1970s and 1980s about the redundancy or counter-productiveness of infant industry policies (Krueger, 1974, Lal, 2000 (1983)). The approach was consistent with other pro-industrial policy, multi-country studies of the period, such as Evans (Evans et al., 1985). However the adoration of state capacity displaced valid questions about the limits and durability of state industrial policies (as highlighted, for instance, by Little, 1982, 1993, Little et al., 1970).

The limits of *dirigiste* industrial policy became apparent, I suggest, in the 1990s when Japanese, and to a lesser extent Taiwanese, growth collapsed, and South Korea became embroiled in the Asian Financial Crisis, necessitating a request for International Monetary Fund (IMF) assistance. If the classic texts of the 1980s shed light on the potential for state policy to guide rapid economic accumulation, actual experience in

the 1990s pointed to a more complex, dynamic development experience than those texts allowed for.

The north-east Asian country studies of the 1980s had three major weaknesses. First, state industrial policy was treated in monolithic terms. Its costs and benefits were not analysed relative to the evolving capabilities of the firms, or the aggregate economies, which state policy sought to build up. Infant industry programmes were presented somewhat simplistically as necessary and positive, rather than as time-specific responses to transitory problems. Second, and equally and oppositely, the contribution of the entrepreneur was treated monolithically, rather than as something that co-evolved and changed as infant industry policies impacted firms and economies. And third, the phenomenon of successful 'off-plan' firms highlighted by Johnson in Japan was not explored, even though it pointed to a more nuanced relationship between state industrial policy and entrepreneurial success than, in particular, Amsden's (1989) blunt early dismissal of the entrepreneurial role allowed. The seminal country studies from east Asia did not offer dynamic explanations, and left large empirical and theoretical holes in our understanding of latecomer industrialisation. The holes were longitudinal in nature – to do with how industrial policies need to be adjusted and scaled up and down over time, how the relationship between the state and the entrepreneur evolves, and what the entrepreneur delivers, and why, at different points in this process.

The one major study of the era to focus explicitly on firm-level learning in South Korea and Taiwan, as well as Hong Kong and Singapore, was

Hobday (1995). This study provided a thorough taxonomy of firm-level learning channels: foreign direct investment (FDI), joint ventures, licensing, original equipment manufacture (OEM), original design manufacture (ODM), other sub-contracting, learning through buyers, learning through hiring of foreign specialists and returnees, overseas acquisitions, and strategic partnerships. However, the study was limited to the electronics industry up to the early 1990s. It concentrated on learning in terms of products and production processes. There was some discussion of the learning of marketing and organisational skills, such as the transition from OEM to ODM. But the research period was too early to take in systems integration and servitisation capabilities that are important competitive dimensions in this thesis. After four decades of development in China, the capabilities of the best firms analysed in this thesis are greater and more complex than those of firms considered by Hobday in South Korea and Taiwan after three decades of catch-up learning.

In the early 2000s, Amsden and Chu (2003) completed a longitudinal study of Taiwan, which also focused on the electronics sector. They argued that developmental success in the late 1980s and 1990s in Taiwan was characterised by a new type of 'second mover' firm that combined three things: scale, technological and management capabilities, and distribution capacity. The observations that state firm leadership in Taiwan gave way in some cases to private firm leadership, that 'big man' entrepreneurs played important roles<sup>9</sup>, that returnee

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<sup>9</sup> 'Behind almost every big electronics company in Taiwan was a "big man" – the owner-entrepreneur who could make decisions quickly with respect to ramping up... With a big man at the top and salaried

technical specialists became important, and that government R&D support of enterprises became ever more critical, all pointed to a dynamic state-firm relationship. However there was no theorisation of the overall process and no clear connection made to Amsden's earlier (1989) theoretical assertions with respect to South Korean development. Moreover, the Taiwan electronics sector's technology acquisition model was anomalous in north-east Asia in that it depended heavily on capability building conducted within state research agencies and then gifted to existing private firms or spun out to new private start-ups.<sup>10</sup>

It was China scholarship of the 2000s and 2010s that produced a much richer literature of longitudinal studies, including the sectors of automotive (Anderson, 2012, Thun, 2006), electronics (Fu, 2015b, Jakobson, 2007), computing (Lu, 2000, Fuller, 2016), telecommunications (Harwit, 2008) and renewable energy (Fu and Zhang, 2011, Lewis, 2012). These studies began to provide greater empirical depth in their treatment of the unfolding challenges facing both developmental state policymakers and firm-level strategists. Several China studies referred explicitly to multiple 'stages' of innovation capability building against a background of changing economy-wide capabilities (Fu, 2015b, Rein, 2014, Yip and McKern, 2016).

In an important early study of the automotive sector, Thun (2006) showed how much the requirement for state policy intervention to

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managers in the middle and bottom, leading enterprises became hierarchically managed but fast to respond' (2003:41).

<sup>10</sup> The main agencies involved were the Industrial Technology Research Institute (ITRI), ITRI's subsidiary the Electronics Research and Service Organisation (ERSO), and the National Science Council (NSC).

support firm-level development changed over time. He described how, initially, *laissez-faire* approaches to building firm-level capabilities in Beijing and Guangzhou failed on the one hand, while directly nationally-controlled carmakers under fragmented bureaucratic control, in Wuhan and Changchun, came up short on the other.<sup>11</sup> It was a local developmental state (Oi, 1995) in Shanghai that delivered effective coordination in the auto sector, co-financing and organising production networks for components, and thereby creating the first genuinely capable car firm, Shanghai Automotive Industry Corporation (SAIC).<sup>12</sup>

Thun highlighted, however, that the Shanghai developmental state-SAIC relationship needed to change if the latter was to move towards global competitiveness, brand development and export capacity (2006:chapter 8). At its simplest, he identified a two-stage challenge under which the component production structure that made SAIC the market-leading assembler needed to become more entrepreneurially managed, more flexible and more disintegrated in order to nurture technical and design skills, reduce costs, and raise profits (Figure 1, below). The challenge that confronted developmental-state policy therefore changed, from coordination of component production to enhancement of efficiency and profitability.

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<sup>11</sup> 'There was nothing virtuous about the development process for firms in localities with *laissez-faire* local states. The fragmented local bureaucracies were unable to concentrate resources in key firms, and thus did little to ameliorate the collective action problem within the network of local suppliers... local supply firms quickly withered on the vine... The outcome was not much better for the firm-dominated localities of Changchun and Wuhan during this early stage. Although the fragmentation had a different source in these cases – the split between centrally controlled business groups and the locality – the result was the same. Domestic [component] firms at the local level did not have the financial resources that development required' (2006:32).

<sup>12</sup> In the 1990s, SAIC controlled over 50 percent of the Chinese market for sedans (Thun, 2006:32).



**Figure 1. Stages of Development in the Chinese Auto Sector**

**Stage 1: Development as a coordination problem**

Need for coordinated development of a supply network creates high level of capital intensity for sector as a whole.

The small number of potential customers (due to low levels of development and local protectionism) leads to high levels of asset specificity for many key supply firms.

Urgent need to master manufacturing and project execution skills makes learning and feedback critical, particularly in forms conducive to the dissemination of tacit knowledge.

**Stage 2: The race for competitiveness**

Broader range of pre-existing customers and suppliers leads to decreasing need for investment coordination for the sector as a whole.

An urgent need for cutting costs is created by rapidly increasing levels of competition. Effective governance of firms becomes critical.

For firms that aspire to belong to the upper tiers of the supply chain and compete with global suppliers, the development of technical and design skills is of paramount importance and the key to future competitiveness.

Source: Thun (2006:39)

Thun recognised that change was difficult and that path dependency was the easiest course of action, posing a threat to the continued success of the developmental state-firm relationship: 'The very success of a development effort will result in an economic environment that is different from the one in which the initial policy was formulated. The question is not whether change will occur, but whether states will have adequate capacity to respond' (2006:38). Thun suspected that, given institutional path dependency, the Shanghai government and SAIC would find it difficult to cut costs as fast as subsequent market entrants, destroying SAIC's early monopolistic pricing power. He was correct. In the 2000s, off-plan private firms in China, typified by Geely, Chery and Great Wall, accessed supply networks created by groups like SAIC,

established lower cost structures, more resourceful approaches to marketing, and began to take market share, principally in the lowest-cost sedan segments (Anderson, 2012).

Subsequent longitudinal sectoral studies across the automotive, motorcycle and construction machinery sectors in China highlighted a tendency for early-stage state industrial policy to become counter-productive as sectors and firms approached the technological frontier (Brandt and Thun 2010, 2016). Policy flexibility was a pre-requisite for continued competitive progress. In a study of China's telecommunications equipment sector, Harwit similarly found that it was relatively greater government industrial policy flexibility compared with other sectors that accounted for the rise of a larger number of globally competitive firms (Harwit, 2008).

Longitudinal firm and sectoral studies in China also questioned whether the heavy presence of state-owned enterprises in the country's industrial planning was crowding out private sector entrepreneurs and making relatively less efficient use of investment capital than the private sector (Huang, 2008, Steinfeld, 1998, Fuller, 2016). Fuller (2016), in an investigation of China's IT sector, including software and semiconductors, concluded that in recent years state sector firms failed to deliver technological progress. The finding was borne out by quantitative studies showing that China's state enterprises are characterised by both lower levels of profitability and less efficient R&D activity than private firms (Johansson and Feng, 2016, Xia and Walker, 2015, Zhou et al., 2017, Zhang et al., 2003).

The suggestion that state ownership of firms was a growing impediment to technological and competitive progress echoed earlier concerns in Taiwan, which for common historical reasons (Kirby, 1990) also had a large public sector. While long-term state ownership was associated with positive outcomes in Taiwan's semiconductor foundry operations (Tsai and Cheng, 2006), it was less successful elsewhere. After Taiwan began its heavy industrialisation drive in 1969, referred to locally as its 'second stage' development programme, state firms dominated three of four target sectors, with lacklustre results (Gold, 1986, Fei et al., 1999, Li, 1988).<sup>13</sup> At the same time, private sector Taiwanese firms were often denied the scale and scope of industrial policy support afforded to peers to in South Korea, with negative implications for them, as a comparison of firms like Acer and Samsung Electronics highlights (Chang, 2008, Tsai and Cheng, 2006).

A second group of longitudinal studies with potentially significant implications for China was ones that reviewed industrial policy outcomes in north-east Asia's most mature developmental-state economy. Japan's post-1989 economic crisis gave rise to a number of studies that were important in highlighting that manufacturing capabilities *alone*, on which developmental-state literature concentrated, had not been sufficient to deliver true global competitiveness to emergent firms. Manufacturing capability was a necessary, but not a sufficient, requirement for international competitiveness.

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<sup>13</sup> Petrochemicals, machinery, shipbuilding, iron and steel.

Case studies conducted in the post-crash Japanese economy highlighted that while Japanese industrial policy had been highly effective in upgrading the variety and quality of manufacturing products, Japanese firms often failed to achieve profit margins on par with US and European multinationals (Emmott, 1989, Wood, 1992, Pempel, 1998, Motonishi and Yoshikawa, 1999, Pafomansu, 1997). The reasons for this included a failure to disintegrate production chains in favour of less capital-intensive operating structures and a shortfall of marketing capabilities, especially in export markets (Sakiya and Porter, 1982:chapter 5, Cusumano, 1985, Pafomansu, 1997, Morita et al., 1994:83pp).<sup>14</sup>

The outstanding case study of entrepreneurial success in Japan was the country's automakers, led by Toyota, that in the 1950s and 1960s created an asset-light 'systems integration' model (Prencipe et al., 2003) – a strategic management rather than a manufacturing breakthrough. Branded automakers exercised control of supplier firms with either minority or zero equity positions, cutting their investment and operating costs while passing risks of overcapacity on to suppliers, thereby maximising leverage in the value chain with the smallest possible asset base (Fine, 1999, Cusumano, 1985).<sup>15</sup> The system integrators then focused more investment on sales and marketing activities.<sup>16</sup>

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<sup>14</sup> Chapter 2 of *Nihon Indasutoriaru* Pafomansu (1997), on the Home Electric Appliance Industry, included a close analysis of how that sector lagged far behind global multinational peers in disintegrating production chains, and often in profitability; Chapter 4, *Metallic Materials*, makes similar points about heavy industry; Chapter 8, *Common Problems*, highlights 'low manufacturing profits' as a systemic problem. Akio Morita wrote a number of publicly influential essays (in Japanese) in the 1990s on Japan's still-poor profitability record; a small taste of points he made can be found in English at <http://www.akiomorita.net/en/contents/philosophy/007.html> Accessed 23 October 2017.

<sup>15</sup> Cusumano described the asset-light approach as supply networks with 'minimum direct investment, established long-term programmes to increase productivity and quality, subcontracted components and final assembly at unusually high levels to firms with lower wage scales' (1985:2). Cusumano estimated that between 1965 and 1980, Toyota and Nissan increased production 600 percent while

Consistent with Johnson's (1982) observation in his seminal country study, the most profitable and successful Japanese firms continued to be ones outside the developmental state's core industrial planning regime. These more 'off-plan' firms included Sony (Morita et al., 1994:note, particularly, 200pp with respect to Japan's best firms, Nathan, 1999), Honda (Sakiya and Porter, 1982), Toyota (Cusumano, 1985, Toyoda, 1987), and Softbank (Lynskey and Yonekura, 2001), which combined narrow product capabilities with strategic capabilities that made them flexible, leaner, and more able to adjust strategy to fit with rising economy-wide capabilities and new opportunities (Fine, 1999, Toyoda, 1987, Sakiya and Porter, 1982). The experience suggested that what the developmental state delivered in orchestrating manufacturing upgrading was ultimately superseded by strategic capabilities honed within firms.

Notably, the finding that in north-east Asian developmental states manufacturing capability was a necessary but not sufficient requirement for competitive dominance echoed Chandler's conclusion in his historical studies of the emergence of leading US firms in the late 19<sup>th</sup> century. Chandler observed that during the formative 1880-1900 period of industrialisation there was a consistent pattern whereby competition

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increasing fixed investment at their factories by one-third as much (1985:215). It should be noted that this strategy was consistent with, and combined with, innovative forward integration, particularly at Toyota and Honda, which invested in national dealership networks where dealers were employed to sell individual model lines so that not only existing best-selling models were sold, maximising throughput in the Chandlerian (Chandler, 1977) tradition (1985:123pp).

<sup>16</sup> For an indication of how important marketing capability was to the success of Toyota and Honda, the two outstanding Japanese car firms, see Cusumano (1985:135) Table 37: 'Dealer Network Comparison [of 11 major Japanese car firms], December 1983'. Honda was a pioneer in not distributing through Japan's general trading companies. In the United States, Honda also took direct control of its sales and marketing operations for motorcycles, setting up dealerships not through existing American motorcycle dealers, but through sporting goods stores and hobby shops in such a way that the firm could control the entire marketing process (Sakiya and Porter 1982:chapter 5).

through manufacturing scale alone was insufficient because barriers to entry in most types of manufacturing were too low. He found that a struggle to control sales and marketing channels, including logistics, became the early US economy's defining strategic battleground (Chandler, 1959, 1967, 1982, 1990 (1962)).<sup>17</sup>

Longitudinal studies established a number of dynamic empirical regularities in the developmental state-firm relationship. Three of these are of particular consequence for this thesis: the first is the basic fact of discrete stages in the developmental state-firm relationship that depend on the broader context of evolving economy-wide capabilities; the second, which is particularly important in China in the light of the country's transition from a socialist economy, is that the benefit of state ownership of firms under the developmental state is increasingly questionable as economy-wide capabilities increase; and the third is that manufacturing capabilities, which are those are most easily nurtured by the developmental state, are not, on their own, sufficient to deliver true global competitiveness to firms – strategic capabilities are required. In order to understand *why* the developmental state-firm relationship must be a dynamic one, it is necessary to look to theories of economic growth.

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<sup>17</sup> In Chandler (1990 (1962)), the key sections of the role of forward integration are Chapter 1 and pp386. Chandler's work on the 1880-1900 period of US firm-level development was mostly undertaken in the early part of his career in the later 1950s and early 1960s. It built on his earliest research on the creation of the US railway network (Chandler, 1956), which made possible the markets in which he argued that organisational strategy became more important than scale in determining winners and losers.

## **1.2. Developments in theories of economic growth**

The approach to the theoretical discussion in this thesis was to search for relevant theory without *a priori* assumptions (Brown and Eisenhardt, 1997:5).<sup>18</sup> The quest looked principally at theoretical developments in three areas: macro- and microeconomics; development economics; and strategic management theory. This first section deals with *economic* theory and three new theoretical schema that, since the 1980s, claimed to offer fresh tools with which to analyse the process of economic growth and development.

### **1.2.1. Transaction costs**

The first was transaction cost economics (TCE) (Williamson, 1975, 1987 (1985), an attempt to create a comprehensive micro-economic framework consistent with the tenets of orthodox, marginalist<sup>19</sup> economics. TCE built on and systemised the post-Second World War literature on market failure (for instance, Akerlof, 1970, Arrow, 1962, 1969). Market failures resulting from the absence of large numbers of market participants, complexity and uncertainty, the exploitation of imperfect information by opportunists, and the ‘bounded rationality’ (Simon, 1957:198) of human beings when analysing the world about them were directly confronted, rather than assumed away by spontaneous, costless coordination. The institution that resolved these failures was the firm, which (building on Coase, 1937) existed in order to coordinate transactions that could not be more efficiently handled by

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<sup>18</sup> This much-cited paper is of itself a case study in why, in theory building, it is often important not to have *a priori* assumptions.

<sup>19</sup> In line with A.K. Dasgupta (1985), the adjective ‘marginalist’ is preferred to ‘neo-classical’ as being more descriptively accurate. Recently, the creators of endogenous growth models might make a stronger claim to the description neo-classical, but their work has not become central to contemporary orthodoxy, which remains best described as marginalist.

markets. Firms dealt with failures in the market by internalising transactions through vertical integration, which allowed *fiat* within the firm to replace problematic transactions in the marketplace.

At first blush, TCE had little to say on the subject of long-run technological progress, a central subject of this thesis. Its objective was to explain which current-period transactions were handled by the market and which were internalised within firms (Shin, 2013).<sup>20</sup> As Perrow (Perrow et al., 1986:236) put it in his critique of TCE: 'Transaction-costs economics is an efficiency argument for the present state of affairs.'

Despite this, TCE's acute focus on problems of information and coordination made its empirical application well suited to questions of technology acquisition. For example, TCE offered an explanation of why high levels of vertical integration were observed in firms in their formative stages of technology acquisition, as was the case in Japan, Korea and Taiwan (with respect to Japan, for instance, see Gregory, 1985, OECD, 1979). In the TCE paradigm, an integrated production structure improved information sharing and coordination, overcame weak public systems of dispute resolution and legal enforcement, and circumvented under-developed markets for intermediate goods. Equally and oppositely, TCE pointed to distortions resulting from internal procurement, tendencies to undisciplined expansion and strategic path dependency, and problems rewarding entrepreneurship, that made

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<sup>20</sup> Shin (2013:44) notes that TCE is 'an attempt to rectify the deficiencies of the concept of production cost in standard neo-classical economic theories'. Total costs of economic activity are therefore defined as production cost (specified in the production function) *plus* transaction cost – although Williamson never directly discusses production cost.



vertical integration a potentially inefficient structure in the longer term (Williamson, 1975:117pp, 129pp). TCE might therefore help to explain dynamic hierarchical change in firms acquiring technology over time.<sup>21</sup>

The problem was that a profound contradiction was inherent in TCE. On the one hand, TCE sought to complement a marginalist framework that had no explicit place for ongoing technical change. On the other, Williamson's undoubted analytical advances pointed to change in vertical scope as a natural firm-level response to issues of technological learning and progress, dragging technology into view. Williamson's inability to resolve this contradiction was clear in the one chapter of his key theoretical work devoted to technology (Williamson, 1975:chapter 10, 'Market Structure in Relation to Technical and Organisational Innovation'). Here, Williamson avoided the more specific term 'technological progress', preferring the ambiguous catch-all -- 'progressiveness' -- and claiming, without evidence, that this was a variant of efficiency:

'Earlier chapters are mainly cost oriented; progressiveness is featured here... although efficiency and progressiveness are by no means independent, there is a difference in the emphasis of each...' (1975:176).

There was no elucidation of what the difference of 'emphasis' might be and the claim was uncharacteristically obtuse in what was otherwise a highly cogent theoretical explication. The problem for Williamson was

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<sup>21</sup> This in turn explains why the TCE framework has continued to be an important point of reference for scholars of technological change, whether in the value chain literature (for instance Gereffi, Humphrey, Sturgeon, 2005) or in strategic management studies (for instance Teece, 1986).

that by analysing internal firm organisation so rigorously he pointed to the fact that firms do not only economise on current transaction costs, they also economise on longer-run learning costs associated with technological change. Indeed, TCE's focus on hierarchy was sometimes *more* convincing in explaining firm structures as a response to long-run knowledge acquisition and technological challenges than as a short-run response to efficiency demands and profit pressures.<sup>22</sup>

TCE made an important, if unwitting and theoretically confused, contribution to our understanding of internal firm-level responses to problems of technological progress. The theoretical confusion arose because of the determination to stick with the static efficiency analysis at the core of marginalist economics, rather than an explicitly dynamic approach that technical change demands. It subsequently fell to strategic management theorists, influenced by TCE, to consider changes in vertical scope dynamically (see below). It is the work of those management theorists that is particularly relevant to this thesis. To be fair to Williamson (1975, 1987 (1985):18), he did repeatedly state that TCE should be used in tandem with other analytical methodologies.

### **1.2.2. TCE extended to the state**

The explanatory power of transaction cost economising was sufficiently alluring for heterodox development economists that Chang (1994) extended it to the institution of the state. Consistent with the FDC experience in north-east Asia, Chang argued that not only firms, but

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<sup>22</sup> In turn, early, influential empirical applications of TCE dealt with technology absorption and development at the firm level (see, for instance, Ogden and Teece 1980, Monteverde and Teece 1982).

governments, played a role in coordinating economic activity and thereby economising on transaction costs. A valid view of the economic process – particularly the FDC development process -- therefore compared the cost of the state resolving market coordination problems with the cost of other solutions:<sup>23</sup>

‘In the real world, *both state intervention and market transactions are costly*. Therefore the comparison must be between the costs of allocating resources through market transactions (or the transaction costs of market allocation) and the costs of allocating resources through state intervention (or the transaction costs of state allocation). Thus seen, the real question is whether the state can achieve the same allocative efficiency at a lower cost than the market can do, and not whether state intervention is costly *per se*. Introducing transaction costs into our scheme allows us to introduce a role of the state which has hitherto been neglected in conventional economic theory, that is, the role of lowering transaction costs in the economy’ (Chang, 1994:48).

The costs with which Chang dealt were primarily those relating to ‘strategic uncertainty’. The state was presented as a potential agent of efficiency – a least-cost solution – when it came to investment coordination at the early, and least certain, stages of economic development. Equally, the state was shown empirically to be a cost-efficient manager of recession cartels to smooth external economic shocks, and the most efficient arbiter of negotiated exits and capacity scrapping in the middle stages of latecomer industrialisation. Various

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<sup>23</sup> Chang is South Korean and has written, most extensively, about the development of South Korea, an FDC.

types of transaction cost economising associated with state industrial policy are set out in Figure 2.

However Chang's concern to bring the state into the transaction cost paradigm saw him push the firm out. His construct was state versus market, not state versus firm versus market, as a true extension of Williamson would be. Where this dissertation deals with vertical scope and transaction cost economising in pursuit of technological learning, it envisages a comprehensive, three-way trade-off between all the potential economisers on transaction costs – state (state choosing what to do), firm (firm choosing what to do), and market (decentralised, arm's length exchanges between firms and firms or firms and state). The relationship between the three institutional possibilities is fully dynamic, constantly adjusting as the technological capabilities of firms and the broader economy increase. Consequently, what the state might do cost-efficiently at one moment, the entrepreneur-led firm is better placed to do at another, and the market at another.

It is argued that the key point to register with respect to hierarchy -- whether in the form of state *fiat* from without the firm or managerial *fiat* within -- is that it solves *transient* problems to do with information and coordination (the latter normally being subsidiary to the former because failures of coordination result from incomplete information about the right course of action (Rothschild and Stiglitz, 1976, Stiglitz, 2000). By its very nature, when a transient informational problem – or 'learning problem' – is resolved, the result is to call into question the

**Figure 2. The developmental state economising on transaction costs**

**Early stage  
transaction cost  
economies**

Create and coordinate  
production hierarchies,  
overcome investment  
risk aversion

Reduce technology  
acquisition costs  
through centralised  
bargaining

Discourage short-term  
profit-chasing where it  
occurs at the expense of  
technological learning

**Mid stage transaction  
cost economies**

Compel mergers,  
negotiate exits, limit  
'irrational  
competition'

Organise recession  
cartels

continued hierarchical arrangements that solved the problem because the costs of hierarchy may no longer be justified.

There are two main mechanisms that dynamically undermine the case for an existing hierarchy. One is that productive knowledge garnered through hierarchy may disperse to many firms (via 'externalities' in the parlance of Endogenous Growth Theory, see below), in which case the value of the knowledge is competed away and a firm's costs, most immediately operating costs, need to fall in order to maintain profit levels. The second is that information may be retained within a firm (or group of firms), allowing for Schumpeterian temporary monopoly profits (Schumpeter, 1955 (1934)). However, the monopoly profit scenario encourages firms to manage their proprietary information such that they can provide less critical parts of it to other firms, employ them as 'captive', low-margin suppliers that risk their own capital, and thereby also disintegrate the hierarchical production chain. This latter possibility, today commonplace under the direction of global systems integrators (Prencipe et al., 2003), was not clearly foreseen in the era when Williamson formulated his original TCE framework.

Under a developmental state, as the economy matures and transaction costs are reduced, there is a general, long-run trend in manufacturing from state-orchestrated hierarchies to firm-orchestrated hierarchies to arm's-length markets and systems integration. (This point is made by Stigler (1983 (1968)) although, in the US, he was not confronted in his work by so many state-orchestrated hierarchies as existed in the north-east Asian FDCs, and nor was systems integration yet a recognised

concept.) However, as management theorists have shown (again, see below), this is not permanently or consistently the case because new learning challenges associated with new technologies, or radically new combinations of existing technologies, are constantly emerging in all economies and may recommend new, again transient, vertical structures for learning. At all times, therefore, the state, firms and markets have their different, dynamic roles to play in vertical integration, where the trade-off is frequently between learning and earning.

### **1.2.3. Evolutionary economics**

A second theory of economic growth to emerge in the 1980s was evolutionary economics. In contrast to TCE, evolutionary economics set out to build a fundamentally different analytical paradigm to that of marginalist economics. Instead of making the role of technological change secondary and concentrating on static analysis based on fixed production functions, evolutionary economics made the process of *change* its central concern. The authors of the original schema hailed Schumpeter as having had the correct perspective: ‘Schumpeter pointed out the right problem – how to understand economic change.’ (Nelson and Winter, 1982:ix).

In confronting change, evolutionary economics dispensed with two pillars of the marginalist framework: the notion that economic relationships tended towards natural equilibrium positions, and the idea that economic actors made maximising decisions based on clear, informed choices. The rejection of these assumptions reflected a position that both information and objectives were far from clear in the

process of economic change.<sup>24</sup> Instead of accumulating physical capital on a static production function as happened in the marginalist framework, in evolutionary economics firms built up ‘capabilities, procedures, and decision rules that determine what [firms] do given external conditions. They also engage in various “search” operations whereby they consider, discover, and evaluate possible changes in their ways of doing things’ (Nelson and Winter, 1982:207). In other words, in a world of incomplete information, firms groped their way between different technological and organisational possibilities – different production functions -- only gradually coming to understand the implications of those possibilities.

The one constant, therefore, was the generation, or destruction, of broadly-defined ‘technological’ capabilities *within* firms. One part of those capabilities was embedded in a firm’s machines, the other in its people. The latter set of skills was harder to copy, transfer and change because people often could not articulate and codify the skills they had; their knowledge was, in a strict sense, tacit, or silent. The importance of tacit knowledge (Polanyi, 1962, 1967) made it difficult for firms to quickly adjust their strategies and contributed to an economic adjustment process that was ‘jumpy’ and typified by a lack of equilibrium (Nelson and Winter, 1982:9). Per Schumpeter, firms that that did manage to adjust their competitive positions and create ‘new combinations’ (Schumpeter, 1955 (1934):66-67) had the opportunity –

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<sup>24</sup> Or, as Schumpeter put it: ‘While in the accustomed circular flow every individual can act promptly and rationally because he is sure of his ground and is supported by the conduct, as adjusted to the circular flow, of all other individuals, who in turn expect the accustomed activity from him, he cannot simply do this when he is confronted by a new task... Carrying out a new plan and acting according to a customary one are things as different as making a road and walking along it’ (1955:79).



not least because of the difficulty of what they achieved -- to reap temporary monopoly profits.

The focus of evolutionary economics on technical change, on the quest for temporary monopoly profits as part of technical and organisational progress, as well as the paradigm's embrace of imperfect information, were all considerable strengths. The discussion of firms' differing capabilities (prefigured in Richardson (1972) and extending the insights of Penrose (1959)) provided a new conceptual framework with which to analyse economic change within the firm -- one that proved highly attractive to management theorists (see below) because they could relate it more easily than the orthodox paradigm to real-world, firm-level experience. Capabilities made the firm a heterogeneous, fallible, potentially infinitely capable, people-driven actor in the economic universe and spawned a vast strategic management literature in the period after Nelson and Winter first published.

Nonetheless, evolutionary economics had its own set of limitations -- some of specific consequence for the study of economic development, and some general. To take the specific issues for a country like China, evolutionary economics left the state and other institutions outside the firm largely outside its analysis. In this respect, evolutionary economics was a symmetric counter-paradigm to TCE -- one that focused on the process of economic change rather than on static efficiency, but with the firm still in place as the locus of analysis. Nelson and Winter (1982:235) showed how a catch-up economy that invested in more productive technologies advanced by upgrading its human and organisational

capital rather than simply by increasing its stock of physical capital. However, they did not explore the critical role of the state and of other non-market institutions in enabling this process. Evolutionary economics was not, as Blankenburg observed (2007:176), tailored to the conditions and needs of what Marx termed 'primitive accumulation'.<sup>25</sup>

At a general level, Nelson and Winter's attempts to formalise the evolutionary model bumped up against the logical impossibility of perfectly, or perhaps even closely, modelling the world of imperfect information. The original text (Nelson and Winter, 1982:Part IV, Part V) employed simulations of firms choosing between different technological production possibilities. In some models (1982:chapter 12), consistent with Schumpeter's schema (1955 (1934)), firms were able to choose between attempting to innovate themselves, or copying other firms that had already successfully innovated (thereby operating as 'fast followers'). However, despite the fact that the theory of evolutionary economics rejected clear 'choice sets' for technical and organisational progress, simulation was only possible where a finite number of choices was specified, albeit with selection between those choices randomised.<sup>26</sup>

The unlimited potential 'combinations' of product, technology and organisation that the individual entrepreneur might deploy were beyond the realm of any manageable simulation. Indeed, it remained the defining characteristic of the literature on entrepreneurship (see

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<sup>25</sup> This is an 'historical stage view' (Glassman, 2006:611), defined by Marx as the (initial) 'historical process of divorcing the producer from the means of production', transforming 'the social means of subsistence and of production into capital' and 'the immediate producers into wage labourers' (Marx, 1967 (1867):714).

<sup>26</sup> As the authors state when specifying their most complex simulation: 'there is a given set of techniques to be found', (1982:211).

discussion below) that scholars failed to produce *any* strong insights into requisites that consistently predicted the success of entrepreneurs. As one example, no manageable simulation could allow for the entrepreneur who jumped between different lines of unconnected business, as is often the case, particularly in developing countries, until he happened on something that ‘worked’ (a phenomenon sometimes referred to under the rubric of the ‘serial entrepreneur’ (Li et al., 2009)). In this respect, entrepreneurship remained the blacker box within what is referred to as ‘the black box of technology’ (Rosenberg, 1994) that evolutionary economics sought to confront. As the ultimate arbiter of technological choice, the entrepreneur defied modelling, a point the case studies in this dissertation will reinforce.<sup>27</sup>

Another limitation of evolutionary economics was both specific to the case of developing countries and this dissertation on the one hand, and general to economic analysis on the other. It was that by focusing so acutely on technological change, evolutionary economics lost, or at least occluded, some of the insights of an orthodox focus on competitive efficiency. In particular, costs disappeared into the background. Hence, for example, while Nelson and Winter paid great attention to internal firm capabilities, they said nothing about vertical integration as a means of *economising* on the acquisition of technology.<sup>28</sup> Yet, as TCE (albeit somewhat inadvertently) showed, institutional adaptation, including

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<sup>27</sup> Nelson and Winter played down the contribution of their formal modelling and simulation efforts: ‘Of the two parts of the endeavor, we view the development of the general theoretical approach [rather than the models] as by far the more important,’ (1982:399).

<sup>28</sup> Nelson and Winter (1982:37) stated that they drew on the insights of Williamson, but it is difficult to identify where.

changes to vertical scope, to reduce costs, was a rational response to the challenges of technological progress.

#### **1.2.4. Endogenous Growth Theory**

A third area of theoretical development in the period when the east Asian 'tiger' economies were booming was Endogenous Growth Theory (EGT). This was an attempt to endogenise the technical change that the Solow-Swan growth model recognised (Solow, 1957), but left as an exogenous variable, and hence something unexplored in terms of the R&D efforts within individual firms. Romer (1986, 1990) formalised models of the development of new technological ideas based on the observations that ideas were non-rivalrous (unlike physical phenomena, ideas were not consumed when used) and only partially excludable – in other words, firms' capacity to prevent other firms using their new ideas was limited by the extent and enforceability of legal protections and by practicability. These considerations led, on the one hand, to increasing returns -- because ideas were characterised by high development costs but low marginal utilisation costs -- and imperfect competition because firms achieved temporary or partial monopolies as the result of developing new ideas. On the other hand, ideas produced large 'spillovers', or 'externalities', because their full economic value could not be privately captured.<sup>29</sup>

Many models of endogenous technical growth were created in the 1980s and 1990s. Romer focused on the creation of new ideas, for which firms prospected as if for nuggets of gold. Aghion and Howitt (1990) and

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<sup>29</sup> This heuristic embodied the technological 'copying' phenomenon at the heart of economic catch-up.

Grossman and Helpman (1991a, 1991b) based models on improving the quality of existing technology. Lucas (1988, 1993) focused not on improved ideas but on increased human capital.

EGT models had the benefit of recognising increasing returns, and giving up the decreasing returns that entered economic theory through an analysis of the economics of land in the eighteenth and early nineteenth centuries, yet remained dominant during the era of global industrialisation (Dasgupta, 1985). The models also showed that markets failed to optimise R&D because markets did not value externalities, only private profit. The case for government intervention to support the creation of positive externalities was made clearly. Moreover, while increased intellectual property rights (IPR) might help firms in rich countries, the models sometimes showed that growth in technologically backward states was impeded by enhanced IPR. Helpman (1992), for example, employing a model similar to those of Romer and found that the net effect of stronger global IPR was negative for developing countries as increased innovation in rich states failed to offset decreased possibilities for imitation in poor states.

Nonetheless, EGT models suffered from serious analytical limitations. As Blankenburg (2007) noted, ever since externalities entered the economic lexicon in the 1920s, in an attempt to make Marshallian partial equilibrium analysis logically consistent, they defied effective categorisation (see Bator (1958) for an attempt to categorise externalities). Or, as Krugman put it in a recent critique of EGT: 'too much of it [EGT] involved making assumptions about how unmeasurable

things affected other unmeasurable things'.<sup>30</sup> Unlike TCE and evolutionary economics, which had far greater micro-analytical content and connected directly to the management literature that is central to arguments presented in this thesis, EGT was really a macro-economic contribution to growth modelling that rested on appropriated and unexpanded micro foundations. EGT put learning inside the production function, but it had little to add about how learning took place in the real world.

EGT economists connected their work to developing countries through models of technology transfer, and through institutional improvements in poor countries that facilitated the allocation of resources to an economy's 'best' firms, in the marginalist tradition (Jones, 1998). The logic of this approach assumed that capable firms pre-existed in poor states, that the development problem was one of resource allocation, and that the state's key tasks were to improve institutions, write laws and ensure macro-economic stability.

In contrast, the main deduction from EGT for this thesis, which holds pro-active, state-led infant industry policies to be essential to accelerated economic transitions, is that the non-excludability of ideas is greater in developing countries than in developed ones. In poor states, not only is IPR weaker, facilitating imitation *within* an economy, but most technology is imported, in a mature condition, from more developed countries, meaning that technology is acquired off-the-shelf and has a particularly strong tendency to non-excludability. In addition,

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<sup>30</sup> [http://krugman.blogs.nytimes.com/2013/08/18/the-new-growth-fizzle/?\\_r=1](http://krugman.blogs.nytimes.com/2013/08/18/the-new-growth-fizzle/?_r=1) Accessed 12 May 2016.

since the successful developmental state must foment competition under its industrial policy, it frequently *dictates* that imported technology is distributed to multiple firms, as was the case in China's thermal power equipment sector after 1978. These considerations help to explain how firms in an FDC like China competed for a long time on the basis of price (and hence volume) rather than product differentiation and why new ideas and techniques entering the market through one firm diffused quickly to other firms.

Two important theoretical points, supported by both empirical evidence in the literature and the empirics of this thesis, connect to this basic deduction about the non-excludability of information in early-stage development. The first is that there is a natural, dynamic trend over time from less to more excludability of information as an IP regime is slowly put in place and enforced in an FDC. The successful developmental state in east Asia moved from ensuring non-excludability of imported manufacturing technology to slowly building a regime in which excludable, monopolistic information could be protected. The tolerance and enforcement of non-excludability fomented firm-level competition. The gradual building of an IP regime allowed firms, once their capabilities had grown, to reap temporary monopoly profits from innovations that they were gradually able to self-develop. This is essential context for the 1978-2017 China case studies in this thesis.

The second point is that, logically, effective state industrial policy for technology acquisition is conservative in the choices that it makes. The successful east Asian FDC was -- particularly at an early stage -- content

to purchase technology of limited excludability because it was mature, well-understood technology, because it could be learned despite low capabilities, and because it facilitated competition that identified the most capable firms and entrepreneurs in an emerging capitalist economy. Equally logically, the pursuit of more excludable technology at an early stage would have been a policy mistake. More excludable technology tended to be newer, more tacit and more complex, the pursuit of which would have relegated competition between firms to a lower level than was desirable.

Despite this, the empirical reality in east Asian FDCs has been that policymakers sometimes were tempted by early purchases of more excludable technology, seeking to jump to the technical frontier rather than arrive there step by step. The empirics in this thesis will speak to this point in China's energy equipment sector. To set the scene for that analysis, I highlight here a two-country case study comparison from extant empirical literature that contrasts a successful FDC with a putative FDC that failed.

Amsden (1989) analysed the growth of South Korean steel producer Posco under developmental state direction, highlighting a conservative, methodical approach to technological learning that deliberately began with manually-controlled production lines and only later progressed to computer-controlled lines. Because of the vast investment required, Posco was not subjected to domestic competition at the outset, however the firm was pressured to export, while competing facilities – including a sister plant at Gwangyang and steel plants owned by private



*chaebol* – were authorised in the 1980s (Amsden, 1989, Kirk, 1994).

Posco was a remarkable success.

In Malaysia, under the premiership of Mahathir Mohamad from 1981, the state pursued a strategy of emulating the industrial policies of Japan and South Korea. The strategy was called ‘Look East’ (Khoo, 1995, Jomo, 1994, Wain, 2012). At the heart of Look East was a project to develop integrated steelmaking capabilities, like those learned by Posco.

However, Mahathir decided to make a technological jump. His government committed an initial US\$520m<sup>31</sup> to build Perwaja, a cutting-edge, Direct Reduced Iron (DRI) steel plant that would turn iron ore directly into high-grade sponge iron, ready for steelmaking without sintering and blast furnace procedures. The lead technology provider was Nippon Steel, the same firm employed by Posco in its earliest phases (Jomo, 1994, Studwell, 2013, Wain, 2012, Amsden, 1989).

This leap was a disaster. Nippon Steel had never operated a commercial DRI plant, and its technology failed. Mahathir pressed on with a ‘big push’ industrial policy requiring high-grade sheet steel for sectors including car making. However, Perwaja could not deliver. Replacement DRI capital equipment was purchased and brought on line, in 1993. But Malaysian engineers understood too little about the complex technology, and only ever produced low-grade DRI sponge. In more than 30 years since inception, Perwaja never produced high-grade steel; it mostly supplied the construction sector (Studwell, 2013, Wain, 2012, Jomo, 1994).

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<sup>31</sup> Converted to USD at the average 1985 exchange rate.

Posco started production in 1973 with rudimentary technology that could be quickly absorbed. In 10 years, proceeding in fast incremental steps, the firm learned the full range of high-grade steelmaking processes, and increased capacity from 1m to 9m tonnes for an investment (at today's prices<sup>32</sup>) of US\$20 billion. Perwaja attempted to leap to the technological frontier in 1985 with 1.5m tonnes of capacity. The firm still has only 1.5m tonnes of capacity, never became an internationally competitive steelmaker and consumed, over the next 25 years, an estimated US\$6-8 billion. The failure of Perwaja also helped to undermine Malaysia's broader industrialisation efforts (Studwell, 2013, Wain, 2012, Amsden, 1989).<sup>33</sup>

The final point – a caveat -- to note in this section on EGT is that technology transfer, the prevailing IPR environment, and 'externalities' are only part of the overall context for growth and competition at an early stage of economic development. The other, main parts are the evolving internal capabilities, and positional choices in the value chain, of firms, where EGT models offer no useful insights. As Blankenburg says of externalities, their main role is to impart theoretical coherence to the

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<sup>32</sup> I have adjusted reports of Posco investment, and estimates (budgets were never made public) of Perwaja investment, to 2016 prices using the US consumer price index. This is crude; however, the comparison is sufficiently stark that this crudeness can be tolerated (Studwell, 2013:117pp, Wain, 2012).

<sup>33</sup> A single pair of case studies was offered for the sake of brevity. However, there are many others. Nakaoka (1991) examined the acute technical difficulties early Meiji firms experienced in Japan in the 1870s and 1880s with advanced, imported textile machinery, before the country had adequately trained engineers. The better, stop-gap technical solution was for small textile producers to use modified and improved foot-pedal (*takabata*) looms, and to weave imported cotton weft to provide strength with Japanese silk warp. The output was sold as 'silk'. It was only after engineers returned from training in the UK, from the mid-1880s, that production using imported power looms became relatively more efficient. Subsequently, the Japanese reengineered, improved and re-exported the power loom technology.

marginalist framework (echoing Williamson's objective for TCE), thereby reconciling entrepreneur and R&D-led microeconomics with balanced growth dynamics at the macro level. However, if we ask probing questions about externalities, we may sympathise with Blankenburg's dismissal of them as a 'vacuous concept' (2007:166).

### **1.3. Assumptions in a changing world**

The shortcomings of the three theoretical constructs discussed recall Kindleberger's sharp question as to whether there could ever be 'one general economics' (1962:foreword). Dasgupta (1985) argued cogently that the answer, based on historical analysis, was no, and that different schools of economic theory have been defined by their different historical foci resulting from the different stages of economic development they confronted.<sup>34</sup>

TCE sought to provide orthodox, marginalist economics with solid microeconomic foundations, but many of the analytical insights it gave rise to simply highlighted the shortcomings of standard marginalist models and their failure to deal explicitly with technological change. EGT models of the 1980s and 1990s brought technology within the production function and modelled increasing returns, but relied on assumptions that technological progress occurs in a predictable fashion, whether reflected in accumulation of new units of ideas determined by the population of researchers or by an increase in some measure of human capital (Jones, 1998, 2005). These assumptions were crude for a

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<sup>34</sup> Dasgupta's observations echoed, in turn, Sraffa's assertion that grand theories of causation are an impossible dream for economics, and that the best we can hope for is 'snapshots' of reality (discussed in Blankenburg (2007:chapter 2).

developed economy, but exponentially cruder for a developing economy, where the role of the state is highly unpredictable. In a developing country, the state's role varies from being the vanguard in organising technological learning (Abramovitz, 1986, Gerschenkron, 1962) to extractive kleptocracy (Krueger, 1974, Acemoglu and Robinson, 2013). A technology transfer function with a degree of automaticity – such as those employed in extensions of EGT models to developing countries – cannot reflect a situation in which the state is not simply a conduit for technology, but anything from the dominant entrepreneur to a highly-resourced thief; and, of course, is capable of sometimes abrupt change.<sup>35</sup>

Evolutionary economics models did capture the often spasmodic and unpredictable nature of technological progress. However, where EGT models assumed too much automaticity with respect to technology transfer to developing countries, evolutionary economics assumed too little – at least with respect to the capable developmental state. Such states, as active players in the technology acquisition process, confront much clearer choice sets than those envisaged by evolutionary economics. Since a developmental state operates within the global technological frontier, it can, to a considerable extent, 'see' the

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<sup>35</sup> Note that the world in which TCE developed in the 1970s and 1980s has been altered by globalisation. A vastly increased global division of labour and outsourcing possibilities have not ended the case for vertical integration in order to acquire new technological capacities. But it will be argued that the advantages of investment in vertical integration tend to be more fleeting than ever when fast-evolving global supply chains offer asset-light alternatives to the firm that has acquired the requisite capabilities to become a system integrator. Equally, a constant trade-off between *either* investment in R&D *or* capacity expansion, such as was modelled by Nelson and Winter (1982:chapter 12), is no longer inevitable. In a globalised world, outsourcing is available not just for assembly and manufacturing, but also for subsidiary design work. To some extent, it is therefore possible for firms that acquire dominant capabilities to have their cake and eat it -- cutting both in-house manufacturing costs and R&D costs.

technological path the economy needs to follow (Abramovitz, 1986, Gerschenkron, 1962, Reinert, 2007). As the economy moves closer to the technological frontier, of course, the choice sets become less clear (Wong, 2011).

In north-east Asia, Japan, South Korea, Taiwan, and now China, moved from an early-stage developmental state-led economy to a relatively mature, decentralised economy in a matter of half a century, growing at up to 10 percent a year on a sustained basis. Rather than a unified theory of causation to explain this FDC experience, this thesis focuses on a process of transition, from a political economy that emphasises learning to one that emphasises efficiency. The latter is broadly consistent with orthodox, marginalist economics. However the former is very different; its focus on accelerated technological progress is such that the economics of learning is sometimes, as Amsden (1989:chapter 6) put it, about ‘getting relative prices wrong’ in order to incentivise firms to prioritise investment in technology *in order to secure higher profits in the future*.

The notion of a political economy transition is what Friedrich List had in mind in his debate with Adam Smith. List did not reject free trade or Smith’s incipient economic orthodoxy. Rather he argued that the economics of efficiency was reached by a transition from an earlier-stage economics of learning: ‘In order to allow freedom of trade to operate naturally, the less advanced nations must first be raised by

artificial measures to that stage of cultivation to which the English nation has been artificially elevated.’<sup>36</sup> (List, 1885 (1841):72)

#### **1.4. Micro insights: the pure firm level**

Under the developmental state, the transition from the economics of learning to the economics of efficiency is centred on the changing relationship between government, firms, and markets. The firm is the hinge in this relationship. Initially, the firm learns under the guidance of a state whose capacities exceed those of the private sector (the core logic for the existence of the developmental state). But over time the firm acquires greater capacities, is ready for a more arm’s length relationship with the state, and a closer one with decentralised, independent markets.

To understand how, exactly, this transition occurs, requires an investigation of the manner in which firms learn. In this respect, two literatures are particularly relevant to this thesis: a rich empirical literature on the nature of firm-level learning developed by heterodox development economists beginning in the 1980s; and a business school strategic management literature that emphasised the dynamic nature of firm-level capabilities and their co-evolution with vertical scope. The

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<sup>36</sup> Elsewhere (1885:2), List made the point still more explicitly with reference to the historical example of the Venetian Republic: ‘Unrestricted freedom of trade was beneficial to the Republic in the first years of her existence; for how otherwise could she have raised herself from a mere fishing village to a commercial power? But a protective policy was also beneficial to her when she had arrived at a certain stage of power and wealth, for by means of it she attained to manufacturing and commercial supremacy. Protection first became injurious to her when her manufacturing and commercial power had reached that supremacy, because by it all competition with other nations became absolutely excluded, and thus indolence was encouraged. Therefore, not the introduction of a protective policy, but perseverance in maintaining it after the reasons for its introduction had passed away, was really injurious to Venice.’

second literature captured, refined and expanded many of the insights generated, or provoked, by TCE and evolutionary economics.

#### **1.4.1. Development economists and the firm level**

Among heterodox economists who set out to describe the process of firm-level technology acquisition beginning in the 1980s, Sanjaya Lall was particularly important. Lall's empirical studies segmented the technology learning process, stressing its gradual and cumulative nature, and its tendency to path dependency once initial choices had been made. One of Lall's earliest examinations of the learning process (Lall, 1987) set out a stages framework that progressed from pre-investment choice, to project execution, to plant operation, to technological improvement, to technology transfer to other businesses. In a series of studies (Lall, 1990, 1992, 1996, 2001a, 2001b, Najmabadi and Lall, 1995, Urata and Lall, 2003) such segmented analysis allowed Lall to show that technological, including organisational, choices were heterogenous, that the earliest decisions set the context for later ones, that firms faced ongoing uncertainty about objectives and techniques because of the importance of tacit knowledge, and that knowledge built up incrementally. In addition, Lall expanded from his earlier work on transfer pricing by multinational companies (Lall and Streeten, 1980 (1977), Lall, 1983, 1985, 1993) to show that foreign direct investment (FDI) played a qualitatively different, indirect, often weak and sometimes counter-productive role in local technology accumulation.

Lall's concern to nail down the basic characteristics of what he termed 'capability building' and 'micro-level technical change' was echoed in

related publications of the era including Rosenberg (1982), Pack and Westphal (1986), Bell and Pavitt (1993), and Radosevic (1999).

Rosenberg stressed variation in firms' capacity to absorb technology as the single biggest differentiator of their progress, echoing Abramovitz's (1986) concept of 'social capital', as distinct from technological capital. Bell and Pavitt segmented learning challenges for developing countries according to the characteristics of target industries in developed countries: machinery and input supplier dominated; scale-intensive; information-intensive; science-based; and vertically-disintegrated supplier networks led by system integrators. Radosevic pointed to changes in the nature of technology and in the global trading environment as requiring firm-level adjustment of technology acquisition strategies in the globalisation era.

Studies of firm-level and industry-level technology acquisition in the late 1980s and 1990s were a natural fit with the co-evolving National Innovation Systems (NIS) school, to which scholars such as Lall contributed. NIS, as the name suggested, stressed national economies – informed by national political economy conditions – as repositories of evolving technological capability within which firm- and industry-level technological accumulation took place. The point was that the national innovation economy was more than the sum of its firm-level parts, because it included the state -- in all its manifestations, direct and indirect – and other non-state institutions as economic actors. State action was considered in dimensions ranging from industrial policy to management of education systems.



Freeman's (1988) work on Japan was an important early text under the NIS rubrik. Almost concurrently, Lall (1987) published a study of India, part of a World Bank-financed project to compare technology acquisition in India, South Korea, Brazil and Mexico. Nelson (1986, 1987, Rosenberg and Nelson, 1994) examined public versus private sector contributions to innovation in the United States, seeking to fill gaps in our understanding of the role of institutions that he had noted in the conclusions of Nelson and Winter (1982). Porter (2011 (1990)) published an ambitious survey of technology acquisition experiences across 10 countries. Lundvall (1992) edited a collection of papers by mostly Scandinavian scholars, reflecting a long research effort that built on the catch-up experiences of Denmark, Sweden and Norway. Nelson (1993) brought together the most widely cited and geographically wide-ranging collection of papers, covering both developed and developing economies.

Each of these studies examined interactions between private firms, government industrial policy institutions, and public institutions ranging from financial sector agents to structures of S&T research. Differences were largely a matter of emphasis. Freeman focused on institutions making and implementing industrial policy; Nelson focused on interaction between public and private actors and institutions; Porter focused on firm strategy in the context of national structures of industry, institutions and factor endowments; the Scandinavian scholars attempted to identify all the institutional components and relationships that mattered at national level – hence their claim to the national systems moniker. All the empirical studies in the NIS tradition recognised

the historical contexts and precedents for the technology acquisition strategies they described. Freeman (1995) set out the historical analytical antecedents for NIS beginning with List's (1885 (1841)) National System of Political Economy. Shin (2013) further emphasised historical continuities with a comparison of national technology policies in Germany, Japan and South Korea that referenced experiences ranging from the late nineteenth century to the 1980s.

All such heterodox development economics and NIS research and taxonomies brought attention to the multi-faceted, variable nature of learning challenges. Among the themes of greatest relevance to this thesis were: segmented analysis of the technological learning process; concepts of structural variation between industrial sectors, where scholars introduced multiple stylised taxonomies; examination of the roles of gradualness and steady accumulation in technological learning; path dependency; uncertainty about the best course of action and the role of tacit knowledge; recognition that there are multiple ways to achieve a learning objective; exploration of the positive and negative impacts of FDI; a heuristic separation of 'absorptive capacity' and 'social capital' from narrow technological capital; and elevation of the whole subject of institutional interplay of state and firm -- via NIS scholarship -- to a central status in development economics.

However, the studies cited concurred that cross-sectional analysis should be the default methodology. NIS, indeed, was the logical conclusion of the cross-sectional approach. Both the potential and the limits of this methodology were made clear in one of the most rigorously

analytical studies in the NIS tradition, Evans' (1995) work comparing state industrial policies across South Korea, India and Brazil.<sup>37</sup> Evans' schema distinguished four different archetypes of state intervention in the firm-level technology acquisition process: the state as direct manufacturer ('demiurge'); the state as 'midwife' to different industries; the state performing 'husbandry' of individual private firms; and the state as arms-length regulatory 'custodian'. Across these different possibilities, the optimum development policy mix was held to be one of 'embedded autonomy' – a combination of midwifery and husbandry stated to be present in South Korea -- under which the state nurtured, but remained independent of, rising firms.

The analysis was compelling in delineating the myriad choices available to the state and situating them by means of careful description in local political-economic conditions. Evans' assertion that state policy must never become captive to private sector interests also appeared to be universally valid. But the study's superficially attractive conclusion that there was an optimum balance in the relationship between state and private sector depended on its being situated in what might be called the 'middle reaches' of capability development. The economies analysed were neither so weak in capabilities that government had to play a dominant role in technology acquisition (Thun, 2006), nor so strong that there was a case for state withdrawal to the 'custodian' position.

The conclusions were valid for the developmental moment considered, but they obscured the stark historical fact that all successfully developed

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<sup>37</sup> Evans (1995) did not self-identify as an NIS study, but is self-evidently in this tradition.

countries, though they featured industrial policy in their early stages (Lockwood and Bronfenbrenner, 1970, Lockwood, 1974 (1954), Hudson, 2010, Chang, 2002, Trebilcock, 1981) progressed to more ‘free market’ policies over time (Carlile and Tilton, 1998, Lardy, 2014, Kroeber, 2016, Pempel, 1998, Lundvall et al., 2006, Amsden and Chu, 2003). Most important, the development of entrepreneurial capability and globally competitive firms in leading economies continued *across this transition*, something the NIS analyses ignored. Finally, in Evans’ study as in others, entrepreneurs remained in the background, pushed and pulled by whatever state policy was pursued. In the real, longitudinal world, as this dissertation will show, entrepreneurs stepped out of the shadows of state industrial policy as economic development progressed.

Cross-sectional analyses labelled state policies as one type or another, occluding the longitudinal reality that those policies evolved over time. Indeed, at the extreme, the cross-sectional studies exhibited the very lack of dynamism that heterodox economists accused orthodox, marginalist economics of exhibiting. Radosevic, in his study of international technology transfer, was unusual in explicitly acknowledging the limitations of the cross-sectional approach:<sup>38</sup>

‘The processes of integration of technological knowledge into a domestic economy co-evolve with the structural features of the domestic environment. Trying to capture the determinants of such a process through cross-sectional studies is faced with serious limitations and

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<sup>38</sup> Unusual but not unique. Lundvall (2006:pp5) stresses the need for national systems of innovation to evolve as an economy develops; however, his research is overwhelmingly concentrated on questions of state choices in industrial policy.

requires knowledge of history and the specific nature of this co-evolution.’ (Radošević, 1999:243)

The co-evolution of technological capacity and political economy in the form of a changing state-firm-market relationship required empirical research directly focused on a longitudinal rather than a cross-sectional axis of analysis. For this thesis, some of the most enlightening research in this respect has been published by strategic management scholars at business schools. Moreover, business school researchers brought to the fore a character who rarely appeared in any detail in the empirical analyses of development economists – the entrepreneur.

#### **1.4.2. Strategic management research and the firm level**

Scholars in the field of strategic management had no choice but to tackle the subjects of longitudinal dynamism and the role of the entrepreneur because their discipline focused them narrowly on the operational realities of the individual firm.

The difficulties of research into entrepreneurship are well known. Researchers have struggled both to define meaningfully what entrepreneurship is (Baumol, 1968, Shane and Venkataraman, 2000, Davidsson, 2005), and to empirically link cause and effect in predicting which human character traits and qualities lead to entrepreneurial success (Sandberg and Hofer, 1988, Chrisman et al., 1998, Zott and Huy, 2007, Chandler and Lyon, 2001, Schoonhoven et al., Venkataraman, 1997). Nonetheless, the status of entrepreneurship as the least understood aspect of microeconomics does not justify ignoring it any

more than when the subject of technology was ignored by marginalist economics. No scholar of venture formation – and particularly no scholar of developing country venture formation – would omit the entrepreneur who sets strategy. Early-stage, private FDC companies are, almost by definition, ‘big boss’ companies driven forward by a charismatic leader (Chandler, 1959, Lockwood and Bronfenbrenner, 1970, Huang, 2008, Chernow, 1999, Kirk, 1994). Beyond the earliest state work units, the case study firms in this dissertation are barely intelligible without an introduction to their entrepreneurial leaders.

With respect to their investigation of dynamic change over time, management scholars were less concerned with the quest for a monolithic methodology of economics at the macro level than the originators of TCE and evolutionary economics.<sup>39</sup> The result was that scholars were able from the 1990s to move towards a synthesis of insights from TCE and evolutionary economics, one that proceeded in three stages. First, they examined the ‘absorptive capacity’ through which firms digested and utilised new information and techniques. This was, in part, an investigation into the *preconditions* for dynamic learning and productivity enhancement.<sup>40</sup> Second, management theorists looked at the manner in which, as firms built capabilities, their operating environments changed. These external changes recommended adjustments within firms, both reactive and pro-active. A firm’s ability to adjust to its changing environment reflected what were dubbed its

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<sup>39</sup> David Teece, a strategic management theorist and one of the key developers of the concept of dynamic capabilities (see below) was a student of Oliver Williamson. Teece never exhibited the same concern to make his construct complementary to the tenets of marginalist economics.

<sup>40</sup> Under the original definition of absorptive capacity given by Cohen and Levinthal (1990). As reconceived by Zahra and George (2002), the meaning of absorptive capacity becomes explicitly dynamic and much closer to the concept of dynamic capabilities.

*dynamic capabilities* – capacities to forge and manage change, particularly organisational change. Third, researchers examined the manner in which a changing environment impacted, over time, a firm's optimal structure of vertical integration. This led to a theory of dynamic co-evolution of operating environment and vertical scope that involved both disintegration and re-integration of activities depending on circumstances and learning needs. Finally, the stress that these theories placed on the requirement for dynamic action brought the entrepreneur into view because it was the entrepreneur – operating in the context of evolving state industrial policy -- who set the agenda for strategic change.

From a development economics perspective, absorptive capacity at the firm level (Cohen and Levinthal, 1990) was in many respects an analogue of the concept of 'social capital', used by development economists to describe the requisite capability of states to engage in effective industrial policy (Okawa and Rosovsky, 1973, Abramovitz, 1986, 1995). Cohen and Levinthal defined a firm's absorptive capacity as its ability to value, assimilate, transform and exploit knowledge. Their empirical findings – in line with those of researchers of technology acquisition experiences like Lall, as well as north-east Asian experience cited above – stressed that the ability to learn was cumulative and path-dependent, and 'largely a function of the firm's level of prior related knowledge' (1990:128). However, while the concept of absorptive capacity emphasised the preconditions for, and importance of, dynamic change, Cohen and Levinthal failed to articulate that embedded knowledge and

routines within the firm could be impediments to adjustment when external circumstances changed.

It was the concept of dynamic capabilities that shifted the focus from a firm's internal capability and absorptive capacity development alone to its internal capability and absorptive capacity development *in the context of changes in its operating environment*. In a seminal paper, Teece and Pisano (1994), expanded and restated in Teece et al. (1997), the authors defined the reconfigured perspective as follows:

'This source of competitive advantage, "dynamic capabilities", emphasizes two aspects. First, it refers to the shifting character of the environment; second, it emphasizes the key role of strategic management in appropriately adapting, integrating and re-configuring internal and external organizational skills, resources, and functional competences toward changing environment.' (1994:537)

Dynamic capabilities were defined under three headings, each of which involved internal and external considerations. 'Organizational processes' covered a firm's routines for coordination, learning and transformation, including such outward-looking capabilities as strategic alliances, technical collaborations, and benchmarking systems. 'Asset positions' included a firm's technological endowments, customer base, supplier base and relations with 'complementors'. 'Paths' referred to the possible technological and organisational paths of development open to the firm (Teece et al., 1997:518). A sharp distinction was drawn between these capabilities, which were firm-specific, hard to replicate, and therefore a



durable source of competitive advantage, and factor endowments which were generic, more easily replicated, and therefore not usually a source of durable competitive advantage. The dynamic capabilities that were a firm's most valuable asset were its 'ability to integrate, build and reconfigure internal and external competences to address rapidly changing environments. Dynamic capabilities thus reflect an organisation's ability to achieve new and innovative forms of competitive advantage given path dependencies and market positions' (Teece et al., 1997:516).

The critical point here was that dynamic capabilities were not simply an ability to identify and ingest in the manner of absorptive capacity – akin to a sponge absorbing liquid. Instead, dynamic capabilities involved reconfiguration (including technological 'recombination' (Lawson, 2017)) when external conditions changed. To continue the metaphor, under dynamic capabilities the sponge of learning could be squeezed out, ridding it of redundant knowledge and routines, and then refilled, in a repeatable process.

Teece and Pisano (both 1994 and 1997) listed 'Schumpeter (1934), Penrose (1959), Williamson (1975, 1985), Barney (1986), Nelson and Winter (1982), Teece (1988), Teece et al. (1994)' as providing the theoretical foundations for dynamic capabilities (Teece and Pisano, 1994:538).<sup>41</sup> These were the key texts of TCE and evolutionary economics. Teece and Pisano stressed the need to protect capabilities and to avoid opportunistic behaviour as the drivers to conduct particular

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<sup>41</sup> The cited works not mentioned elsewhere in the body of this chapter are Barney (1986), Teece (1988), Teece et al. (1994).

activities within firms, consistent with TCE. They stressed the role of the firm as a vehicle for learning, and as a repository of, capabilities, as well as for re-configuring capabilities, consistent with evolutionary economics and the resource-based view of the firm.

Nonetheless, a full integration of the ideas contained in TCE and evolutionary economics required an understanding of how a firm's vertical scope evolved dynamically. Building on Teece and Pisano (1994, Teece et al., 1997), empirical studies began to confront vertical integration more directly in the context of discussions of dynamic capabilities (Poppo and Zenger, 1998, Schilling and Steensma, 2001, Afuah, 2001, Doig et al., 2001, Jacobides, 2004, Jacobides and Hitt, 2005, Raynor and Christensen, 2002). Afuah, for example, showed through empirical research in the computer industry that firms suffered if they were already vertically integrated when a new technology came into play because they were committed to unhelpful forms of internal organisation with respect to learning and the absorption of new technology. On the other hand, firms benefited from becoming vertically integrated when a new technology was being absorbed and developed because the vertical integration was tailored to, and supported, a new learning experience.

It was Jacobides and Winter (2005) who synthesised a general theoretical framework for the co-evolution of capabilities, on the one hand, and vertical scope informed by transaction costs on the other. They argued that a unifying theory needed to move beyond the focus of dynamic capabilities on the firm *in the context of its environment*, and

instead view the firm and its environment as strictly *co-dependent*. Capabilities within a firm, and transaction costs relating to suppliers, partners, buyers and competitors outside the firm, were inseparable and mutually influential -- particularly over long periods of time:

‘The analysis at the individual firm level must be complemented by a systemic view that takes the full roster of participants into account... Further, important causal mechanisms operate over substantial time periods; to elucidate these requires a dynamic, co-evolutionary view of how capabilities and transaction costs change and interact.’ (2005:396)

The ‘systemic’ view emphasised four interactions, operating in a circular fashion. First, a firm’s capabilities (and its ongoing need to develop new capabilities) influenced its vertical scope at any given moment. Second, firms invested to manipulate their operating environments and thereby reduce those transaction costs that it was within their power to affect. This tended to facilitate vertical disintegration, particularly where dominant firms could pass on risk and capital expenditure requirements to suppliers. Third, any change to vertical scope, at both the firm and the wider industry level, affected the ways in which new capabilities developed. Periods of vertical disintegration might be followed by periods of re-integration as a response to new learning challenges, supplier hold-ups and new market demands.<sup>42</sup> Fourth, vertical disintegration and changing capabilities across an industry opened up

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<sup>42</sup> In general, vertical structures tended to become more homogeneous across firms, and vertical disintegration tended to increase, over a product or business lifecycle: ‘Whether integration or disintegration provides the stronger basis for capability improvements is an empirical issue; the answer tends to vary with industry life-stage.’ (2005:404). This finding is consistent with Stigler (1983 (1968)).

opportunities for participants from other sectors to enter the market, with potentially disruptive effects.

Jacobides and Winter (2005) offered as one example of vertical disintegration, driven by differential capabilities and competition, the break-up of US mortgage banking in the 1980s. The value chain split into wholesale loan management and trading on the one hand, and retail loan origination activities on the other. Upstream, wholesale firms invested to standardise mortgage data, thereby reducing transaction costs and facilitating a more focused competitive advantage. Downstream, disintegration had the effect of allowing real estate agencies into the previously bank-dominated mortgage origination business.

In the Swiss watch manufacturing industry, by contrast, Jacobides and Winter showed how the advent of quartz movement technology disrupted an already-disintegrated industry. The new technology favoured more vertically integrated Japanese firms, as well as a new, vertically-integrated Swiss entrant, Swatch -- at least until incumbent firms also moved to greater integration. As Jacobides and Winter subsequently summarised the keys to their theoretical framework, changing 'industry architecture' and capabilities constantly interacted: 'structure determines the *feedback* that will drive the system's dynamics. Thus we highlight the role of context and higher level causal forces that cannot be understood simply by looking at the level of individual agents' (Jacobides and Winter, 2012:1366).

To the knowledge of the author, the concept of dynamic capabilities has not previously been applied to work on emerging economies. This may be because the world of high-technology business, high-velocity markets (Eisenhardt and Martin, 2000), and firm boundaries that are either non-existent or shifting (Santos and Eisenhardt, 2009) -- on which most dynamic capabilities and dynamic vertical scope literature concentrates - - appears far removed from that of an FDC like China.

However, this presumption is questionable for two main reasons. First, FDCs are characterised by a constant flow of experience with (locally) new technologies, induced by the state-led drive to industrialisation. High-velocity markets and unclear boundaries are probably closer to the experience of many Chinese firms than are the experiences of mature industries in developed economies. Second, the ambition of industrial policy is to reach the global technological frontier quickly, and in this respect leading Chinese firms already began to experience the frenetic uncertainties of advanced high-technology markets. Indeed, the most successful Chinese firms assessed in this dissertation exhibit a capacity to create, invest in, and manage cross-border networks and alliances to capture value that appears superior to that which Japanese, Korean or Taiwanese firms achieved at a similar level of national development measured by GDP per capita. Herein – despite (or perhaps because of) China’s more fraught political relations with the West – may lie a distinct Chinese ‘cosmopolitan advantage’ that derives from a forced march of global integration when compared with the paternalistic American indulgence of infant industry policies during the Cold War industrialisation of Japan, Korea and Taiwan.

The development of dynamic capabilities and the co-evolution of capabilities and vertical scope are important concepts in framing the case studies in this thesis. The concepts provide benchmarks for the capabilities that the best case study firms are constructing in the context of rapidly changing operating environments.

### **1.5. Limitations of the current literature; the case for theory building; and measuring firm-level success**

There are several important limitations to the existing developmental state and industrial policy literature. First, the existing literature implicitly downplays longitudinal changes required for effective industrial policy. There is a gap in the literature for studies that focus explicitly on longitudinal change.

Second, although strategic management literature emphasises that longitudinal change is at the heart of firm-level competitiveness, this literature has not been integrated into the industrial policy framework. An understanding is required of how the theoretical constructs of strategic management scholars connect to infant industry literature. Such an understanding will in turn guide the implementation of more effective policies. In particular, studies at the individual firm and sectoral level are required in order to parse capability development that is derived through developmental state policies versus capability building that is orchestrated from within the entrepreneurial firm.

Third, empirical studies have continued to concentrate on quantitative analyses, using output measures such as R&D expenditures, publications, and patent applications to judge capability building. However, data aggregation and proxy measures do not capture the complexity and nuances of industrial capability building and the effects of developmental state industrial policies. There remains a gap in the literature for highly detailed qualitative case studies.

The review of selected empirical and theoretical literatures in this chapter indicates that an analytical structure to deal with the transition from a developmental state-led to a more decentralised, entrepreneur-led economy can be built on foundations from extant literature employing a multi-disciplinary approach (Eisenhardt and Graebner, 2007). This is the approach taken in this thesis.

Both empirical studies in north-east Asia, and theoretical explications of the logic of 'getting prices wrong' in order to incentivise firm-level capability-building (Amsden, 1989), demonstrate the catalytic role of the developmental state. Transaction cost economics (TCE) highlights the role of vertical integration in promoting firm-level learning and TCE extended to the institution of the developmental state (Chang, 1994) explains why such governments play a critical early role in coordinating the economic capability-building process at the firm level. The weak excludability of intellectual property in early-stage developing economies, which is highlighted by endogenous growth theory (EGT), is not an obstacle to developmental state-led acquisition of technologies. Instead, EGT recommends that developmental states focus early

upgrading efforts on non-excludable technologies and orchestrate high levels of competition at the firm level in order to ensure those technologies diffuse widely.

Empirical studies of *how* firms learn manufacturing technologies stress that successful acquisition is sequential and cumulative, flowing from less to more challenging tasks, and from lower to higher requirements for tacit knowledge. The successful developmental state is the institution that ensures this conservative, cumulative approach to manufacturing technology acquisition is observed. The state's key roles are those of identifier of sequential targets for technology absorption and organiser of the requisite mix of subsidy and competition that ensures firm-level attention to those targets.

However, longitudinal empirical studies in north-east Asia also highlighted that narrowly-constructed manufacturing technologies were, on their own, insufficient to make emerging firms globally competitive. Evolutionary economics in turn theorises that the most difficult to replicate firm capabilities, and the ones that provide the most durable competitive advantages, are tacit capabilities that are not located in machine-embedded production skills, but rather in firms' strategic and organisational resources and their capacity to change 'ways of doing things' (Nelson and Winter, 1982:207). This theoretical construct echoes the empirical regularities highlighted by Chandler in his historical studies of US industry. More recently, the view was reinforced and crystallised by the empirical and theoretical work of management scholars, who emphasised not only the importance of dynamic capabilities within



firms, but also that those capabilities must co-evolve with changing external environments. When the external environment is frenetic, as it is in high-technology sectors or in the high-growth environment of an FDC, the importance of entrepreneurial dynamic capabilities in determining firm-level success is particularly pronounced.

A multi-disciplinary analytical framework suggests there will be an inevitable tension between the competitive advantages that the developmental state delivers and those that the entrepreneur delivers. The fundamental reason for this is that the developmental state's contribution is focused on the management of technological upgrading, whereas the entrepreneurial firm's contribution derives principally from the development of dynamic capabilities – capabilities that are more clearly reflected in ongoing strategic choices rather than in narrow technological capacity. This distinction is, of course, a simplifying one. In reality, the developmental state impacts on the creation of firm-level dynamic capabilities and firms are the institutions through which developmental state technology plans are actioned. Nonetheless, the empirical and theoretical literature reviewed highlights that the contributions of the developmental state and the entrepreneurial firm differ. The manner in which they differ is stylised in Figure 3.

**Figure 3. Developmental state versus entrepreneurial firm: an analytical framework**

<b>Developmental state</b> <i>focused on</i>	<b>Entrepreneurial firm</b> <i>building</i>
<b>Manufacturing capabilities</b>  Facilitated by vertical integration  Conservative, step-by-step learning  Not impeded by low excludability of IP  Honed through competition  Largely insulated from external environment	<b>Dynamic capabilities</b>  Require change  Reward risk-taking  Supported by greater excludability of IP  Aim for monopoly profits  Driven by evolving external environment

The strategic management literature highlights dynamic capabilities as the defining attribute of the most competitive firms and hence the challenge in the developmental state-led economy is that of a *transition* in which the interventionist strategies of the state do not impede the growth of dynamic capabilities within entrepreneurial firms. The three empirical chapters of this thesis examine how the transition took place in three different, but related, industrial sub-sectors. Within the three sub-sectors, firms were repeatedly pressed by the developmental state to learn new, imported technologies. These technological challenges, or ‘resets’, provide the tests by which transitions in different sub-sectors, and the performance of individual firms, are qualitatively assessed.

In terms of quantitative assessment, the research questions require that the most globally competitive case study firms are identified. In order to do this, the thesis follows orthodox convergence theory (Dollar and Wolff, 1993, Kerr, 1983, Spence, 2011, Baumol et al.) in assuming that, as the Chinese economy develops, there will be a convergence of profit margins between China's best firms and their leading multinational peers.

Consequently, the best companies in the power equipment businesses surveyed are compared on a range of standard profit ratios, including gross margins, operating margins, net margins and returns on assets with the most profitable multinational firms. All but one of the case study companies are listed on stock markets in Hong Kong and the United States, and so financial returns under similar accounting regimes are available for them and can be compared with multinational competitors. Inevitably, such comparisons are subject to many possible distortions; the comparison seeks only to establish long-run trends.

## **Chapter 2**

### **Methodology and research design; and the research challenge posed by China's decentralised polity**

#### **2.1. Methodology and research design**

In order to address the research questions, this thesis uses a positivist, exploratory case study methodology. Yin (2003) asserted that case studies are appropriate for research questions that tackle 'how' and 'why' questions and require the building of explanatory links. The research questions in this thesis demand that explanatory links are developed as to how state-to-firm relationships evolved under conditions of industrial policy and industrial capability building; and how this process connected to the rise of the most competitive firms in China's electricity generating equipment sector.

Yin (2003) also noted that case studies are appropriate where research has minimal control over events and focuses on contemporary phenomena. On the first point, the evolution of state-firm relations in China could not be subjected to experimental control. On the second point, the subject of this thesis is the evolution of relationships and conditions that exist in the contemporary economy. In addition, Eisenhardt (Eisenhardt and Graebner, 2007, Eisenhardt, 1989) argued that case studies may be used to build theory where existing theory is insufficient to answer research questions. As discussed in Chapter 1, there is a paucity of theoretical work on the longitudinal evolution of state-firm relations under industrial policy, or the factors that contribute to firm-level success during this process.

This thesis employs an embedded case study design, allowing for multiple levels of analysis (Scholz and Tietje, 2002, Yin, 2003). The reason is that the research questions can only be answered by examining both the industry sub-sector and firm-level experiences in each of the thermal, wind, and solar power equipment businesses. The different electricity generating sub-sectors allow this thesis to use technological ‘resets’ – the launch of a new product category – to determine which government- and firm-level structures and strategies led to the best firm-level outcomes when new learning challenges occurred.

The research construct does not, however, include every sub-sector of the electricity generating industry. Hydropower turbines were excluded as being too technologically similar to thermal coal turbines, and made only by state-owned firms. Large gas turbines (LGTs) are also made only by state-owned firms, but were included because they represented a significant step up in terms of the technological challenge to manufacturers. Nuclear power equipment was excluded, despite China having a major commitment to it, because: only two, state-owned firms are involved; nuclear technology – like thermal coal turbine technology – evolved in a linear, non-disruptive fashion; and it is less certain that nuclear power will be as important in the future as wind and photovoltaic power (Madhavan et al., Forthcoming, Lu, 6 June 2016).<sup>43</sup> The choice of technological resets considered is summarised in Table 1.

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<sup>43</sup> The two Chinese nuclear firms are China National Nuclear Corp. (CNNC) and China Guangdong Nuclear Power Corp. (CGN), founded in 1989 and 1994 respectively. Madhavan et al.’s recent study of China’s nuclear programme provides strong ‘validating’ support (see discussion below) for the

**Table 1. Technological resets by scale of technical challenge and firm ownership**

Sub-sector	Major new technology challenge?	Diverse firm-level ownership?	Included?
Coal turbines	Yes	No	Yes
Hydro turbines	No	No	No
Large gas turbines	Yes	No	Yes
Nuclear turbines	Yes	No	No
Wind turbines	Yes	Yes	Yes
Photovoltaics	Yes*	Yes	Yes

\*It is argued in Chapter 5 that photovoltaics (pv), represents a major technology challenge in terms of the production of polysilicon and pv manufacturing equipment, as well as downstream servitisation, rather than in the pv module assembly area in which China started.

There was a further constraint of space in an 80,000-word thesis. On this point, it should be noted that I visited key lithium-ion battery and electric vehicle manufacturers in China in order to further inform and test the evolving theory in this thesis. These sub-sectors of the broad power industry are characterised by both diverse firm-level ownership and major technological resets. The firms visited included Tianjin Lishen Battery (天津力神电池), Great Wall Motor in Baoding, and BYD in Shenzhen. The empirical material is not included in the thesis, however it did further validate several of the findings presented in Chapter 6.

Within the thermal, wind and photovoltaic sub-sectors, the research strategy, similar to the logic of Eisenhardt and Graebner (2007), was to visit a larger number of case study firms and then to focus on a

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findings of this thesis. In particular, the authors highlight returns from China's 'skilful [centralised] bargaining' for nuclear technology; and they find that it was three forces, namely 'industrial policy, regulation and enterprise initiative [that] have shaped the direction and scale of investment and capability building in this technically demanding field' (forthcoming:510).

subsidiary group of firms that appeared most likely to succeed. The identification of success was based on polling industry leaders, consultants, suppliers and customers throughout an extended fieldwork period, from 2009 to 2016.<sup>44</sup> As was expected, particularly in an FDC environment, there was some adjustment of choice of core case study firms during the fieldwork. In the wind sub-sector, Envision Energy rose rapidly in the estimation of industry participants to be recognised as the key challenger to leader Goldwind.<sup>45</sup> In photovoltaics, the industry leader in the middle of the manufacturing chain, Suntech, collapsed in a spectacular bankruptcy. However, the mistakes that Suntech management made were sufficiently informative to the theory-building exercise to warrant the firm's inclusion in this study. With respect to the sectoral leaders in thermal, wind and photovoltaics, an overwhelming majority of persons polled was in agreement throughout the research period: Shanghai Electric, Goldwind, and GCL Poly, respectively.

The sampling framework for the research varied across the three sub-sectors. In the thermal sub-sector, universal state ownership was accompanied by a competitive environment in which only three large firms – Shanghai, Harbin and Dongfang – were permitted to operate and hence the sampling frame was very small. In the wind and photovoltaic sub-sectors, unrestricted market entry saw more than 100 firms enter each of the businesses, according to anecdotal press reports and industry estimates. No complete sampling frameworks were available as many of these firms were small and not identified in national lists.

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<sup>44</sup> The fieldwork started in 2009-10; I then intermitted for almost two years.

<sup>45</sup> Industry participant estimation of Mingyang fell significantly during the research period as the firm failed to deliver technologically; however, Mingyang remained a major player in volume terms (see Chapter 4).

However, industry associations – the China Wind Energy Association (CWEA) and the China Photovoltaic Industry Association (CPIA) – and data aggregators including Bloomberg New Energy Finance provided sampling frameworks for larger firms based on sales volumes that were cross-referenced. In both the wind and photovoltaic sub-sectors, the 10 largest firms accounted for the majority of output and it was among these firms that the most promising businesses were sought. The sampling framework was not complete, but it was comprehensive. Ongoing analysis of performance data and polling of industry participants were employed to tackle any selection bias in identifying the most successful firms. Nonetheless, it should be noted that it was not critical to the research programme that *only* the very best firms were studied, rather that those studied were among the best and reflected strategies leading to success in each sub-sector.

The focusing down of the core case study group of seven firms was important in two ways. First, as with Zott and Huy's seminal investigation of entrepreneurship and symbolic management (Zott and Huy, 2007), it was the core group of more successful firms that produced the clearest insights; the discarded, or secondary, case study firms simply tended to confirm the findings because their relative lack of success was consistent with them.<sup>46</sup>

Second, as Eisenhardt (1991) noted in an earlier analysis of case-study based research, what she termed 'background' cases validate core case

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<sup>46</sup> Zott and Huy (2007) focused down from 26 to seven firms; in this thesis I focused down from 20 (three thermal firms, seven wind firms, 10 photovoltaics firms) to seven firms; the less established the industry sub-sector the more firms I initially looked at.



studies. There was an instance of this in my fieldwork, where early research into the development of the Harbin and Dongfang thermal equipment manufacturers, covered in Chapter 3, produced sufficiently similar results to what was observed in Shanghai that it was decided to make the former subsidiary, background cases. Fieldwork in the thermal sub-sector could therefore be concentrated on Shanghai, with sufficient information about Harbin and Dongfang available from secondary sources, from technology suppliers to Shanghai who also worked with Harbin and Dongfang, and from Shanghai's own managers, to be confident that Harbin and Dongfang's experiences validated the development pattern set out. This focusing approach allowed for the conduct of a large number of interviews in Shanghai, and the identification of difficult-to-trace interview subjects who worked there starting in the 1980s, providing a level of analytical detail for the most successful firm in the sub-sector that would not otherwise have been possible.

The successful firms in the chosen electricity generating equipment sub-sectors provide a qualitatively homogenous group in which I searched for variances in order to build 'precise mid-range theories' (Zott and Huy, 2007:75, Gartner, 1985). The seven foreground case study firms are listed in Table 2.

**Table 2. The seven case study firms and their industry sectors**

Formal firm name	Sector	Abbreviation
Shanghai Electric Group Co.	Thermal	Shanghai
Xinjiang Goldwind Science and Technology Co.	Wind	Goldwind
China Mingyang Wind Power Group	Wind	Mingyang
Envision Energy Co.	Wind	Envision
Suntech Power Holdings	PV	Suntech
Canadian Solar Inc.	PV	Canadian Solar
GCL-Poly Energy Holdings	PV	GCL

One drawback of the selected core case study firms was that one firm, Envision Energy Co., remained unlisted and hence audited financial statements were unavailable. However, as noted, Envision was deemed sufficiently important by industry participants -- in representing a new stage of strategic competition -- that it was included.

This thesis employs two types of data. The first is semi-structured interviews (Flick, 2002): with contributors to the government industrial policy-making process; with entrepreneurs and managers at the firm level; and with foreign technology suppliers able to comment on both government industrial policy evolution and the development of firm-level technological capabilities. In their analysis of effective theory-building from case studies, Eisenhardt and Graebner (2007) highlighted the need for numerous, highly knowledgeable informants; and for informants at different hierarchical levels within organisations, who are able to offer different perspectives.

In this thesis, the government group of interviewees included employees of the NDRC, of subsidiary 'support units' (*shiye danwei*) that provide research input to the NDRC and its National Energy Administration, academics retained as government policy consultants at Tsinghua and Jiaotong (Shanghai) universities, and third-party analysts of government policy evolution. The firm-level group included founding entrepreneurs at two of the case study firms, main board directors at two others, and senior managers at the remaining three. Mid-level managers with relevant specialist knowledge, mostly in strategic planning and technology sourcing, were interviewed at all of the firms. In the case of Shanghai Electric Group Co., where it was necessary to interview managers responsible for technology transfer beginning in 1978, current management convened a group of retired managers and technical specialists for a full day of discussions. The third, foreign technology supplier group of interviewees comprised on-site and off-site consultants to Chinese firms, third-party vendors of technology, joint venture partners, and foreigners directly hired by Chinese companies for limited periods to deliver specific technical upgrades.

In total, 74 interviews were undertaken, lasting between one and three hours (Tables 3 and 4). Most interviews took place face-to-face in China; those with executives of Chinese firms employed outside China, and with foreign technology providers based outside China, took place either face-to-face or by telephone in Europe and the United States. This dissertation is based primarily on detailed field notes rather than full transcripts as most interviewees requested not to be recorded. The researcher took extensive notes of each interview and reviewed and

annotated these within 24 hours of the interview. The interviewees were granted anonymity. An anonymised list of the interviewees with indicative information about their roles is contained in Appendix 1.

**Table 3. Interviewees by category**

Government industrial policy institutions and analysts	11
Case study firm interviewees	39
Technology partners and suppliers	24
Total	74

**Table 4. Firm-level interviewees by category\***

Thermal power equipment case study firm management	5
Thermal power equipment case study firm technology partners and suppliers	10
Wind turbine case study firm management	16
Wind turbine case study firm technology partners and suppliers	8
Photovoltaic case study firm management	18
Photovoltaic case study firm technology partners and suppliers	6

\*Two important interviewees in the solar sector were private equity financiers who funded technology acquisition at Chinese firms prior to their IPOs. They are not included here.

Interviewees were selected by snowball sampling (Flick, 2002), beginning with cold call approaches by the researcher to target firms and government agencies. In a small number of instances, executives at target firms were immediately responsive to requests for meetings. In others, multiple approaches were necessary before an initial interview was secured. In still other instances, initial contacts were made with otherwise inaccessible firm employees and government officials through technical and sales conferences and seminars that the researcher

attended. One important introduction to a senior Chinese government official was secured via a senior academic with whom the person had a long-term working relationship. In all cases, the logic of the snowball sampling was to identify and interview subjects who could materially contribute to answering the research questions of the thesis.

At the case study firms, a consistent approach was taken to interviews with senior executives by beginning the interview with a standard set of five questions, which forms Appendix 2. The questions focused on executives' perceptions of key issues in the research: the nature of competition in their industry; their firm's relationship with the developmental state; their firm's strategic choices; their firm's approach to innovation; and their firm's export strategy. The questions were consistent but broad and open-ended, and used as part of a quest for common themes as the number of interviewees at case study businesses built up.

Interviews were analysed through thematic coding (Flick, 2002). Manual coding was preferred to an automated software package since the interview data was mostly derived from detailed field notes. The use of manual coding allowed for greater precision and flexibility in discerning thematic patterns. Data analysis in the thesis follows Yin's (2003) pattern matching technique, requiring revision to the theoretical expectations set out in Chapter 1 based on data findings. Multiple sources were used to enable data triangulation in the quest for 'replication logic' (Yin, 2003).

The second type of data in this thesis is firm, government, and industry association documents such as quarterly and annual company reports, technical publications, government reports, and written press coverage. Some Chinese language radio and broadcast interviews with entrepreneurs and government personnel handling industrial policy were also reviewed. The sampling method for this data source was theoretical sampling (Flick, 2002). In practice, this meant that as interpretative theory was developed during the interview coding process, secondary materials were sought on the basis of their relevance, either supporting or contesting the interpretation (Marshall, 1996).

All monetary figures quoted in this thesis that are given with currency conversion, usually from Renminbi to US dollars, were converted on the basis of the average exchange rate during the year in question.

The central unit of analysis in the thesis is the seven case study firms. Since the different firms developed capabilities in three different, but related, businesses, and did so in periods ranging from the late 1970s to the current era, a standard template is applied in examining their progress. This template is consistent with studies in the development economics (for instance: Lall, 1987) and value chain (Gereffi, 1999, Kaplinsky and Morris, 2001) literatures on technology acquisition in using a stage-based approach. Three fundamental stages are considered. The first is dubbed 'search and bargaining', when either the state or firms search for, assess, and bargain for necessary technology. The second stage is one in which firms initially master the manufacturing of

globally mature technologies. The third stage is one in which firms approach the global technological frontier and begin to adapt and alter current technology in a step towards the capacity to create new technology. This three-stage construct is not designed to analyse the acquisition of manufacturing technology in exhaustive detail, since the thesis concentrates much of its attention on aspects of competition outside narrow manufacturing capabilities. However, the arrangement does provide a common structure for discussion across all three business sectors.

The sample size of seven firms in this thesis is sufficient to enable valid inferences to be drawn in Chapter 6 for three reasons. First, the research is limited to three sub-sectors of the electricity generating equipment industry and does not claim wider generalisability, something that is not necessary to valid qualitative research (Marshall, 1996). Instead, this thesis contributes to a theory building process and identifies important areas for fruitful future research. Second, the focus of the research questions is on successful firms and successful policies that nurtured those firms. The sample includes some of the best-performing firms, if not the best firms, in the three sub-sectors. Seven cases is therefore a substantial population. Third, and of greatest practical consequence, answering the research questions required a high level of case study detail involving many interviews and the sample size is necessarily reduced in order to deliver this detail.

As noted, the findings set out in Chapter 6 do not claim generalisable status across different industries; however, it is hoped they will be

tested across different industries. The minimum aim of Chapter 6 is to highlight empirical regularities that contribute to a theory-building process that aspires to produce ‘theory that is accurate, interesting and testable’ (Eisenhardt and Graebner, 2007:26).

## **2.2. The research challenge posed by China’s decentralised polity**

China fits the industrial policy model associated with Japan, South Korea and Taiwan for four main reasons. The first is the simple fact of central government’s commitment to proactive industrial policy since 1978, in addition to market reforms (Naughton and Tsai, 2015). The second is the presence of a small, focused, formal industrial policy planning apparatus, centred on the NDRC, and playing a role similar to that in the past of the MITI in Japan, the Economic Planning Board (EPB) in South Korea, and the Industrial Development Bureau (IDB) in Taiwan (Studwell, 2013). The third reason is that, as in Japan, South Korea and Taiwan, China’s planning bureaucracy is coupled with a substantial, applied science and technology (S&T) apparatus that supports and funds research at firm level, overseen by the MOST. And the fourth reason is the presence of close state control over the financial system in order to support industrial policy objectives (Naughton, 2007, Patrick and Park, 1994, Woo, 1991).

However, as noted in Chapter 1, China differs from the other three north-east Asian states in its degree of political and fiscal decentralisation. A large literature exists about whether, from a developmental perspective, China’s decentralisation has been beneficial or not. Optimists argued that powerful local governments competed



with one another and delivered efficient, pro-development governance (Oi, 1999, Montinola et al., 1995, Xu, 2011) while still answering to and coordinating with central control (Landry, 2008, Li and Zhou, 2005). Pessimists argued that China's decentralised polity was associated at local level not with efficacious competition, but with protectionism, industrial over-capacity and local government debt (Poncet, 2005, Li et al., 2004, Young, 2000, Li, 2002, Walter and Howie, 2012), while vested interests and policy idiosyncrasies frequently undermined central government objectives in industrial policy planning (Wong, 1987, Thun, 2004, Li and Wu, 2012).

This variation of views reflected the fact that decentralisation had both positive and negative implications for development. What was consistent was that central and local influence over policy-making in China ebbed and flowed. This makes a longitudinal research design in China (at least where the research is not focused on the phenomenon of changing centre-local relations) particularly challenging. In the case of this thesis, when the research design was initially put together in 2010, the photovoltaics sector was one whose development was largely determined by local government policy, making it a 'control' for the influence of central government industrial policy support when compared with the wind turbine business. For reasons discussed in Chapter 5, in 2012 central government changed its policy on the photovoltaics sub-sector, becoming more important to the industry than local government and creating national, demand-side subsidies on par with those in the wind sub-sector. However, as will be detailed, the NDRC and the NEA, following central government's change of policy,

were slow to adjust to the idiosyncrasies of the solar sector and to centralise policy control. The result was that the impact of a changed state-firm relationship in the photovoltaics industry was only just becoming apparent at the time of writing. This renders some of the conclusions reached with respect to the solar sector more tentative than they would be in a country where local policy-making was less important and the centre-local policy relationship more stable.

## **Chapter 3**

### **Thermal power: the state sets off**

Of the three case study sectors analysed in this thesis, the thermal power equipment business is the one that shows the Chinese technological learning process in its earliest stages after 1978. The sector highlights both how much the developmental state was able to achieve in setting the agenda and framing the means for manufacturing technology acquisition, and how this was ultimately inadequate for competitiveness at the global frontier, as suggested by the strategic management literature. In particular, state policies tended to ossify pre-existing path dependencies in the sub-sector, inhibiting the emergence of the most globally competitive firms possible.

#### **3.1. Historical background**

From 1954 to 1960, as part of the Sino-Soviet technology transfer partnership begun during the first Five-Year Plan (1953-7), China imported manufacturing technology and production training for 6MW, 12MW and 50MW coal-driven turbine-generator sets from Russia and Czechoslovakia. The technical cooperation ended prematurely when Russian advisers left in 1960 as a result of the Sino-Soviet split (Lüthi, 2010). In the following two decades, Chinese state-owned manufacturers sought to scale up the imported technology. Harbin, the locus of the Russian technology transfer project, developed a 200MW turbine-generator set, as did Dongfang, a 'third-line' (Naughton, 1988) manufacturing unit located in Sichuan province, and Beijing Heavy

(BeiZhong) in the capital. Shanghai developed a 125MW unit and a 300MW unit.<sup>47</sup>

While Shanghai's 125MW turbine-generator set, first commissioned in 1969 at the city's Wujing power plant, functioned reliably, the 200MW and 300MW units were plagued with breakdowns, including turbine blade breakages that closed plants for months and caused considerable collateral damage, and even with instances of turbine rotors being bent out of shape such that entire turbines needed to be replaced. In sum, Chinese engineers were unable to deliver reliable performance when much higher operating pressures and multiple cycle steam re-heating were required for the larger turbine units. Even in the mid-1970s, with an installed electricity generating base of just 60GW, China was unable to meet its demand for power equipment from domestic sources and consumed a substantial share of scarce foreign exchange reserves importing generating units of 300MW and above from European and Japanese suppliers (Shi, 2013).<sup>48</sup>

### **3.2. Stage 1: Search and bargaining**

The importation and absorption of modern technology for making power equipment was a Chinese priority from the inception of the 'reform and opening' era. In the two months leading up to the Third Plenum of the 11<sup>th</sup> Central Committee of 18-22 December 1978 – the

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<sup>47</sup> The key, state-owned power equipment production units discussed in this chapter have changed the names of their main manufacturing units on numerous occasions since 1978. For the sake of consistency and simplicity, the businesses are referred to simply as 'Harbin', 'Dongfang' and 'Shanghai'; see Company names, p9, for their current formal names. This paragraph and the following one are based on Th11, Th13, Th14, 20 July 2016 involving current and retired staff of Shanghai Electric Group. See also Tan and Seligsohn (2010).

<sup>48</sup> Th11, 20 July 2016 confirmed this background. Installed power-generating capacity in China rose to 65.9GW by the end of 1980 according to data from the National Bureau of Statistics.

event from which the reform and opening era is normally dated – two multi-week, high-level Chinese government delegations visited more than one dozen manufacturers of power-generating equipment in six European countries and Japan. The Europe delegation was led by Zhou Zijian, Minister of the First Ministry of Machine Building (FMMB), and the Japanese delegation by Zhou Jiannan, a vice minister of the FMMB (Shi, 2013).

The visits to power equipment makers and scores of other European and Japanese industrial firms in priority sectors covered by the FMMB<sup>49</sup> led to a ‘Report on the use of foreign experience in order to speed up the development of the machinery industry’<sup>50</sup>, submitted to the State Council on 25 January 1979, shortly after the Third Plenum concluded. The power equipment sector was a particular focus of the report.

The report reviewed the range of possibilities for technology transfer, including licensing, joint ventures, and personnel training by international firms, as well as suggesting the possibility of exporting in order to recoup investment in technology transfer.<sup>51</sup> During 1979, the State Planning Commission and interested agencies, including the FMMB and the Ministry of Electric Power (MEP, which operated the power

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<sup>49</sup> As well as power equipment, the FMMB was responsible for industrial sectors including agricultural equipment, automotive, and machine tools. Not all company visits on the foreign tours by the Ministry in October-December 1978 were formally scheduled. According to Martin Posth, who headed Volkswagen’s first joint venture in China, a group led by Minister Zhou Zijian turned up at Volkswagen’s Wolfsburg headquarters in November 1978 unannounced. Through an interpreter Minister Zhou told a security guard: ‘I am the Chinese Machine Building Minister, and I would like to speak to somebody in charge at Volkswagen.’ (Anderson, 2012:56).

<sup>50</sup> In Chinese the report was titled *Guanyu jiejian guowai jingyan jiakuai jixie gongye fazhan de baogao*.

<sup>51</sup> Wishful thinking about export possibilities and foreign exchange earnings from upgraded industrial plants was a common theme of early Chinese industrial planning. See Anderson’s (2012) review of the automotive industry.

plants), reached a consensus that the best strategy was to license the use of manufacturing technology and to purchase necessary training to make the transfer successful (Shi, 2013). The specific focus of the technology transfer would be 300MW and 600MW sub-critical turbine-generator sets and auxiliary equipment, representing the mature contemporary products of multinationals. (The technological frontier undergoing commercialisation at the time was 750MW units with super-critical heat and pressure performance.)<sup>52</sup> In February 1980, the strategy was formally approved by the State Council (Shi, 2013). Negotiations with foreign technology suppliers were to be led by the FMMB. The MEP, which wielded outsize influence as the end-user of power-generating equipment, was also involved.<sup>53</sup>

It is unclear how many foreign power equipment firms entered negotiations for the technology transfer. A senior technical director at Shanghai who participated in the negotiations recalled General Electric (GE); Brown, Boveri & Cie. (BBC, from 1988 part of the ABB Group); Alstom; and Westinghouse.<sup>54</sup> It is unlikely that Japanese firms tendered because at the time they remained dependent for thermal power

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<sup>52</sup> Westinghouse was commercialising 750MW super-critical units in 1980; Th1, 9 June 2014. Super-critical power plants operate at higher temperatures and pressures (approximately 565 degrees centigrade and 24 MPa depending on mechanical configuration) in order to increase the efficiency of energy conversion from coal to electricity to 37-42 percent. Ultra super-critical plants, discussed later in this chapter, operate at approximately 600-615 degrees and 32 MPa to achieve conversion efficiencies of 42-45 percent (Nalbandian, 2008).

<sup>53</sup> Th2, 26 January 2016. Th11, 20 July 2016. Within the FMMB, the Electrical Power Bureau and the Machinery Import-Export Bureau were the offices leading negotiations. A retired senior engineer at Shanghai who was present at the negotiations said that the MEP was in practice more powerful than the FMMB because the end-user had greater budgetary clout than the equipment supplier. Westinghouse executives involved in the negotiations concurred that MEP officials consistently gave the impression of having great power in the negotiations.

<sup>54</sup> Th11, 20 July 2016.

equipment designs on technology licences from GE and Westinghouse.<sup>55</sup>

Overall, Chinese government approaches to potential technology providers appear not to have been exhaustive in their scope. According to a senior Westinghouse executive, the firm found out about the technology transfer tender only because of information gleaned in the marketplace by its Hong Kong marketing manager.<sup>56</sup>

There were three main areas of discussion for a Chinese technology transfer agreement. First, the cost and parameters of the technology transfer: would it include only plans for the machines that were licensed or would it include the IP rights, files, software and so on necessary to develop a design capability? Second, the cost and scope of worker and management training. And third, the arrangements for payment of royalties on power equipment manufactured under licence.

General Electric (GE) and Westinghouse, which emerged as the two preferred bidders, had licensed power equipment technology to manufacturers in different parts of the world, including Europe. In east Asia, the precedent for what might happen in China was Japan, where GE and Westinghouse were licensors, respectively, to Hitachi and Toshiba, and to Mitsubishi Heavy Industries (MHI), before the Second World War, and entered new licensing arrangements after the war ended.

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<sup>55</sup> Details two paragraphs below. The Japanese firms did not achieve technological independence until the late 1980s and early 1990s, as discussed later in this chapter.

<sup>56</sup> Th3, 11 February 2016. The information led to a request to tender from Westinghouse and a visit by Eugene Cattabiani, President of the firm's Power Generation business group, to Beijing.

A retired executive from the licensing department at Westinghouse (which won the tender) outlined the history of licence agreements with MHI. Until the late 1960s MHI, which had been making turbine-generator sets to Westinghouse designs since the early 1920s, was content with what he described as 'build to print' licences, meaning that the firm simply produced machines based on specifications and drawings it was supplied with. MHI was granted 10-year licences, for which it paid upfront fees plus royalties on every machine sold. In negotiating royalty percentages, Westinghouse aimed, as a rule of thumb, to secure one-quarter to one-half of the net profit expected on each machine.

Beginning in the late 1960s, and continuing in 10-year licence renegotiations in the late 1970s, and 1980s, MHI pressed to include progressively more design know-how, including access to software used to calculate stresses on different parts of a turbine, as well as requesting to be allowed to change the designs of different parts of turbine-generator sets without case-by-case payment to or approval from Westinghouse. MHI's technical capabilities continued to increase and, in a final 10-year agreement signed in the late 1980s, the Japanese firm made a 'concluding' payment for technology so far received and henceforth became an equal co-developer with Westinghouse of new products, on which no royalties were paid.<sup>57</sup>

The context of the negotiations in China in 1980 for US power equipment firms was markedly different to that in Japan following its

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<sup>57</sup> Th4, 4 February 2016; Th1, 9 June 2014. The focus of co-development work was gas turbines. The joint development relationship was terminated prior to, and as part of, Siemens' takeover of Westinghouse in 1998.



defeat to the US in the Second World War. In 1980, the US economy was in recession, with the power equipment sector in dire straits. After a boom in the mid-1970s, domestic demand for coal-fired power plants fell close to zero, while the partial nuclear meltdown at Three Mile Island in March 1979 put the American nuclear sector, which had been expected to deliver steady growth for power equipment firms, into reverse (Cen et al., 2009:26-31).

In these conditions, noted a senior Westinghouse executive responsible for technology licensing, Chinese central bargaining for the technology transfer was highly effective in negotiating up the scope of the technology transfer and negotiating down the final price. The package ultimately agreed with Westinghouse in September 1980 included all documentation, software and software source code necessary to design as well as manufacture 300MW and 600MW turbine-generator sets. The contract included 1,700 man months of worker training and 260 man months of management consultation. Royalties were not payable on power equipment produced for the domestic market, only on exports.<sup>58</sup>

The terms were far superior to those secured by Japanese companies, which Westinghouse never provided access to computer program source code and which always paid royalties on domestic sales, including at a rising rate for turbine-generator sets of higher output. In the course of negotiations in China, Westinghouse reduced its price for the complete technology transfer package from US\$60m to US\$13.8m.<sup>59</sup> Moreover,

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<sup>58</sup> Th8, 14 September 2016.

<sup>59</sup> Th2, 26 January 2016. In a separate interview, a senior engineer from Shanghai Electric who was present at some of the negotiating sessions said GE asked US\$60m for the technology licence alone,

payment for the licence was conditioned on the successful commissioning of two ‘verification’ power plants to show that the technology had been accurately transferred and absorbed; again, there was no precedent for this in Japan.<sup>60</sup>

Westinghouse executives involved in the negotiations recalled that the Chinese side was able to maximise competitive pressure and create a Dutch auction atmosphere in the final days of bidding by assembling representatives from Westinghouse and GE on different floors of the same building in Beijing. On occasion, representatives from the two firms found themselves in the same elevator, but did not speak.<sup>61</sup> GE was the favoured bidder of the MEP, the end user, which preferred its technology. However, GE would not match Westinghouse’s terms and Westinghouse technology had supporters within the FMMB and among a handful of senior Chinese engineers who had received Westinghouse training in the 1940s.<sup>62</sup>

In the year that followed the contract signing, Westinghouse dispatched 20 tonnes of equipment specifications, manufacturing layout plans, engineering drawings, computer program and source codes to China.<sup>63</sup>

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before any training, while BBC asked US\$30m for the technology licence alone; it is not known what the final offers from these two firms were; Th11, 20 July 2016. A 2001 case study of Harbin reported that for boilers (which Westinghouse did not manufacture), Harbin signed a contract with Combustion Engineering of the US that specified payments of US\$13.45m for 600MW boiler technology and US\$20m for ‘air pre-heating technology’; the case study provided no source for this information. If accurate, the information suggested Combustion Engineering, which was taken over by ABB in 1990, fared much better than Westinghouse in negotiations (Nolan, 2001:chapter 6).

<sup>60</sup> Th8, 15 September 2016, Th2, 26 January 2016. The verification plants were built under separate contracts under which Westinghouse supplied those components that could not yet be manufactured.

<sup>61</sup> Th2, 26 January 2016.

<sup>62</sup> Th11, 20 July 2016.

<sup>63</sup> Th2, 26 January 2016. A Chinese interviewee said he was told that documents alone amounted to 17 metric tons. Separately, 102 computer source codes were provided. Th11, 20 July 2016.

Westinghouse and Chinese interviewees who were party to the negotiations concurred that Chinese negotiators consistently demanded ‘everything Westinghouse uses and everything Westinghouse has’<sup>64</sup> be included in the technology transfer contract;<sup>65</sup> however it appears that the final text specified all technology *in commercial operation*.<sup>66</sup>

In order to deliver on the terms of the contract, Westinghouse managers described the development of scores of training manuals -- typically several hundred pages long -- to support training across manufacturing, quality control, and engineering design. Since the contract defined training time as that of the trainer, not the trainee, the Chinese were able to send an average of three trainees for every module taught. Managers, power plant engineers, design institute engineers and others were all dispatched to the United States for training. At a peak at Westinghouse’s Pittsburgh generator plant alone, there were 100 Chinese trainees; a total of 554 persons were trained at different factories, staying in the US for an average 2-3 months.<sup>67</sup>

At one level, China secured an exceptional deal. All Westinghouse executives interviewed concurred that the US company lost money in delivering the training involved in agreement. The senior leadership of

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<sup>64</sup> Th2, 26 January 2016.

<sup>65</sup> Or as a Chinese interviewee put it: ‘all the technology they had in their database’. Th11, 20 July 2016.

<sup>66</sup> It was not possible to view the final contract. It became apparent to the Chinese side during training that Westinghouse was developing new technology. The FMMB asked for access to this but was told that it was not included under the terms of the contract.

<sup>67</sup> Th2, 26 January 2016. Persons travelling to the US for manufacturing and quality control modules normally stayed around two months; those travelling for engineering design modules stayed 2-5 months. All those who travelled from China were given a six-week crash course in English-language power equipment vocabulary before they left. Interviewees at Westinghouse reported that language barriers were less of a problem than anticipated, largely because engineering concepts are universal.

Westinghouse had given clear instructions to negotiators that they should not lose the tender on price; the contract was regarded as a loss leader and a foot in the door of an important new market.<sup>68</sup> On its side, apart from paying a low price, China gained access to the information and training required not only to manufacture thermal turbine-generator sets, but to develop a design capability, too.

### **3.3. Stage 2: Manufacturing of mature technology**

China's capacity to absorb the technology it secured, however, was limited. The FMMB acted as the central technical hub for all power equipment production, and key technical personnel worked there. This facilitated the central bargaining process and the diffusion of the technology acquired, but it discouraged competition and initiative at the manufacturing sites. Westinghouse technical documentation was received in Beijing, copied, and distributed to the manufacturing operations in Harbin, Shanghai and Sichuan, and to relevant design institutes. The ministry assigned roles to the different manufacturers, with Harbin told to produce a 600MW turbine-generator set, Shanghai a 300MW turbine-generator set, and Dongfang (in Sichuan) the auxiliary pump turbines required by power plant boilers.

However, the manufacturing operations, as units of the FMMB, showed almost no independent initiative in carrying out their tasks. In a grindingly bureaucratic working environment, Westinghouse managers responsible for training noted, for example, that Chinese engineers from the manufacturing sites would not engage in any learning beyond their

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<sup>68</sup> Th2, 26 January 2016.

remit and did not share information.<sup>69</sup> Some of the constraints were directly attributable to the legacy of the Cultural Revolution, during which the FMMB had been run by a 'revolutionary committee' and headed by an army officer (Gilley, 1998:64pp). Despite several rounds of personnel changes since the mid-1970s, in 1981 Westinghouse managers noted that military officers and semi-literate political cadres continued to hold senior positions at the production sites. Many among the first groups sent to the US for training -- who tended to be *politically* senior employees -- were described by a Westinghouse manager responsible for training as 'not qualified to learn'.<sup>70</sup> With respect to the analytical framework employed in this thesis, the Chinese government in the early 1980s was struggling to build an effective developmental state.

It was not until the mid-1980s, when the production plants developed greater independence from what became the Ministry of Machine Building (MMB)<sup>71</sup> and began to show individual ambition, that Westinghouse managers noted the pace of technological learning modestly increased.<sup>72</sup> The central government's reform strategy was to devolve steadily expanding authority to enterprises, achieved in part by allowing them to retain larger shares of profits. Moreover, as discretion at firm level increased, headcount at the central line ministries was cut (Nolan, 2001a).

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<sup>69</sup> Th1, 9 June 2014; Th2, 26 January 2016; Th8, 15 September 2016; Th11, 20 July 2016.

<sup>70</sup> Th2, 26 January 2016.

<sup>71</sup> The First Ministry of Machine Building became a bureau of the Ministry of Machine Building as of May 1982. In 1998 the Ministry of Machine Building became a bureau of the State Economic and Trade Commission. See Watson et al., (2011).

<sup>72</sup> Th1, 9 June 2014.

Nonetheless, despite a clear perception by Westinghouse managers that technology transfer and firm performance improved in the mid-1980s, the learning process remained slower than contractually envisaged. Under the technology transfer contract, the objective was to build a 300MW verification power plant within five years -- by the end of 1985 - - and a 600MW plant within six years. In the event, both the 300MW and 600MW verification plants were commissioned in 1987.<sup>73</sup> Even after more units were manufactured across the first full decade of technology transfer cooperation, ending in 1991, Westinghouse executives reported that they remained frustrated by the slow pace of technological and productivity progress.<sup>74</sup> By 1992, the Shanghai site produced only eight 300MW turbine-generator sets.<sup>75</sup>

There was some further acceleration of production during the last four years of the Westinghouse licence, from 1992 to 1995, against the background of a booming domestic economy sparked by Deng Xiaoping's 'Southern Tour'. Harbin manufactured only five 600MW turbine-generator sets by 1996, but it produced 23 300MW units, preferring to refocus its efforts on these in the early 1990s (Nolan, 2001a:377). Moreover, Harbin began from 1990 to secure a significant number of export orders from Pakistan and Vietnam, albeit for units smaller than 300MW.<sup>76</sup> Shanghai also secured export orders in this

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<sup>73</sup> Th2, 26 January 2016; Th11, 20 July 2016. The 300MW verification plant was in Shandong province, the 600MW verification plant in Anhui province.

<sup>74</sup> Th1, 9 June 2014; Th2, 26 January 2016.

<sup>75</sup> Th11, 20 July 2016.

<sup>76</sup> According to a table provided by Nolan (no source given), between 1990 and 1995 Harbin signed contracts to export 16 units, with capacities ranging from 18MW to 250MW. Westinghouse managers interviewed noted that the technology transfer programme enabled the Chinese producers to substantially improve the quality of their smaller turbine-generator sets as well as manufacture 300MW and 600MW units.

period, including for 300MW units directly based on Westinghouse technology.<sup>77</sup>

According to official data, China's installed generating capacity increased from just under 66GW in 1980 to 138GW in 1990 and 217GW in 1995. Annual production of power-generating equipment rose from less than 5GW in the early 1980s to 11-13GW between 1988 and 1992 and over 16GW in 1994-7 (Nolan, 2001a:342). (See Table 5). In many respects, this was an impressive performance. However, between 1980 and 1995, the growth of installed electricity generating capacity in China was only 0.79 times the growth of GDP. Since the long-run elasticity of power output growth to GDP growth in the global economy has been close to 1, China's increase in installed generating capacity needed to accelerate further if it was not to constrain future economic growth (Nolan and Dong, 1990: chapter 15). In 1992 and 1993, against a background of real GDP growth of 14.2 percent and 13.9 percent, China experienced electricity brownouts and rationing (McElroy et al., 1998:643pp).

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<sup>77</sup> The exported 300MW units from Shanghai were the only ones on which Westinghouse received royalty payments. A retired Westinghouse executive recalled the total number as 'a few'; Th8, 14 September 2016.

**Table 5. China's installed power generating capacity and domestic output of power generating equipment, 1980-1997. GW**

	Installed capacity	Output of power generating equipment
1980	66	4.2
1981	69	1.4
1982	72	1.7
1983	76	2.7
1984	80	4.7
1985	87	5.6
1986	94	7.2
1987	103	9.4
1988	116	11.1
1989	127	11.7
1990	138	12.3
1991	151	11.6
1992	167	13.0
1993	183	14.7
1994	200	16.7
1995	217	16.7
1996	237	16.1
1997	250	16.9

Source: Nolan (2001:342)

### **3.4. Stage 3: Manufacturing current technology; and incremental modification of current technology**

It was in this era of frenzied economic growth that the Chinese government approached the end of the 15-year Westinghouse licence period. Super-centralised control of power equipment manufacturers by the MMB had ended. However, the firms were far from autonomous and



required central government approval for changes in production strategy, contracts with foreign technology providers, and more. Within this framework, it is significant that Harbin and Dongfang were centrally-owned state enterprises, while Shanghai was a provincially-owned state enterprise (Thun, 2006, Evans, 1995).

The interest of multinational power equipment manufacturers in the China market in this period was increased by rising imports of generating equipment, which compensated for domestic producers' inability to keep up with demand. Where China imported 20GW of power generation equipment in the 1980s, it imported a further 20GW in the four years from 1990 to 1993 (McElroy et al., 1998: 664-5). At the same time, a very weak global market for coal-based turbine-generator sets – the market in developed countries was dominated by large gas turbines (LGT) from the late 1980s – meant that the multinationals looked to China, with its dominant coal resource, as the critical future consumer of steam turbine equipment.<sup>78</sup>

This context in the power equipment sector, and the broader one of state sector reforms in the 1990s, gave rise to a second phase of technology transfer characterised by experimentation and uncertainty. Experimentation reflected central government's commitment to further reform and opening of the economy. Uncertainty reflected the fact that while greater authority had been devolved to firms, they remained state-controlled and subject to central government supervision; it was

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<sup>78</sup> In 1995 it was reported that China was already the largest market in the world for power equipment and 70-80 percent of this was for coal-burning plants. *Financial Times*, 16 May 1995 and 26 June 1996.

not clear what strategic firm choices might be approved at the central level. A symptom of central government's own struggle to manage the dissonance created by reform was the setting up of a Ministry of Energy in June 1988, with the aim to provide central oversight for the entire energy sector. The ministry failed to integrate with the more powerful State Planning Commission, and was disbanded after less than five years, in March 1993 (Cunningham, 2015).<sup>79</sup>

Central government indicated greater willingness to entertain joint ventures following Deng Xiaoping's Southern Tour and, in the absence of a clear template on technology transfer strategy from the centre, in the 1992-5 period each of the three key Chinese power equipment manufacturers engaged in joint venture negotiations with multinational firms. Shanghai entered discussions with GE and (what since 1990 was) ABB in order to compare terms offered by, and increase negotiating pressure on, its licensing partner Westinghouse. Harbin entered discussions with multiple potential partners, and in 1994 signed memoranda of understanding to set up joint ventures with both GE and ABB (Nolan, 2001a: 391-2). Dongfang was involved in joint venture negotiations with Siemens and Hitachi.<sup>80</sup> According to a senior Westinghouse manager, the firm attempted initially to pull both Harbin and Shanghai into a joint venture that could dominate the Chinese market. However, the MMB informed Harbin that a joint venture with

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<sup>79</sup> A deficit in comprehensive energy sector planning remained a recurrent theme for the next two decades.

<sup>80</sup> Th7, 13 September 2016.

two partners would not be approved, leaving Westinghouse to concentrate on a deal with its preferred single partner, Shanghai.<sup>81</sup>

It was notable that the three state-owned Chinese firms all preferred to enter joint ventures with foreign firms, even though this might limit their capacity to develop independent technological capabilities. In Japan, the private firms that developed modern power equipment manufacturing capabilities – MHI, Hitachi, Toshiba, Fuji – did so through licensing arrangements. It was not the need for capital from the multinationals that drove the Chinese firms; they had other funding options. In 1994, Harbin and Dongfang were included in a second batch of companies permitted to list in Hong Kong (Smyth et al., 2004), raising Rmb1.26bn and Rmb752m respectively.<sup>82</sup> Nonetheless, in the absence of clear central government direction on the technology transfer process, each of the big three firms sought to transition from licensing to joint ventures with multinational partners.

Ultimately, central government decided that Harbin would not be allowed to follow this route. Its joint venture plans with GE and ABB had, according to Nolan (2001a:391), been given a green light by both the Harbin city government and the MMB. But the State Council rejected the plan, insisting that Harbin remain fully in state hands. Provincially-owned Shanghai, in contrast, concluded negotiations in 1995 for a series of five joint ventures with Westinghouse. According to Westinghouse managers, Shanghai government leaders lobbied aggressively in Beijing

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<sup>81</sup> Th4, 4 February 2016.

<sup>82</sup> Harbin Electric Co. annual report 1996, Dongfang Electric Co. annual report 2000.

for approval of the joint venture deals,<sup>83</sup> which covered not only turbines and generators, but auxiliary equipment, control systems and overseas project development. The contract, according to one of its principal Westinghouse negotiators, specified Shanghai's full access to current Westinghouse technology, no royalty payments on domestic sales, and Westinghouse minority positions in the different businesses ranging between 30 and 40 percent; the other multinationals were unwilling to meet these terms. The interviewee stated that Westinghouse was made acutely conscious by Shanghai counterparties of the need for central government approval, and that this enhanced the Chinese firm's bargaining position.<sup>84</sup>

Notably, before the joint ventures began to operate, in 1996, Shanghai had already established itself as the leading Chinese power equipment firm in terms of output of thermal units (Table 6). Shanghai did not require joint ventures in order to become number one in China, despite having trailed well behind Harbin in the 1980s. Equally, in preventing Harbin from entering joint ventures, central government was not insulating its best-performing power equipment firm, but rather the one with the greater historical and political significance for the CPC and government.

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<sup>83</sup> Th7, 13 September 2016. One of the Westinghouse negotiators said that Wu Bangguo, Shanghai Party Secretary when the joint ventures were being negotiated, was instrumental in winning support for them in Beijing. Wu became a vice premier in 1995.

<sup>84</sup> Th4, 4 February 2016. The Westinghouse stakes in the key production ventures were: turbines 33%, auxiliaries 35%, generators 40%. The Westinghouse investment was valued at US\$82m, of which approximately 20 percent was the price of technology, 20 percent was training and management input, and 60 percent was cash.

**Table 6. Output of thermal power equipment, 1990-95. MW**

	Shanghai	Dongfang	Harbin
1990	2140	2420	1960
1991	2387	1577	2095
1992	2536	1934	2975
1993	3002	2347	2910
1994	3510	3296	3410
1995	4023	2372	2835

Source: Song and Wang (1997).

In Sichuan, Dongfang's protracted negotiations with Siemens failed to produce an agreement, largely because Siemens' negotiators insisted on a majority equity position and were unwilling to include access to all the firm's current steam turbine technology.<sup>85</sup> Monopsony bargaining was not effective where a counterparty was willing to walk away. Instead, from 1991, Dongfang began to work with Hitachi, buying Hitachi components that could not be manufactured in China in return for technical support with steam turbine-generator sets (Nishimura, 2014). In 1994, Dongfang entered a 50:50 boiler joint venture with Hitachi, the terms of which included further technology transfer to support the manufacture of larger turbine-generator sets (Nolan, 2001a). As a result, the first 600MW and 660MW Dongfang turbine-generator sets went into service in December 1996.<sup>86</sup> (Dongfang had participated in Westinghouse technology transfer in the 1980s but only it to improve its existing, smaller turbines.<sup>87</sup>) Dongfang did not enter into other equity tie-ups for coal-fired power equipment.

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<sup>85</sup> Th7, 13 September 2016.

<sup>86</sup> Annual report, 1997.

<sup>87</sup> Th2, 26 January 2016; Th4, 4 February 2016.

### **Industrial policy in the midst of an FDI boom**

The early to mid 1990s was a time when line ministry control of state companies weakened considerably – a core aim of market reformers like Zhu Rongji (Zheng, 2004) – and this contributed to incoherent outcomes in terms of technology transfer arrangements. On the question of joint ventures, there was no consensus in central government as to how necessary these were to technological progress in the power equipment sector. Rather, increased openness to joint ventures was one, evolving and ill-defined, aspect of a new push on ‘reform and opening’ put into full throttle by Deng’s February 1992 peregrination in southern China (Vogel, 2011).

Between 1993 and 1997, foreign direct investment in China exploded to an unprecedented level, accounting for almost one-sixth of fixed investment (Kroeber, 2016). This investment was not the result of radical changes to laws and regulations governing foreign capital. Instead, the surge in FDI was the result of the political call to arms expressed by the country’s senior political figure (Chen et al., 1995, Chen, 1997).

In this context, there was no intention of central government to reduce its industrial policy role in researching and framing technology transfer objectives for different sectors of the economy, or in funding S&T programmes in order to see objectives realised. In fact, mechanisms to support the more effective central leadership of manufacturing

capability development were given greater weight (Zhong and Yang, 2007, Huang et al., 2004).

The earliest of the major programmes was the National Key Technologies Research and Development Programme, established in 1982 and operated in conjunction with China's Five-Year Plans (Li et al., 2008). In the period 1986-95, the manufacture of large-scale, sub-critical electricity generating equipment was a listed 'key project' in both the 7<sup>th</sup> and 8<sup>th</sup> Five-Year Plans (1986-90 and 1991-95). In 1986, the High-Technology Research and Development Plan (known as the 863 programme for the year and month of its inception) was initiated, with a specific focus on high-tech sectors supported through grants for applied research. These two programmes became the most important vehicles, in terms of budget and impact, in providing firm-level subsidies for technological development. In 1997, a National Basic Research Programme (known as the 973 programme, again for the year and month of its inception) was added in order to systematically support more basic research, although still, normally, linked to current technology acquisition objectives.<sup>88</sup> As an OECD review observed, the defining characteristic of the S&T programmes in China, from their inception, was their top-down nature, involving central government agencies unilaterally setting out manufacturing technology road maps for different industries (OECD, 2007).<sup>89</sup>

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<sup>88</sup> When China localised super-critical and USC power equipment technology in the 2000s, for instance, the 973 programme contributed through a number of national research centres, including the National Research Centre for Clean Coal Combustion, the National Laboratory for Multiphase Flows, the High Temperature Material Performance Laboratory, and the Coal Characteristics and Combustion Test Laboratory (Zheng, 2004, Tan and Seligsohn, 2010a).

<sup>89</sup> Feigenbaum (1999) noted that the role of military scientists in conceiving the 863 program and convincing Deng Xiaoping to support it guaranteed its super top-down nature from the outset.

The overarching idiosyncrasy of the Chinese reform era was that it combined two distinct and sometimes conflicting tasks: the opening and marketisation of a socialist command economy and the introduction of an east Asian ‘developmental state’ approach to industrial upgrading (Kroeber, 2016). This explains how, on the one hand in the mid-1990s the power equipment sector could open up to foreign equity participation in a manner which would subsequently be criticised as a ‘market for technology’ model that under-emphasised the need for domestic capability building (Cheung and Ping, 2004, Li et al., 2008, Zhou et al., 2016) and, on the other, the central government could continue to increase its developmental state capabilities with respect to the oversight and support of technology transfer. Indeed Zheng (2004:96) went so far as to say that Zhu Rongji’s creation of the State Economic and Trade Commission (SETC) when he was vice-premier in 1993, which absorbed line ministries including the Ministry of Machine Building under his premiership in 1998, was an attempt to create ‘a Chinese version of [Japan’s] MITI’.<sup>90</sup>

### **Shidongkou and the quest for super-critical technology**

On the eve of the establishment of the SETC, there occurred an event that highlighted the limitations of centrally-managed technology transfer, consistent with experience in other developmental states. This was the 1992 start-up of China’s first, 600MW super-critical power plant, a demonstration project operated by Huaneng. The MMB had since the mid-1980s taken an interest in super-critical technology, which would

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<sup>90</sup> The SETC absorbed 10 line ministries, state conglomerates and industry councils as part of an overhaul of central government bureaucracy in 1998.



increase electricity yields from China's dominant coal energy source.<sup>91</sup> Super-critical technology was not new, having been pioneered in the US and Germany in the 1950s and 1960s; however, nor was it a mature technology. In the US, 147 super-critical coal plants were built before 1990, mostly in the 1970s (Cen et al., 2009:28). But problems of reliability and high operating costs meant that US utilities stopped constructing super-critical plants in the late 1980s in the context of falling coal prices and limited regulatory pressure to curb emissions. In choosing a technology source for super-critical power generation, Chinese bureaucrats therefore had to decide between US power equipment manufacturers with greater production experience but no current orders, and European ones, which claimed to have undertaken development work – particularly related to new materials – that would resolve reliability problems (Otsuka and Kaneko, 2007).<sup>92</sup>

According to a retired technical director at Shanghai, the MMB, the MEP and Huaneng formed a consensus that ABB was the leader in super-critical technology. During negotiations for a demonstration project, pressure was applied on the European company to structure a co-manufacturing deal with Shanghai (outside its Westinghouse joint venture). However, in this instance the Chinese side did not appear to exercise the same negotiating power it had enjoyed with Westinghouse, either in 1980 or in the 1995 joint venture discussions. A US\$5m technology fee was paid as part of a Shanghai co-production agreement, and the licence was a one-off for the Shidongkou plant, while ABB did

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<sup>91</sup> Th11, 20 July 2016.

<sup>92</sup> A common problem with early super-critical units was the introduction of contaminants from new 'once-through' boilers into the steam turbines causing turbine blade degradation and breakages. It was therefore necessary to make the central turbine rotors 'more rugged'. Th7, 13 September 2016.

not transfer any computer source code or other design capacity-enabling IP.<sup>93</sup>

Worse still, ABB turned out not to have reliable technology. Within weeks of commissioning, the Shidongkou plant suffered a blade breakage and a control station failure. ABB replaced the casing, rotor and blades of the high-pressure section of the turbine, but still it did not achieve its contractually guaranteed efficiency level. The low-pressure section of the turbine was then replaced. According to the Shanghai technical director, the experience was a chastening one for the Chinese side, making bureaucrats and engineers alike nervous of taking risks with new technologies for several years.<sup>94</sup>

It was not until 1995 that the MMB (which became the State Administration of Machinery Industry (SAMI) under the SETC in 1998), began a new, protracted feasibility study into super-critical technology. Meanwhile, through the 1990s, construction and technical development of super-critical plants continued in Europe and in Japan. Japanese government agencies in particular pushed programmes to overcome reliability problems. Beginning in 1980, MITI orchestrated a national project to develop new steel alloys that were essential to robust super-critical and ultra super-critical (USC) power equipment.

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<sup>93</sup> Th11, 20 July 2016. The fee was Swiss francs 7m, converted here at the average 1992 exchange rate to US dollars. The interviewee at Shanghai said that all software provided as part of the co-production arrangement was set to stop functioning after three years. The Shidongkou power plant boilers were manufactured by Combustion Engineering, which was acquired by ABB in 1990.

<sup>94</sup> Th11, 20 July 2016.

During the 1990s, 30 super-critical and USC power plants were built by Japanese firms in Japan without reports of reliability problems (Otsuka and Kaneko, 2007).<sup>95</sup> It was in this context that in the later 1990s the MMB/SAMI directed key research institutes, such as the Xi'an-based Thermal Power Research Institute, and universities including Tsinghua and Shanghai Jiaotong, to engage with foreign technology owners and to identify the R&D programmes that would be necessary to localise super-critical technology.

By 2000, almost a decade after Shidongkou was contracted, the SETC was confident that reliability problems with super-critical units were resolved. From 1995 to 2005 (when domestic production ramped up), China imported 30 super-critical power plant units without operational problems occurring (Zhao, 7 February 2007:slide 11). The localisation of super-critical technology was included in the 10<sup>th</sup> Five-Year Plan (2001-5), and the SETC and the then State Development and Planning Commission (SDPC) orchestrated a collaborative R&D project, funded through the applied and basic research funding vehicles, that brought together state research centres, universities, and the big three manufacturers to attack identified targets for technology. The decision was taken to license technology from Japanese firms. In 2002, MHI was chosen for the turbines, and Hitachi for the generators and boilers, for a new demonstration super-critical, 600MW-unit power plant, Qinbei, in Henan province (Tan and Seligsohn, 2010b).

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<sup>95</sup> Th11, 20 July 2016 confirmed that this was also the Chinese view of the Japanese firms' progress in the 1990s.

MHI offered to work with either Harbin or Shanghai in assembling the turbines; the central government indicated its preference for Harbin.<sup>96</sup> Hitachi collaborated with Harbin for the generators, and with its existing joint venture partner, Dongfang, for the boilers. The Japanese firms supplied the most technologically demanding components – including the high- and medium-pressure rotors and blades for the turbines – and oversaw assembly by their Chinese partners. In this respect, the arrangements were similar to those between ABB and Shanghai for Shidongkou in 1991-2. However, in this case the Chinese side was sufficiently confident of the reliability of the technology that new agreements with the Japanese firms were signed while Qinbei was still under construction. In late 2003, MHI agreed a deal with Harbin for the co-production of 12 600MW super-critical turbines (Minchener, 2010). Qinbei was commissioned in 2004. In terms of the analytical framework of this thesis, the lesson was that manufacturing capabilities had to be built sequentially and incrementally, using established technologies.

### **Ultra-supercritical (USC) technology**

The SDPC had begun an initial feasibility study of USC technology in 2000. As the super-critical programme moved forward smoothly, this was accelerated. The transition from super-critical to USC involved further upgrades to materials and coatings; however, the design of the turbines and valves was similar.<sup>97</sup> Research and development projects for USC technology, overseen by the MOST, were put in place in 2002. The overall project management role of the SETC was taken over from

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<sup>96</sup> Th11, 20 July 2016.

<sup>97</sup> As a senior Siemens engineer put it: ‘the design of high-pressure and intermediate-pressure turbines and valves [in USC units] is basically the same as in previous super-critical design.’ (Quinkertz et al., 2008:6).

2003 by the renamed planning agency, the National Development and Reform Commission (NDRC).<sup>98</sup>

Given that Shanghai played no part in the Qinbei project, there was aggressive lobbying from both the Shanghai government and the firm for the latter's joint venture partner, Siemens, be considered as the technology provider for the USC demonstration project.<sup>99</sup> Siemens installed its first large-scale USC plant, Isogo, in Japan in 2001.<sup>100</sup> In the event, in 2004 Siemens, which had been leading European development of USC technologies through the 1990s, was chosen to supply both elements of the turbine-generator set for a 1,000MW USC national demonstration plant, Yuhuan, in Zhejiang province. MHI was selected to supply the boilers, in collaboration with Harbin.

However, Shanghai and Siemens, assembling the turbine-generator set, and MHI, manufacturing the boiler, were not really given a head start with the demonstration project. At the same time as Yuhuan was contracted in early 2004, Hitachi was awarded a contract in tandem with Dongfang to provide turbines, generators and boilers for another 1,000MW USC plant, Zouxian, in Shandong province. And in 2005, Toshiba was awarded a contract in tandem with Harbin to provide turbines and generators for a 1,000MW USC plant, Taizhou, in Jiangsu province; the boilers were ordered from MHI in conjunction with Harbin. Yuhuan and Zouxian were both commissioned in December 2006, only

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<sup>98</sup> The SETC, which had overall responsibility for the super-critical R&D programme, was abolished in 2003, with most of its functions absorbed by the SDPC, which was in turn renamed the NDRC.

<sup>99</sup> Th11, 20 July 2016.

<sup>100</sup> Isogo was undertaken in partnership with Fuji Electric, a long-time licensee of Siemens. Other Japanese power equipment manufacturers developed USC technology independently.

two years after Qinbei (Zhao, 7 February 2007). Taizhou was commissioned in 2007.<sup>101</sup>

**Table 7. Sources of super-critical and USC technologies for the big three Chinese power equipment firms**

	Equipment	Technology Source	Transfer method
Shanghai	Turbine	Siemens	Joint venture
	Generator	Siemens	Joint venture
	Boiler	Alstom	Licensing
Dongfang	Turbine	Hitachi	Licensing
	Generator	Hitachi	Licensing
	Boiler	Hitachi	Joint venture
Harbin	Turbine	600MW: MHI 1000MW: Toshiba	Licensing
	Generator	600MW: MHI 1000MW: Toshiba	Licensing
	Boiler	SC: Mitsui-Babcock USC: MHI	Licensing

Sources: Company reports, interviews, Tan and Seligsohn (2010a)

The background to the rush to deploy USC technology was China's accelerating economic expansion, beginning in 2002. Having entered double digits in 2003, GDP growth continued to increase to a peak of 14.2 percent in 2007. The growth was accompanied – contrary to China's long-term post-1980 experience – by a rise in energy intensity (Zhou et al., 2010). This resulted in an unprecedented increase in demand for new electricity generating equipment, just as super-critical units were commencing local manufacture in 2003-4, and continuing through the

<sup>101</sup> In 2007 Harbin also commissioned two 600MW USC units, the first in China. Annual report, 2007.

inception of USC manufacturing. There was a remarkable ramping-up of production capacity from 2003 (Table 8). A technical director at Shanghai stated: ‘2003-4 was the fastest learning experience we ever underwent.’<sup>102</sup>

**Table 8. Real annual change in GDP, year-end installed thermal generating capacity, and annual change in installed capacity. % and GW**

	Real GDP growth. %	Installed thermal generating capacity at year-end. GW	Annual increase in installed thermal generating capacity. GW
1999	7.6	210	18
2000	8.4	238	28
2001	8.3	253	15
2002	9.1	266	13
2003	10	290	24
2004	10	329	39
2005	11.4	391	62
2006	12.7	484	93
2007	14.2	556	72

Sources: World Bank, NEA

From end 2003 to end 2007, China’s installed thermal electricity generating capacity increased by more than 260GW, or four-fifths of the existing base. Where the *total* increase in installed generating capacity in the period of the 9th Five-Year Plan (1996-2000) averaged 16GW per year, during these four years the annual increase in thermal capacity alone averaged more than 60GW. Based on the reports of its listed unit, Harbin’s revenues from thermal generating equipment tripled from

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<sup>102</sup> Th11, 20 July 2016.

Rmb7.2bn in 2004 to Rmb21.8bn in 2006. Shanghai's revenues from thermal generating equipment were already Rmb11.4bn in 2004, having outstripped Harbin since the mid-1990s; by 2007 they also tripled, to Rmb33.4bn (Table 9). Dongfang's listed unit did not consolidate comparable thermal power equipment sales until after a 2007 restructuring.<sup>103</sup>

The huge increases in output were accompanied by abrupt shifts to production of the new super-critical and USC machinery. Chen and Xu asserted that from the commissioning of Qinbei in 2004 to the end of 2007, China constructed 124GW of super-critical power station capacity (2010:2126). Separately, China's Thermal Power Research Institute reported that as of 2007 more than 150 super-critical and USC units were on order for domestic installation (Zhao, 7 February 2007). With respect to the analytical framework of this thesis, the observation is that sequential learning steps could be made very fast in conditions of high-volume manufacturing.

The NDRC directed the electricity utilities towards purchasing larger, super-critical and USC units with a number of new policies: a requirement that all new generating plants of 600MW or greater capacity should be super-critical or USC plants; higher tariffs for electricity from super-critical and USC plants (all electricity prices were subject to centrally-set caps); regulations that from 2007 encouraged grid managers to dispatch power from the most efficient power plants

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<sup>103</sup> Dongfang's listed business bought controlling interests in its previously unlisted boiler unit and other subsidiaries in 2007. From the time of its 2008 annual report, Dongfang claimed, across its thermal, hydro, nuclear and other businesses, to be 'the world's largest power equipment manufacturer'.



first; and, from 2006, a programme of forced closure of the smallest and least efficient power plants (Cen et al., 2009: 234pp, IEA, 2009, Tan and Seligsohn, 2010a).

**Table 9. Revenues from thermal power generating equipment, 2003-7.**

	Harbin. Rmb bn	Shanghai. Rmb bn
2003	2.9	na
2004	7.2	11.4
2005	13.3	19.5
2006	21.8	25.7
2007	20.5	33.4

Source: company reports

What guaranteed the building of large super-critical and USC plants, however, was their cost. In the 1990s, the big three Chinese manufacturers sold sub-critical power generating equipment in the domestic market for 60-70 percent of the cost of imported units.<sup>104</sup> With the localisation of super-critical and USC technology in the 2000s, this price differential was maintained or increased. A number of studies of the complete cost of Chinese power plants – including both equipment and construction costs – estimated that costs per kilowatt of installed generating capacity for super-critical and USC units ranged from one-third to three-fifths of prices in other developing and developed countries.

The total cost of the first localised super-critical plant, Qinbei, was reported as Rmb4,000/KW (US\$588/KW) (Chen and Xu, 2010). The cost

<sup>104</sup> Th7, 13 September 2016. The source was responsible for the sale of a number of imported generating units in the early and mid-1990s that were funded internationally.

of the first localised USC plant, Yuhuan, was reported as Rmb3,625/KW (US\$541/KW) (Tan and Seligsohn, 2010b). Different reviews of power plant costs between 2005 and 2010 concurred that costs remained within range of these projects (Table 10). The capital cost per KW of new generating capacity in other countries is indicated in Table 11. Based on these estimates, the cost of super-critical generating capacity in China was at most 60 percent of that in India, and an even lower percentage of that in the US or Romania.<sup>105</sup>

**Table 10. Estimated capital costs of new electricity generating capacity in China. US\$/KW**

	<b>International Energy Agency 2009</b>	<b>World Bank 2009</b>	<b>World Resources Institute 2010</b>
Sub-critical	465-590	600-650	650-800
Super-critical	490-770	540	550-700
USC	535-700	540	550-700

Sources: (IEA, 2009), (Pauschert, 2009), (Tan and Seligsohn, 2010a)

**Table 11. World Bank estimates of capital costs of new electricity generating capacity outside China, 2009. US\$/KW**

	<b>United States</b>	<b>India</b>	<b>Romania</b>
Sub-critical	2290	1440	2530
Super-critical	1960	1290	2250

Sources: (Pauschert, 2009). Note that a report prepared for the Asia-Pacific Economic Cooperation forum in 2007 (Hogan et al., 2007) collated studies from 2001-4 for capital costs of sub-, super- and USC plants in 'a variety of economies' and found them to be significantly lower in this earlier period compared with Pauschert, ranging from US\$950-1350 per KW.

<sup>105</sup> The price differentials for finished power plants indicated that substantial cost differences existed for basic goods, from steel to concrete. Materials accounted for approximately half of total costs (Pauschert, 2009).

### **Harbin leads, then lags**

At face value, each of the big three manufacturers was able to meet the challenges of massively increased demand as well as localisation of super-critical and USC technology. Harbin's output and sales of thermal generating equipment increased faster than either of its competitors in the mid-2000s, while the firm produced its first super-critical equipment before Shanghai and its first USC equipment at the same time as Shanghai. However, Harbin's explosive growth was not sustainable.

After peaking at Rmb21.8bn in 2006, the firm's revenues from sales of thermal generating equipment declined every year through 2015. Shanghai managers observed that once the initial rush to end the power shortages and brown-outs of 2004-5 ended, customers preferred the turbine-generator sets of Dongfang and Shanghai, although Harbin's boilers retained a better reputation and strong sales.<sup>106</sup> Furthermore, Harbin's high aggregate thermal power equipment sales in the 2000s were secured at the expense of much lower gross margins than Dongfang and Shanghai (Table 12). When Harbin's margins were raised, beginning in 2011, its sales decline accelerated.

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<sup>106</sup> Th5, 4 July 2014; Th6, 2 February 2016; Th13, 20 July 2016.

**Table 12. Sales of thermal power equipment and gross margins;  
Shanghai, Dongfang, Harbin, 2000-2015. Rmb bn and %**

	Shanghai sales	Gross margin %	Dongfang sales	Gross margin %	Harbin sales	Gross margin %
2015	28.7	16.8	23	16.1	9.3	21.4
2014	28.7	16.9	24.2	15.3	12.3	15.1
2013	32.7	17.6	23.3	19.9	12.4	20.3
2012	35.7	19.1	20.2	22	15.5	22.3
2011	30.2	21.8	24.5	19.5	17.3	22.2
2010	27.2	17.3	20.4	18.8	17.9	14.1
2009	27.4	15.7	20.9	21.5	19.2	13.4
2008	34	18.6	20.3	17.9	20.5	14.9
2007	33.4	16.3	19.6	21.8	20.5	16.7
2006	25.7	18.2	**		21.8	12.1
2005	19.5	21.8			13.3	11.4
2004	11.4	21.6			7.2	7.8
2003	*				2.9	13.7
2002					1.9	19.2
2001					1.4	23.8
2000					1.37	21.4

Sources: company reports

\* Data for Shanghai not available prior to its listing.

\*\* Dongfang's listed business underwent a major restructuring in 2007. Data prior to 2007 are not comparable.

Dongfang's performance was more impressive. The Sichuan-based manufacturer not only maintained margins in line with those of Shanghai, but further *increased* its thermal equipment sales after the mid-2000s (Table 12, above). Moreover, in most years Dongfang led Shanghai in the reported share of revenues expended on R&D (Table 9). Nonetheless, Dongfang's thermal power equipment business remained smaller than Shanghai's, and its overall business substantially smaller

(partly because of the large Shanghai-Mitsubishi joint venture in elevator and escalator manufacturing).<sup>107</sup> In sum, the technological progress of Dongfang – with only a single, Hitachi joint venture in boilers – was within range of Shanghai. But Dongfang did not enjoy the same economies of scale and scope.

Shanghai, which outstripped the production volumes of the traditionally dominant power equipment producer, Harbin, *before* entering joint ventures in 1995 (Table 6, above), embedded its industry leadership in the late 1990s and 2000s. In terms of products, Shanghai's Siemens-licensed 1000MW USC turbine-generator sets – the preferred size in the Chinese market – became increasingly dominant through the 2000s (Table 13), commanding a market share of 55 percent in 2010, forecast to be as high as 70 percent in 2016.<sup>108</sup> In recent years, as industry operating conditions became more challenging, revenues and profits at Shanghai held up, whereas they fell markedly at both Dongfang and Harbin (Table 14).

**Table 13. Operational power plants (>250MW) of the big three equipment suppliers as of end-2013**

	<b>300MW</b>	<b>600MW</b>	<b>1000MW</b>	<b>Total</b>
Shanghai	91	105	<b>52</b>	248
Dongfang	75	99	<b>18</b>	192
Harbin	74	97	<b>13</b>	184

Source: provided to the author by Siemens

<sup>107</sup> In 2015, for example, revenues at the Shanghai-Mitsubishi elevator-escalator joint venture accounted for 31 percent of Rmb78bn total revenues.

<sup>108</sup> Company reports, 2010, 2015, and Th11, 20 July 2016.

**Table 14. Big three revenues and net income, 2013-15 and peak year.**

**Rmb bn**

	Shanghai revenues	Shanghai net profit	Dongfang revenues	Dongfang net profit	Harbin revenues	Harbin net profit
2015	78	4.7	36	0.46	25.1	0.31
2014	76.8	4.5	39	1.3	23.8	0.57
2013	78.8	4.2	42.4	2.4	20.5	0.7
Peak year	78.8 (2013)	4.7 (2015)	42.9 (2011)	3.1 (2011)	29.9 (2008)	1.8 (2007)

Sources: company reports

Although Harbin and Dongfang spent a higher share of revenues on R&D until the late 2000s, Shanghai spent far more on imported technology in the form of patents, licences, software and other technology rights, in both in absolute and relative terms (Table 15). Much of this purchased technology came from the firm's post-1998 joint venture partner, Siemens. An indication of the scale of the difference in expenditure on imported technology is given by the book value *at cost* of patents, licences, software and other technology rights on the balance sheets of the three firms at the end of 2015: Shanghai, Rmb1,990m; Dongfang, Rmb482m; Harbin, Rmb495m.<sup>109</sup>

<sup>109</sup> Data reflect the full scope of the listed businesses; numbers are not broken out for power equipment segments.

**Table 15. Expenditure on R&D and expenditure on patents, licences, software and other technology rights\*. Rmb m and %**

	Shanghai R&D spend	R&D % of rev's	Shanghai tech' rights spend	Dongfang R&D spend	R&D % of rev's	Dongfang tech' rights spend	Harbin R&D spend	R&D % of rev's	Harbin tech' rights spend
2015	2500	3.2	102	1250	3.47	21	320	1.3	15
2014	2800	3.6	77	1300	3.3	14	370	1.5	10
2013	2000	2.5	105	1300	3.1	57	350	1.7	12
2012	2100	2.7	327	1250	3.3	42	360	1.4	1
2011	1600	2.4	209	1200	2.8	49	340	1.2	192
2010	1500	2.4	158	980	2.6	76	650	2.2	8
2009	1100	1.9	69	650	2	8	460	1.6	7
2008	990	1.7	225	500	1.8	25	470	1.6	10
2007	560	1	331	500	2.1	69	460	1.7	132
2006	300	0.7	108	**	3.1	**	450	1.5	12
2005	190	0.5	72		2.7		300	1.6	54
2004	120	0.5	44		2.4		200	2	***
2003	Pre-listing		Pre-listing		3		120	2.4	***
2002	Pre-listing		Pre-listing		3		46	1.2	***
2001	Pre-listing		Pre-listing		6.2		32	1.1	***
2000	Pre-listing		Pre-listing		0.5		39	1.3	***

\*Recorded as additions to intangible assets on the balance sheet and amortised over multiple years.  
(These data do not include ongoing royalty payments for equipment manufactured as part of technology licensing agreements, which are recorded as current expenditure.)

\*\* Absolute data for Dongfang not comparable prior to 2007; R&D % of revenues for earlier years included as a qualified comparison based on data for the turbine business alone.

\*\*\* No figure given.

Sources: company annual reports.

There is little doubt that the five Westinghouse/Siemens joint ventures negotiated in 1995 supported Shanghai's efforts to reinforce its industry leadership, although the precise contribution of the joint ventures to Shanghai's competitive advantage is impossible to gauge. Nonetheless, Shanghai's industry leadership was associated with a tendency to technological dependence. In 1998, when Siemens bought Westinghouse's global thermal power business, Shanghai had a

contractual right to terminate the joint ventures. Despite having made early learning gains in the joint ventures in terms of management training programmes, technology upgrades and new plant design, a senior manager at Shanghai said the possibility of termination was never seriously entertained.<sup>110</sup> On the contrary, Shanghai accepted Siemens' demands for geographical limits on exports from continued joint ventures, and agreed – in contrast to the Westinghouse joint venture terms -- to pay royalties on domestic sales of equipment based on Siemens' technology.<sup>111</sup> Former Westinghouse and Siemens managers estimated the royalties at 1.5-3 percent of equipment sales prices.<sup>112</sup> When Siemens sought to increase its equity to 40 percent across a unified turbine, generator and auxiliaries joint venture, Shanghai also agreed. It is unclear why. The Chinese firm had no need of cash and did not gain further access to technology in exchange for the sale of equity; the reconfiguration was completed in 2009.<sup>113</sup> What stands out in terms of the theoretical concepts employed in this thesis is the power of path dependencies at Shanghai.

### **3.5. Gas turbine technology**

Shanghai had no more luck extracting complete technology for LGTs from its joint venture partner than did Dongfang and Harbin from other multinationals (Majidpour, 2012). In the 1990s, LGTs became the key international growth business for the leading multinationals. Gas-fired

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<sup>110</sup> Th11, 20 July 2016.

<sup>111</sup> Th11, 20 July 2016; Th8, 15 September 2016. According to Shanghai interviewees, Siemens included a sweetener by providing Westinghouse technology updates for 1995-2000, the five years following the original joint ventures, on a royalty-free basis.

<sup>112</sup> Th8, 15 September 2016; Th4, 4 February 2016.

<sup>113</sup> Th11, 20 July 2016. The interviewee at Shanghai claimed that Siemens promised to bring substantial new international business to the joint venture if its equity increased, but this never happened.



power plants offered flexibility and readily-adjustable output, and met demands for reduced waste emissions. They required lower capital investment than coal-fired plants, but generated higher levels of service business (Watson, 2004).

In 2003, the NDRC attempted to use two rounds of tenders for 39 LGTs – a large build-out of capacity – to organise a comprehensive technology transfer programme, similar to previous ones for coal-fired steam turbines and large hydro turbines.<sup>114</sup> Siemens and Westinghouse interviewees stated, however, that following the lead of the longest-standing multinational LGT supplier in the market, GE, all the multinationals insisted that joint ventures for LGT production be majority foreign-controlled, and that the most intellectual property-intensive components – referred to as Hot Gas Path Parts (HGPP) – be imported.<sup>115</sup>

This episode offered support to Nolan's argument (2001a, 2001b, 2002) that an increasing level of concentration among multinational business since the 1980s inhibited developing countries' capacity to obtain technology. Several waves of consolidation in the 1980s and 1990s left only GE, Siemens, Alstom and MHI as suppliers of the largest units.<sup>116</sup> However, a number of caveats should be considered before concluding

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<sup>114</sup> For a discussion of technology transfer in the hydro-power sector, which was closely linked to tenders for turbines for the Three Gorges project, see RedTech (2011) and McDonald et al. (2009).

<sup>115</sup> Th5, 4 July 2014; Th7, 13 September 2016; Th8, 14 September 2016. GE operated a 51 percent-owned joint venture with Shenyang Liming Aero-Engine for E- and F- class LGTs. MHI formed a 51 percent-owned joint venture for LGTs with Dongfang. Siemens formed a 51 percent-owned joint venture for LGTs with Shanghai. Each of the joint ventures began production in 2004-5. The 2003 LGT orders went ahead despite the multinationals' refusal to engage in full-scale technology transfer; GE supplied 20 of 39 units.

<sup>116</sup> The latest consolidation occurred in 2000, when ABB divested its LGT business to Alstom.

that China will be unable to obtain and develop its own technology for LGTs.

At the time of the NDRC's 2003 effort to bargain for LGT technology, this objective was not a top priority for central government, and bargaining pressure applied to foreign technology providers was not maximised. China had limited proven natural gas reserves (IEA, 2009). The first, major, east-west gas pipeline did not open until 2005. It was only as the strength of central government commitment to reducing coal dependency and tackling pollution increased in the mid-2000s, and large shale gas deposits came into consideration (IEA, 2009), that interest in LGT technology increased. MOST's grant support for LGT R&D was greatly expanded under the 12<sup>th</sup> Five-Year Plan (2011-5) (Gallagher, 2014) and, in these conditions, the big three manufacturers became much more concerned to obtain and develop proprietary gas technology.

Claims of an inexorable trend to concentration in global multinational business must also be set against regulatory limits to concentration. Since business concentration hurts consumers, governments in developed countries are incentivised to limit it. This can support developing countries' access to technology. A case in point occurred with LGT technology in 2014, when GE made a successful bid to acquire the power and power distribution businesses of Alstom. This could have reduced global manufacturers of LGTs to just three. However, as part of negotiations with EU competition authorities to approve the deal, GE was required to sell the intellectual property for Alstom's GT26-series

LGTs to Italy's Ansaldo Energia, maintaining a fourth player. Two ambitious firms from outside the core multinational oligopoly – Shanghai and South Korea's Doosan Heavy Industries – then competed to invest in Ansaldo and thereby gain access to LGT technology. Shanghai won.

It was far from clear that the forced technology transfer to Ansaldo, and Shanghai's investment in Ansaldo, could turn either or both firms into global players in the LGT business. The G-series technology that Ansaldo acquired – successive generations of gas turbine technology are identified by successive letters of the alphabet – was a generation behind the H-series machines that GE and Siemens already had on the market. Ansaldo needed to absorb the technology quickly and then break through, without licensing third-party technology, to a new level of capability – something it had not managed previously.

From Shanghai's perspective, it won the right to invest in Ansaldo by taking a minority, 40-percent stake. It was unclear if this would provide access to the core LGT technology. If it did, would Shanghai, which had never made a significant independent leap in technology development, be able to do so with LGTs? Time will tell.

It could immediately be observed that Shanghai, which formed a separate joint venture with Ansaldo in China to manufacture LGTs for the Asian market, gained a greater level of access to LGT technology than had recently seemed possible. This occurred in the context of a

round of consolidation of multinational businesses.<sup>117</sup> A Siemens interviewee confirmed that Shanghai closed down its minority-owned LGT assembly joint venture with Siemens in 2016 and was completing a new factory for its Ansaldo joint venture.<sup>118</sup>

### **3.6. Wind turbines**

A more telling guide to the competitive limitations of the big three state-owned power equipment manufacturers may be their performances in the wind turbine sector from the mid-2000s, where they had to contend with many new entrants, including private companies. In the US and Europe, the leading incumbent power equipment firms, GE and Siemens, both quickly established themselves as key players in the wind turbine market in the 2000s. GE became the dominant supplier in the US, while Siemens trailed only Vestas in Europe (and led in both Europe and the world market in sales of offshore turbines).<sup>119</sup> In China, none of the big three power equipment firms numbered in the top five suppliers of wind turbines in 2015 (Table 16). The evolution of the wind business in China is the subject of the next chapter, however a brief outline of the development of the wind businesses of Shanghai, Dongfang and Harbin is presented here.

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<sup>117</sup> Shanghai paid Euro400m for its 40 percent stake. Pro-rated, this was cheaper than a Euro1.3bn offer from Siemens to buy the whole business in 2012, which was blocked by the Italian government. *Corriere della Sera*, 8 May 2014; *Modern Power Systems*, 11 September 2015.

<sup>118</sup> Th9, 23 September 2016. An executive at Siemens reported that Shanghai absorbed all the LGT technology that Siemens was willing to hand over by 2010 and that the last four years of the joint venture were characterised by increasing frustration, with Shanghai demands to be allowed to buy the critical technology for HGPP repeatedly denied. The imported HGPP components accounted for around half the cost of the kind of 350MW LGT popular in China.

<sup>119</sup> Japan's diversified power equipment firms were not drawn by their home market into the wind turbine business because Japan had few acceptable onshore sites for wind (for reasons of demographics and topography, as well as environmental restrictions), few shallow offshore sites and, prior to the Fukushima disaster, a strong commitment to nuclear power.

**Table 16. The world's 15 leading suppliers of wind turbines by volume, 2015. GW**

<b>Firm (Chinese firms in bold)</b>	<b>Deliveries. GW</b>	<b>Rank of Chinese firms</b>	<b>Ownership of Chinese firms</b>
<b>Goldwind</b>	7.8	1	Private
Vestas	7.3		
GE	5.9		
Siemens	3.1		
Gamesa	3.1		
Enercon	3.0		
<b>United Power</b>	2.8	2	State
<b>Mingyang</b>	2.7	3	Private
<b>Envision</b>	2.7	4	Private
<b>CSIC</b>	2.0	5	State
Senvion	1.9		
<b>Shanghai Electric (Sewind)</b>	1.9	6	State
<b>XEMC</b>	1.5	7	State
Nordex	1.4		
<b>Dongfang Electric</b>	1.4	8	State

Source: Bloomberg New Energy Finance, company reports

Taking the firms in reverse order, Harbin's response to the growth of the domestic wind turbine market was the clearest failure. The firm only announced its intention to enter the market in 2009, four years after rapid growth in China's wind turbine market began. Harbin opted to construct a wind turbine manufacturing subsidiary in Zhenjiang, Jiangsu province.<sup>120</sup> However, there was no clear strategy for the development of the business. In 2010, Harbin agreed with GE to fold the Zhenjiang facility, and GE's own wind turbine assembly plant in Shenyang, into two

<sup>120</sup> Annual reports, 2008, 2009.

joint ventures.<sup>121</sup> The businesses were not successful. The partners disagreed over strategy and priorities, and the joint ventures were dissolved in 2013.<sup>122</sup> Subsequently, Harbin continued to operate the Zhenjiang facility alone; however it never broke out data for sales, which appear to have been very limited.

Dongfang, in contrast to Harbin, was one of the fastest Chinese firms in not only responding to, but predicting, the growth of the wind turbine market. Dongfang decided to develop a wind turbine capability in 2004, the year before China's Renewable Energy Law (REL) was passed. In 2005, Dongfang produced a first, 1.5MW turbine under licence from Germany's REpower, and from 2007 manufactured a series of turbines under joint development licences with Austria's Windtec and its US parent, American Superconductor Corp. (AMSC) (Zhou et al., 2016).<sup>123</sup>

In 2008-9, Dongfang won large orders for China's earliest 'wind base' developments, and ranked as the number three wind turbine supplier in the country.<sup>124</sup> However, Dongfang was unable to maintain this position. In subsequent years, wind turbine shipments fell and the company dropped down the domestic ranking, managing only eighth place in 2015 (Table 16, above). Dongfang does not publish data for wind turbine sales; however, its annual 'new energy' segment sales, which also

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<sup>121</sup> Harbin held 51 percent of the Zhenjiang joint venture, and GE held 51 percent of the Shenyang joint venture. The motivation for GE was that foreign firms' share of the Chinese wind turbine market declined precipitously, from three-quarters in 2004 to a little over 10 percent in 2010; however, a tie-up with Harbin only made sense if the local firm could deliver cost reductions and sales.

<sup>122</sup> *Wind Power Monthly*, 2 July 2013. See <http://www.windpowermonthly.com/article/1188550/ge-harbin-end-chinese-joint-venture> Accessed 24 November 2016.

<sup>123</sup> For an outline of the basic terms of the 2007 joint development licence, see [http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle\\_Print&ID=983070&highlight=](http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle_Print&ID=983070&highlight=) Accessed 24 November 2016.

<sup>124</sup> In 2008, for instance, Dongfang shipped more than 800 1.5MW turbines. Annual report.

include shipments of conventional power generating equipment used as part of nuclear installations, give a sense of the trend in the larger wind turbine business. New energy sales peaked in 2010 and subsequently fell each year through 2015, involving a cumulative drop of more than 50 percent (Table 17).<sup>125</sup>

**Table 17. ‘New energy’ segment sales at Shanghai and Dongfang, 2010-15. Rmb bn.**

	Shanghai ‘new energy’ equipment sales*	Dongfang ‘new energy’ equipment sales*
2015	12.1	4.6
2014	7.8	4.9
2013	5.9	6.7
2012	6.6	7.7
2011	7.2	8.9
2010	6.2	9.5

\*Includes wind turbines, conventional power generating equipment sold to nuclear projects, and miscellaneous other sales.

Sources: company reports

Shanghai was more than a year behind Dongfang in entering the wind turbine market and, until 2014, experienced lower sales. Shanghai began by licensing a 1.25MW turbine design from Germany’s DeWind in 2006. The company then purchased a complete design platform for 2MW machines from another German design firm, Aerodyn, in 2008. Having learnt from the tie-up with Aerodyn, Shanghai attempted to develop its own 3.6MW turbine. This move into self-development, however, was not a success.

<sup>125</sup> Annual reports. Dongfang released a figure for wind turbine sales in the peak year, 2010. Revenues from wind turbines were Rmb7.6bn of the total reported new energy sales of Rmb9.5bn.

Some 80 Chinese companies entered the wind turbine business by 2010, and prices per kilowatt of equipment almost halved. Facing unprecedented levels of competition, and incurring operating losses, Shanghai began to negotiate with Siemens for a joint venture. After two years, a business owned 51 percent by Shanghai was agreed upon in 2012. The venture bought over Shanghai's Aerodyn platform and, a senior Shanghai manager stated, was thenceforth only allowed to sell Siemens technology.<sup>126</sup>

Siemens, however, did not prove to be a quick or effective solution to Shanghai's problems. The German firm's 2.5MW onshore turbine was not popular in the market. Although its 4MW offshore turbine won orders, technology transfer from Europe, and hence production, were delayed. Management relations at the joint venture, said the Shanghai interviewee, were strained almost from inception. In 2014, the two sides agreed to switch to a pure licensing arrangement. This appears to have worked better. Shanghai enjoyed greater success in the onshore market based on the Aerodyn 2MW platform, modified through work with UK-based engineering consultancy Garrad Hassan<sup>127</sup>, while becoming the market leader, with a majority market share, in offshore turbines based on licensed Siemens technology. In 2014 and 2015 Shanghai's wind turbine order growth outstripped the overall Chinese market, with orders reaching Rmb9.4bn and Rmb11bn, respectively. Revenues from wind turbines far outstripped those at Dongfang.

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<sup>126</sup> Th12, 20 July 2016.

<sup>127</sup> Th12, 20 July 2016.



Despite a difficult start in the wind turbine sector, when Dongfang forged ahead, Shanghai came back to lead the big three power equipment firms, and may move further up the overall rankings of Chinese wind turbine suppliers. The decision to abandon the wind turbine joint venture with Siemens, like the decisions to abandon the Siemens LGT joint venture and to purchase 40 percent of Ansaldo, might reflect a new appetite for technological autonomy. Unlike GE and Siemens, which moved into the wind business by buying, respectively, the mature businesses of Enron Wind in 2002 and Bonus Energy in 2004<sup>128</sup>, Shanghai did not have a 'buy, absorb, and market' acquisition strategy available to it. Like other Chinese wind turbine companies, Shanghai had to build production capability from the bottom up. Nonetheless, Shanghai has not in wind, as in thermal power, yet broken decisively out of the need to license technology and pay out a continuous stream of royalties for doing so. None of the three thermal firms exhibited clear dynamic capabilities in adjusting to the technological reset of wind turbine manufacturing.

### **3.7. Trends in profitability, scale and global reach**

The issue of continuing technological dependency leads directly to the most striking differences today between the big three Chinese firms and their most successful multinational competitors: differences in profit margins, scale and global reach. As Table 18 shows, the overall gross margins of Siemens over the past 10 years were approximately 10 percentage points higher than those of Shanghai and Dongfang, and

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<sup>128</sup> At the times of acquisition, Enron Wind was the leading wind turbine manufacturer in the US and Bonus Energy was number two, after Vestas, in Denmark; both ranked in the top ten suppliers by volume in the world.

further ahead of Harbin. As GE's divestment of GE Capital's business from 2010 made its gross margins qualitatively more comparable with those of other diversified industrial companies, the US firm's gross margins were also reported around 10 percentage points higher than those of Shanghai and Dongfang. Net margins at Siemens and GE were similarly far superior to those of the Chinese companies over the same period (Table 19).<sup>129</sup> Moreover, despite the great scale of China's domestic market, none of the Chinese firms came close to operating at the global scale of Siemens or GE, whether in fossil-based power equipment or renewables (Table 20). Shanghai's thermal power equipment business, much the biggest in China, was still one-third the size that of Siemens by revenues, one-quarter that of GE. Shanghai's renewables segment was around one-third the size of the multinationals'.

Part of the reason the scale of the Chinese firms trailed the multinationals was that, after an impressive build-up by Shanghai and Dongfang in 2009-12, the export shares of their sales fell back (Table 21). Harbin's export share held up, but only at the expense of collapsing margins. The export shares of revenues reported by Siemens in 2015 (85 percent) and GE (55 percent) were far ahead of the peak shares so far achieved in China.

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<sup>129</sup> These margin comparisons refer to the complete, diversified businesses of all the companies. Although data for comparable margins were not broken out by the firms for the fossil-based power equipment on which this discussion is largely based, the differences would likely be even greater since fossil-based power equipment contributed an outsize share of profits at Siemens and GE in the period analysed. In 2015, for instance, the Power segment at GE accounted for 20 percent of industrial revenues but 25 percent of industrial profits.

**Table 18. Gross margins: China big three power equipment firms versus leading multinationals. %**

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Shanghai	18.9	17.7	18.2	16.5	17.7	19.4	19.8	19.4	20.9	21.4
Dongfang	*	*	16.1	17.3	20.2	20.9	21.2	20.4	16.8	16.8
Harbin	11.1	15.7	13.4	12.8	14.4	20	21.5	21.1	14	14.3
Siemens	26.1	28.8	27.2	27	29	30.2	28.3	27.4	28.6	28.9
GE**	55.9	57.6	53.9	51.1	52.1	53.4	49.3	29.5	28.6	29.6
MHI	12.6	14	12.7	13.7	15.2	15.8	18.5	19.5	20.8	21.3
Hitachi	21.1	21.8	21.8	23.6	25.2	24.7	25.4	25.8	26.4	25.7
Toshiba	25.4	27.4	21.4	24	24.6	25.3	26.1	25	23.1	15.1

\*Dongfang data prior to 2008 not comparable due to corporate restructuring.

\*\*GE gross margin inflated by GE Capital prior to divestment.

Source: Morningstar data

**Table 19. Net margin: China big three power equipment firms versus leading multinationals. %**

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Shanghai	4.72	5.1	4.45	4.33	4.46	4.85	3.53	3.11	3.33	2.73
Dongfang	*	*	0.63	4.73	6.77	7.12	5.75	5.54	3.27	1.22
Harbin	3.52	5.53	3.48	2.12	3.56	4.31	5.42	3.44	2.38	0.77
Siemens	3.47	5.25	7.4	2.99	5.13	8.36	5.69	5.65	7.47	9.63
GE**	12.75	12.86	9.5	6.84	7.55	8.91	9.26	8.94	10.25	-
MHI	1.59	1.91	0.72	0.48	1.04	0.87	3.45	4.79	2.77	1.58
Hitachi	-0.32	-0.52	-	1.19	2.56	3.59	1.94	2.76	2.22	1.72
Toshiba	1.93	1.61	-	-0.3	2.12	1.19	1.31	0.93	-0.57	-

\*Dongfang data prior to 2008 not comparable due to corporate restructuring.

\*\*GE net margin inflated by GE Capital, especially prior to 2008 global financial crisis.

Source: Morningstar data

**Table 20. Overall revenues, thermal power equipment revenues, renewables revenues; Siemens and GE versus China big three. US\$ bn\***

	<b>Overall revenues US\$bn</b>	<b>Thermal power equipment revenues** US\$bn</b>	<b>Wind and renewables revenues*** US\$bn</b>
Siemens 2015	83.9	14.7	6.3
Siemens 2014	94.7	16.9	7.5
GE 2015	117.4	21.5	6.3
GE 2014	117.2	20.6	6.4
Shanghai 2015	12.5	4.6	1.9
Shanghai 2014	12.5	4.7	1.3
Dongfang 2015	5.8	3.7	0.7
Dongfang 2014	6.4	3.9	0.8
Harbin 2015	4	1.5	na
Harbin 2014	3.9	2	na

\*Currency conversions at average 2015 and 2014 exchange rates: Euro:USD 1.11 (2015), 1.33 (2014); USD:Rmb 6.22 (2015), Rmb6.14 (2014).

\*\* Different firms' reporting segments for thermal power equipment vary and are only loosely comparable. Siemens Power and Gas segment covers equipment for fossil-fuel-based power generation plus other equipment for the oil and gas sectors. GE's segment includes its GE-Hitachi nuclear joint venture.

\*\*\* Different firms' reporting segments for wind and renewables vary and are only loosely comparable. Shanghai and Dongfang's segments include conventional power components for nuclear power plants and miscellaneous other goods, from sewage treatment to biomass power-equipment.

Sources: company reports

**Table 21. Exports and export share in total revenues, China big three, 2007-15. Rmb bn**

	Shanghai exports	% of total revenues	Dongfang exports	% of total revenues	Harbin exports	% of total revenues
2015	8.8	11.3%	4.9	13.6%	6.6	26.3%
2014	10.6	13.8%	6.1	15.6%	4.3	18.1%
2013	13.2	16.8%	9.4	22.2%	2.2	10.7%
2012	17.9	23.4%	8.7	22.8%	4	15.4%
2011	15.9	23.4%	6	14.0%	6	17.5%
2010	11.8	18.7%	4.4	11.7%	5.3	18.2%
2009	9.4	16.3%	0.3	0.9%	4.3	15.0%
2008	8.9	15.1%	na	na	2.8	9.4%
2007	4.6	8.2%	na	na	2.2	8.0%

Sources: company reports

The performances of Shanghai and Dongfang did look better when the businesses were compared with Japanese peers that obtained power equipment technology from Westinghouse, GE and Siemens. Gross margins at Shanghai and Dongfang over the past decade trailed those at Hitachi and Toshiba by less than they trailed GE and Siemens, and were superior to those at MHI. Net margins at the Chinese firms were superior to those at the Japanese multinationals, while returns on assets (Table 22) were comparable. However, Shanghai, the largest Chinese business, was dwarfed by the scale and globalised character of the Japanese firms. Revenues at Mitsubishi Heavy Industries (MHI) were 2.5 times those of Shanghai in 2015, with 53 percent derived overseas; revenues at Toshiba were 4.5 times those of Shanghai, with 59 percent derived overseas; and revenues at Hitachi were 6.5 times those of Shanghai, with 47 percent derived overseas.

**Table 22. Return on assets: China big three power equipment firms versus leading multinationals. %**

ROA	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Shanghai	3.52	4.15	3.33	2.92	3	3.23	2.41	1.99	1.87	1.39
Dongfang	*	*	0.38	2.43	3.32	3.71	2.73	3.01	1.57	0.51
Harbin	2.77	3.84	2.29	1.19	1.99	2.45	2.68	1.23	0.92	0.31
Siemens	3.42	4.17	6.16	2.42	3.94	5.94	4.2	4.08	5.2	6.47
GE**	3.04	2.98	2.18	1.36	1.48	1.79	1.95	1.95	2.33	-1.08
MHI	1.16	1.38	0.54	0.32	0.73	0.62	2.46	3.64	2.12	1.16
Hitachi	-0.32	-0.55	-7.91	-1.17	2.63	3.73	1.82	2.54	1.85	1.38
Toshiba	2.58	2.15	-6.03	-0.36	2.55	1.33	1.31	0.98	-0.6	-7.82

\*Dongfang data prior to 2008 not comparable due to corporate restructuring.

\*\*GE return on assets diluted by GE Capital.

Source: Morningstar data

Finally, the single biggest profitability issue for the Chinese firms may be that they trailed far behind Siemens and GE in generating high-margin revenues from service activities in the forward parts of the power generation value chain. This reflected particular weakness in dynamic, as opposed to manufacturing, capabilities.

### 3.8. Discussion

China's thermal power equipment sector fitted closely to the analytical framework set out in Chapter 1, whereby the contribution of the developmental state is focused on the upgrading of narrowly-defined manufacturing technology. Although the timing of the developmental state's initial quest for technology was fortuitous, coming during a period of global overcapacity and recession at the end of the 1970s, its impact was profound. The power of the state's monopsony negotiation

for technology delivered a remarkable deal, as Westinghouse agreed loss-leading terms.

Consistent with what the analytical framework recommends in the early stages of capability building -- when the excludability of intellectual property is low -- the developmental state distributed mature, imported technology to multiple firms and created an environment where competition encouraged the diffusion of basic technological capabilities. Competition, and the pace of absorption of technology, increased from a very low base as the corporatisation and marketisation of a centrally planned socialist economy proceeded. Critically, the developmental state stuck with its technology transfer plan over a long period, allowing gradual, cumulative learning gains to accrue, and thereby increasing the base of capabilities with which new technological challenges were confronted.

The developmental state's capacity for coordinating the growth of manufacturing capabilities was further apparent in its success in forcing historically separate, state-owned R&D institutions and universities to integrate with and support the technology needs of less centralised, more market-driven firms (Gu and Lundvall, 2006, Gu, 1999, Fu, 2015a). Through the 1980s and 1990s, a long series of reforms and a budgeting structure that promoted 'excellence-based allocation' of public funds (Gu and Lundvall, 2006:13), led China's R&D apparatus to commercialise and to support firm- and sector-level technology needs. Central government agencies both coordinated front-end research,

development and localisation efforts for technology acquisition, and shaped final market demand for new products.

The one hiccup in the developmental state's quest to build thermal sector manufacturing capabilities occurred when planners attempted to leap ahead from their previously step-by-step technology acquisition programme. In the early 1990s, the state sought to bargain not for mature technology, but for super-critical technology that was still causing technical problems in power plants in developed countries. Chinese government planners were unable to determine which multinational technology provider would overcome the technology issues. The lesson was simple: that the logic of catch-up and central bargaining did not imply a capacity to leapfrog the technological frontier. Fortunately, the Shidongkou failure led to a return to the gradualist technology programme, more double-checking of technology paths, and thereby set the scene for the rapid absorption of super-critical and USC technology in the 2000s.

As manufacturing capabilities increased, the two most salient themes of Chinese firms' modifications to imported technology were cost reduction and adaptation to local market idiosyncrasies.

The role of the domestic market in shaping products that were subsequently exported in the power equipment sector was considerable, reflecting Linder's 'home market' hypothesis (1961). Demand in China was for the cheapest possible electricity generation facilities and modifications to existing global technology reflected this. For example, in 2003 Dongfang reworked the 'pants legs' design of an Alstom



furnace for circulating fluidised bed (CFB) boilers into a single drum design, greatly reducing the manufacturing cost (Cen et al., 2009:219pp). Shanghai took Siemens designs for super-critical and USC systems and scaled them up to 1,000MW units, creating a product that met local demand for very large power stations, reduced emissions and the lowest possible generating cost.<sup>130</sup> Each of the big three firms developed co-generation equipment to supply both electricity and heating, per the tradition of north China (Cen et al., 2009:40pp and 345pp).<sup>131</sup> When the Chinese power equipment firms began to export in the mid-2000s, it was their 'good enough' (Brandt and Thun, 2010, Ghemawat and Hout, 2008), low-cost models honed in the domestic market that were shipped to early markets including Vietnam, India and the Middle East.

The developmental state-led drive for manufacturing capabilities engendered products that were unbeatable in the domestic market and highly competitive in emerging country export markets. However, consistent with the analytical framework of this thesis, manufacturing capabilities alone did not make Chinese firms comparably profitable with leading multinationals (Tables 18, 19, 22). The qualitative reason for this was not a failure of the developmental state's technology acquisition programme, but a shortfall of entrepreneurial dynamic capabilities.

The most striking manifestation of this was the inability of the three thermal power equipment firms to integrate forward and build substantial, high-margin businesses downstream. As a benchmark, over

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<sup>130</sup> Th6, 2 February 2016; Th9, 23 September 2016.

<sup>131</sup> By 2006, 16GW of air-cooled power plants were operational in China; co-generation equipment accounted for an unusually high 15 percent of the national installed base.

the past decade and more, GE and Siemens developed engineering, procurement and construction (EPC) services; power station management, monitoring and optimisation services; and value-adding maintenance service such that, overall, services accounted for the majority of the revenues in their power businesses. GE derived 63 percent of revenues in its Power segment from services in 2015, and those services secured much higher margins than manufacturing.<sup>132</sup>

In 2015 Dongfang, the only firm to break out clear data for ‘engineering and services’ revenues, reported that only 16 percent of turnover derived from those sources.<sup>133</sup> Shanghai’s published accounts suggested that service revenues in the power equipment business may be around one-quarter of the total, but still far behind multinational peers.<sup>134</sup> A Siemens interviewee noted that Chinese firms’ lack of service capabilities in forward segments of the value chain also limited their ability to offer what GE and Siemens term turnkey power system ‘solutions’.<sup>135</sup>

The shortfall of dynamic capabilities at the three thermal firms was brought into domestic competitive relief when they were confronted with the technological reset of wind turbine manufacturing. The competitive position of the thermal firms was undermined in particular by the need for rapid service response when mechanical problems

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<sup>132</sup> GE annual report 2015, p38. Siemens does not break out service revenues.

<sup>133</sup> Dongfang annual report 2015, p12.

<sup>134</sup> Shanghai only reported an aggregate number for a ‘modern services’ segment that spanned its entire business portfolio, accounting for 23 percent of total revenues in 2015. Service revenues relating to power equipment may have been proportionally a little higher, based on interviews conducted.

<sup>135</sup> Th6, 2 February 2016.

occurred with the turbines. They were unable to deliver as effectively as new private firms, as discussed in Chapter 4. In Europe and the US, by contrast, the incumbent thermal power sector leaders, Siemens and GE, moved quickly to become the number two and number one global wind turbine firms respectively. The Chinese firms could not replicate this response to the changed competitive environment.

What, then, accounts for the transitional difficulties from developmental state-led to entrepreneurial firm-led development among the thermal case study firms? Ownership is the variable that appears to link most of the competitive weaknesses identified among the Chinese power equipment firms.

The risk taking and disruption associated with the growth of dynamic capabilities were inhibited by a traditional separation between state-owned firms that manufactured power equipment, government design institutes that designed power plants, state-owned construction firms that built power plants, and state-owned utilities that operated them. Competition was introduced within each of these segments of the value chain, but in the absence of ownership reform Siemens interviewees noted that state-owned firms were reluctant to attack the business terrain of other state units located in different parts of the chain.<sup>136</sup>

After the ending of central bargaining for technology in the thermal sector, universal state ownership also appeared to contribute to a culture of low risk-taking in the acquisition of technology. Shanghai

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<sup>136</sup> Th5, 4 July 2014; Th6, 2 February 2016.

developed overwhelming dependency on technology derived through joint ventures. In the light of this dependency, when Siemens bought the Westinghouse power equipment business, Shanghai renewed its joint ventures on more onerous terms. When Shanghai struggled to compete in wind turbines, the firm turned to another joint venture with Siemens, before renegotiating a licensing deal. Even the investment in Ansaldo, attempting to access technology for LGTs that Siemens refused to sell, was structured with a joint venture as the main operating vehicle, in which Shanghai held a minority.

Beyond ownership reform, the failure of the Chinese government in the thermal power sector compared with more effective developmental state policies in north-east Asia was that the state did not cull the weakest beneficiaries of state support (Chang, 1994:123pp).<sup>137</sup> Despite the small size of the Chinese thermal power equipment firms relative to multinational peers, the developmental state never reduced their number or forced through a merger to allow for increased scale and competition focused more on quality and differentiation rather than price. This was despite the fact that Harbin was clearly the weakest link in the industry.<sup>138</sup>

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<sup>137</sup> Chang notes that only three of the top 10 South Korean *chaebol* in 1966 were among the top 10 in 1974; only five of the top 10 in 1974 were in the top 10 in 1980; and only six of the top ten in 1980 were still in the top ten in 1985.

<sup>138</sup> Several interviewees commented that there were repeated rumours in the 2000s and 2010s that Harbin would be merged with another firm. The fact that nothing occurred was attributed, in part, to the difficulties central government encountered in forcing through industrial rationalisation against the desire of local governments to hold on to sources of patronage, taxation and employment. Th5, 4 July 2014; Th6, 2 February 2016; Th9, 23 September 2016; Th11, 20 July 2016. Lardy (2014:24-33) highlighted the low levels of concentration in many state-dominated industrial sectors, noting there were 880 SOEs in coal mining, 312 in steel, and 264 in non-ferrous metal processing.

With the strongest Chinese power equipment firm ostensibly beholden to multinationals for new technology, and the sector not set for privatisation, it is presently difficult to envisage how a Chinese company will close the innovation and profitability gap to the leading global firms in thermal power equipment. China has made enormous strides in the acquisition of manufacturing capabilities in the thermal power sub-sector, but its firms show few signs of the dynamic capabilities that characterise leading global businesses. In the wind sector, by contrast, we will see how the transition from state-led to world-class firm-led development is proceeding more smoothly because the sub-sector dispensed with ubiquitous state ownership from the outset.<sup>139</sup> Dynamic capabilities are in the ascendancy in China's best wind firms.

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<sup>139</sup> It should be noted that consistent with Thun's findings in the automotive sector (2006), in the power equipment business state ownership by a local government, in Shanghai, proved superior to state ownership by central government, in the cases of Harbin and Dongfang. Thun suggested that there was no logical reason why the 'local developmental state' should be superior in business sectors with simpler supply chains than the automotive sector; however, in this case study it was.

## Chapter 4

### Wind power: state and private firms compete

#### 4.1. Background

In the late 1990s and the 2000s, the Chinese government pursued a new set of national technology transfer objectives for non-hydro renewable energy. In framing this latest round of industrial policy, central government agencies modified their strategy for technology acquisition in three significant ways.

First, central government ceased to restrict its support to a pre-selected group of state-controlled national champions, accepting that all firms, state-controlled and private, should enter into competition. A main-board director at Goldwind, today China's largest wind turbine manufacturer, noted that from the moment that the NDRC began to tender the first two wind farm concessions in 2003 it made clear that firms of all ownership types were welcome to bid.<sup>140</sup> Indeed, while Goldwind, then a state-controlled firm, won one of the first two bids, the other went to a forerunner company of today's Hanergy, a private enterprise.<sup>141</sup>

Second, after early and unsuccessful state-led joint ventures in wind turbines (see below), central government withdrew from central bargaining and management of the process of technology transfer on

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<sup>140</sup> W1, 27 May 2013.

<sup>141</sup> Goldwind won a concession in Guangdong's Huilai county. Huarui, the precursor company to today's Hanergy, won a project in Jiangsu province in combination with GE. These were the first two concessions granted by the NDRC, in late 2003. Note that the Huarui that became Hanergy is not related to the Huarui wind turbine manufacturer later established in Liaoning province, whose English name is Sinovel.

behalf of receiving firms. Instead, government limited itself to setting parameters for the transfer process – notably a minimum level of local content for turbines sold to domestic wind farms – and left manufacturers to decide for themselves how best to obtain technology inputs.

Third, reflecting and reinforcing the move to more open competition, government used the passage of a Renewable Energy Law (REL) to establish the overall playing field for renewable energy sector participants. The approach echoed Japan and Korea's earlier use of 'single-industry' laws to frame the rules of competition under industrial policy (Amsden, 1989, Johnson, 1982). In terms of the analytical framework of this thesis, the three changes opened new possibilities for the development of dynamic capabilities, as well as manufacturing capabilities, at the firm level.

The changes were tied up with progression of China's post-1978 reform and opening process. In particular, the late 1990s and early 2000s were characterised by explicit political acceptance of the role of the private sector in the economy, including a decision in 2001 to admit private entrepreneurs to membership of the CPC (Tsai, 2007, Dickson, 2007), and related amendments to the Chinese state constitution in March 2004.<sup>142</sup> A new approach to industrial policy was also consistent with a

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<sup>142</sup> See [http://www.npc.gov.cn/englishnpc/Law/2007-12/05/content\\_1381906.htm](http://www.npc.gov.cn/englishnpc/Law/2007-12/05/content_1381906.htm) Accessed 3 January 2017. Changes to the constitution included recognition of former General Secretary Jiang Zemin's theory of the 'Three Represents', which asserted that the Communist Party represented the great majority of Chinese people (implicitly including capitalists) rather than just its traditional political constituencies, as well as a statement that lawful private property is 'inviolable'.

further round of marketisation of economic relations connected to China's 2001 accession to the WTO (Lardy, 2004).

The march of reform and opening did not indicate a reduced role for state-led industrial policy. Rather, the era of wind turbine technology absorption was one in which government and a disparate array of firms groped their way towards new arrangements of 'embeddedness' between state and producers (Evans, 1995). Senior political figures continued to spend much time visiting companies deemed important or potentially important to national economic development. The MOST expanded its role as the key vehicle for the state's research and development subsidies, increasing the budgets for its '863' and '973' R&D programmes year after year (Feigenbaum, 1999, Liu et al., 2011).

Instead of directing activity at the firm level, the NDRC and the NEA focused on setting rules. Constrained by their small authorised civil service staffs following successive rounds of government downsizing (Yang, 2004, Brødsgaard, 2002), the NDRC and the NEA depended heavily on two specialist 'service units' (*shiye danwei*, 事业单位),<sup>143</sup> the Energy Research Institute (ERI) and the National Centre for Climate Change Strategy (NCCCS), to develop different policy options. In turn, these subsidiary agencies entered into numerous formal and informal relationships with the private sector and academia. Much of the drafting of the 2005 REL, for instance, was subcontracted to experts at Tsinghua University (Huanjing\_Baohu, 2010).

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<sup>143</sup> The term is sometimes translated as 'public service units'. See, for instance, OECD (2005).



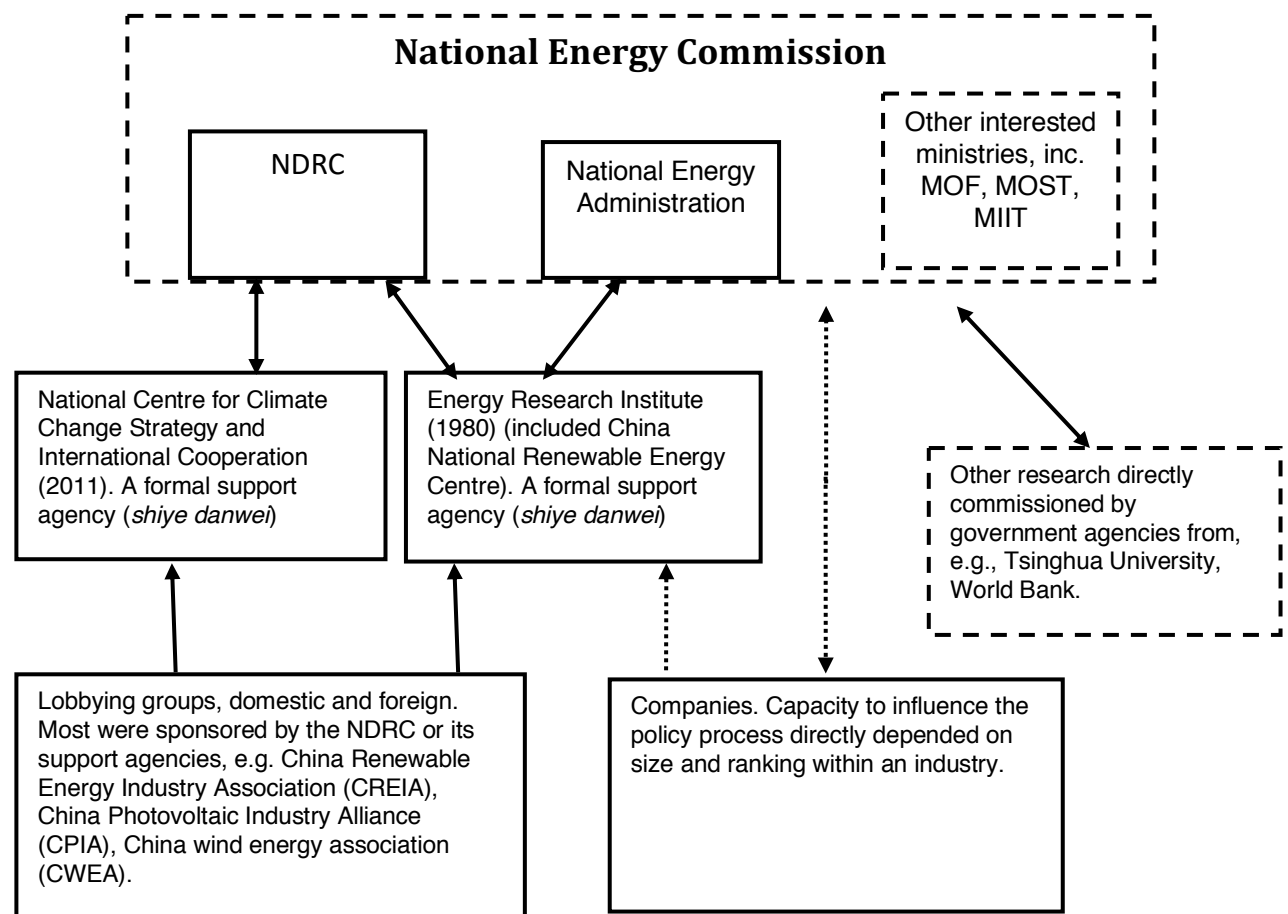
At the same time as government adjusted its approach to industrial policy, a more diverse array of companies sought to influence government policy-making. The development of patterns of communication and lobbying between national government and companies varied by industrial sector in China, influenced by factors including levels of state ownership and market concentration (Kennedy, 2009). In the renewable energy sector, Figure 4 presents a stylised representation of the three-tier structure that evolved. At the top, the NDRC, the NEA and other ministries concerned with renewable energy were, after 2008, coordinated by a National Energy Commission (NEC), chaired by the premier.<sup>144</sup> An interviewee at the NDRC described how, below government, a tier of research agencies directly supported the government's policy development work; these comprised the key formal service units for renewables, and third-party research suppliers including academia, think tanks, and sometimes foreign researchers.<sup>145</sup>

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<sup>144</sup> The NEC was set up at the same time as the NEA, in 2008. Where the NEA replaced the former Energy Bureau of the NDRC, the NEC replaced the former National Energy Leading Group. In essence, both new organisations were bureaucratic upgrades of their predecessors.

<sup>145</sup> G1, 31 May 2013.

**Figure 4. Government, research and lobbying relationships in renewable energy. (Arrows with solid lines denote formal relationships, arrows with dotted lines denote informal relationships)**



The third tier indicates how ministries and firms came to interact through different business associations that functioned as discussion and lobbying groups. All non-government organisations in China required a government unit to sponsor them; NDRC, MIIT, MOST and SASAC were among government agencies that sponsored different renewable energy industry associations (Table 23). In addition to associations established early in the reform era – which became much more active in the 2000s – new organisations were set up to represent particular groups of entrepreneurs.

Most such organisations represented only Chinese businessmen, creating fora in which government could interact with entrepreneurs outside the gaze of foreign competitors. However, there were also dedicated institutions through which foreign investors were engaged. The Chinese Renewable Energy Industries Association (CREIA) was started with UN funds in 2002 and brought together ERI and key foreign and domestic firms in both the wind and solar industries. During the drafting of the REL, CREIA was a conduit for the views of foreign firms and governments.<sup>146</sup>

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<sup>146</sup> G2, 31 May 2013.

**Table 23: Industry associations, government sponsors, start dates**

Name	Acronym	Sponsor	Start date
Chinese Renewable Energy Society	CRES	MOST	1979
China Photovoltaic Society	CPVS	CRES	1979
China Wind Energy Association	CWEA	CRES	1981
China Energy Conservation Association	CECA	Unknown	Unknown
Chinese Renewable Energy Industries Association	CREIA	SASAC, NDRC	2002
China New Energy Chamber of Commerce	CNECC	All-China Federation of Industry & Commerce	2006
China Renewable Energy Entrepreneur Club	CREEC	Unknown	2008
Polycrystalline Silicon Alliance	PSA	MOST	2009
China Photovoltaic Industry Alliance	CPIA	MIIT, NDRC	2010

Sources: Public materials of the industry associations

Most associations featured current and retired government officials as members alongside businessmen. In 2013, with respect to associations listed in Table 23: Retired NDRC vice chairman Zhang Guobao was Senior Advisor to the China Energy Conservation Association (CECA), an important lobby group; the current Head of ERI, Han Wenke, was an Executive Member of CECA's Governing Council. Zhang Guobao was also Chairman of the Thin Film Committee of the China New Energy Chamber of Commerce.<sup>147</sup> The Vice Head of ERI, Li Junfeng, was Vice Chairman of the Chinese Renewable Energy Society, a Committee Member of the China Photovoltaic Society, Deputy Secretary General of the China Photovoltaic Industry Alliance, and Chairman of the Chinese Renewable Energy Industries Association. Mao Rubai, Chairman of the Environment and Resources Protection Committee of the NPC, was Honorary

<sup>147</sup> Zhang Guobao retired from the NEA and NDRC in 2011. After retirement he was appointed head of the NEA's new Specialist Consultancy Committee (*Guojia nengyuanhui zhuanjia zixun weiyuanhui*); See <http://www.nea.gov.cn/nyzjzx/> Accessed 10 January 2017.

Chairman of the Chinese Renewable Energy Society and Chairman of the Advisory Committee of the China Renewable Energy Entrepreneur Club. Shi Dinghuan, Technical Consultant to the office of the premier at the State Council, was Chairman of the Chinese Renewable Energy Society and a Committee Member of the China Photovoltaic Society. In sum, China's business associations existed as state-sponsored institutions designed for government officials to interact with an ever-more diverse range of corporate interests (Foster, 2002, Pearson, 2005).

Firms also attempted to influence national government directly. As Kennedy (2009) illustrated, influence was strongly correlated with a firm's size and position in its sectoral hierarchy. However, it was extremely rare for an individual firm significantly to impact national policy. There were too many different bureaucracies involved in policy-making, and the central role of political consensus-building was inimical to firms' particularistic demands. In this respect, Chinese central government continued to deliver both 'embeddedness' at the firm level and the 'autonomy' required to ensure competition (Evans, 1995).

The above describes a terrain of central government-firm relationships that was evolving as state-owned, privately-owned and state-private firms competed to acquire wind turbine technology and build scale. While policy mechanisms were adjusted, central government's determination to lead the technology acquisition process did not change. Consistent with best practice in the analytical framework of this thesis, and with earlier strategies to acquire super-critical and USC technology in the thermal power equipment sector, this meant an initial

discrete, extended period of research, feasibility studies, and small-scale experimentation. Wind power was one of a number of renewable technologies that underwent evaluation by government agencies. Only slowly did wind turbine technology become a strategic priority as the most cost-effective target for renewable power generation, as well as a technology with a low risk of disruption, and hence an acceptable risk profile for the developmental state (Figure 5).<sup>148</sup>

**Figure 5. Possible central government investment choices in selected green energy technologies 2000-2010, and outcomes.**

Technology	Strategic impetus for national support	Perceived risk of technological disruption	Outcomes
Wind power	High (government seeking renewables expansion; lowest cost technology after hydro)	Low (only issue use of gears versus direct drive)	Steady progression from experimentation to substantial state concession tenders to national FIT. Policy consensus
Solar power	Low (cost per kwh a multiple that of wind)	High (unclear if polysilicon, thin-film or other technology would triumph)	Limited experimentation, limited state R&D, until falling pv unit costs and US/EU anti-dumping cases led to re-evaluation. No policy consensus until solar price structure changed radically
New energy vehicles	High (automotive sector a major target for industrial policy action, but so far with limited success)	High (batteries versus fuel cells)	Experimentation, substantial state R&D No policy consensus

<sup>148</sup> A insight into the extent to which Chinese planners considered risks of technological disruption was given in a speech about clean energy automotive technology by Zhang Guobao in October 2013. Zhang repeatedly stressed how unpredictable the technological development path of electric vehicles had been. See <http://auto.sina.com.cn/news/2013-10-17/23211236461.shtml> (in Chinese).

#### **4.2. Stage 1: Search and bargaining**

The earliest Chinese experiences with wind turbine generators involved the acceptance of grants and low-interest loans in the 1980s, in particular from the Danish government, conditioned on imports of equipment from the funding countries (Lema and Ruby, 2007). It was in this manner that the forerunner of today's Goldwind began its history as a research institute and manager of trial wind turbine installations in Xingjiang in 1986. In 1986 and 1989, Goldwind installed two, followed by 13, 150kw Danish turbines, creating the then largest Chinese wind farm, at Dabancheng, a natural wind tunnel close to Urumqi. China's first nationwide wind resource assessments were undertaken in the early 1990s. Several government agencies secured grants in aid in this period that gave further impetus to wind technology research. Sources included the World Bank and the United Nations Environmental Program (Economy, 2011, Lema and Ruby, 2007).

In the mid-1990s, different ministries and commissions began to develop plans for renewable energy. This occurred before there was any consensus about objectives at senior government level. There was consequently a period of uncoordinated and sometimes wasteful policy-making development.

In 1994, the Ministry of Electric Power set a target of 1GW of installed wind-generating capacity by 2000, but without arrangements to fund this. The SDPC (forerunner of the NDRC until 2003) published a lower target for wind installations (Lema and Ruby, 2007) and sponsored a

technology-transfer manufacturing programme based on two joint ventures – the first between Xi'an Aero Engine Corporation and Germany's Nordex and the second between First Tractor Group in Luoyang and Spain's MADE (Lewis, 2012). The SDPC's joint venture strategy for wind turbines echoed the technology acquisition approach pursued by thermal power equipment firms in the same period. With no strategy to expand demand for wind power, however, the joint ventures foundered. The State Economic and Trade Commission (SETC), responsible for large domestic enterprises and their technological development, published another, small-scale wind sector plan, while MOST developed its own technology transfer agenda (Lewis, 2005). In the face of these uncoordinated policy initiatives the wind sector remained small and dependent on imported turbines. As of 2000, only 344 MW of wind power was installed in China.

Despite the small scale of the wind sector, and the conflicting, uncoordinated plans of different central government agencies, Chinese researchers looked at and learned from a wide variety of foreign turbine technology. According to a database developed by Lewis (2012:134), prior to 2000 different projects employed turbines from 17 companies based in six European countries. Consequently, Chinese engineers, especially those at Goldwind, experienced substantively different approaches to not only the mechanical challenges of wind turbine manufacture, but also to siting and service issues. In addition, MOST provided its first R&D subsidies for wind turbines – for development of 600KW machines – under the 9th Five-Year Plan (1996-2000) (Lewis, 2012:56).



### Central government consensus for wind

At the start of the 2000s, a consensus slowly formed across different agencies of central government that China should pursue a substantial programme of wind turbine manufacturing. According to case study firm executives, a senior manager at ERI and an academic involved in framing the REL, there were three key considerations.<sup>149</sup> First, the relatively low generating cost of wind power compared to other non-hydro renewable alternatives, most obviously solar (Table 24). Second, the wind sector's relatively mature technology and low risk of technological disruption. In the solar sector in the early and mid-2000s, the future roles of thin-film versus polysilicon technologies were subject to widespread disagreement; in the wind sector, by contrast, the biggest technological issue was the secondary one of whether direct drive systems were preferable to gears. Third, local manufacturers dominated in almost all wind markets around the world, suggesting that Chinese firms would have an advantage in harnessing China's wind resource.

**Table 24. Levelised cost of electricity generated from wind, solar and coal inputs in China. 2008 actual and contemporary forecasts for 2020.**

**Rmb per MWH**

	2008	2020 forecast
Wind	500-650	350-430
Solar	2000-2500	700-750
Coal	250-370	250-430

Source: BTM Consult 2008

<sup>149</sup> W1, 27 May 2013, G3, 19 August 2016; G4, 30 July 2012.

An important figure in the pro-wind lobby was Zhang Guobao, since 1999 a vice director of the SDPC responsible for energy matters (in 2008, he became the first head of the NDRC's National Energy Administration). Zhang was a career NDRC bureaucrat with long experience in projects such as China's east-west gas pipeline, the Qinghai-Tibet railway, and the industrial revitalisation programme in north-east China. From 1999, Zhang was involved in several overseas research trips that looked at foreign wind turbine manufacturers and utilities and was convinced there was a case for Chinese industrial policy to target the sector.<sup>150</sup>

#### **4.3. Stage 2: Manufacturing of mature technology**

In 2002, Zhang received a mandate from the State Council to organise a series of larger-scale wind farm tenders, each of 100-300MW. According to a main board director at Goldwind, the projects had two main aims: first, to establish the current price of wind-generated electricity in China; second, to assess the wind turbine manufacturing capabilities of Chinese firms.<sup>151</sup>

The concession projects were carefully designed to ensure that developers and suppliers would participate. Sites were pre-selected by government and came with project approval, guaranteed grid connection, subsidies for supporting infrastructure, preferential tax and loan terms, and a power purchase agreement (PPA) for the first 30,000 hours of output. Bids were judged on the price offered by the developer per kilowatt-hour. In order to achieve rapid acquisition of domestic technological capabilities, the NDRC stipulated an initial local content

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<sup>150</sup> Southern Weekend (*Nanfang Zhoumo*), 27 March 2008 and 14 January 2011.

<sup>151</sup> W1, 27 May 2013.

requirement for turbines used in the concession projects of 50 percent, increased to 70 percent in 2004. In 2005, the NDRC issued a further notice clarifying that no wind farms with less than 70 percent domestic content would be approved in China.<sup>152</sup>

As noted, the criterion by which bids to construct the wind farm concession projects were judged was headline price *alone*. Unlike in international commercial tenders, there was no requirement for turbines to be certified by independent testing agencies and no consideration of estimated lifetime performance of the turbines. In consequence, while the prospect of large projects and the local content requirements encouraged many foreign manufacturers to open Chinese production facilities, the bidding system favoured Chinese manufacturers offering cheaper but lower quality machines.<sup>153</sup>

From 2003 to 2007 a total of 18 concession projects were offered, spread across five bidding rounds; 3.35GW of wind power capacity was installed, a multiple of China's existing wind generating capacity. The projects brought a large number of Chinese firms into the wind turbine manufacturing business. These included the big three state sector thermal power equipment firms, as well as many other state, private and mixed-ownership firms, the latter spun out by state enterprises.

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<sup>152</sup> NDRC notice no.1204, July 2005. 'Notice on the relevant requirements for the administration of the construction of wind farms' (*Fagaiwei guanyu fengdian jianshe guanli youguan yaoqiu de tongzhi*). The local content requirements were almost certainly contrary to China's undertakings as a member of the WTO, from 2001. The requirements were ended under US pressure in 2009, by which time wind turbines made in China were more than 90 percent localised. Many components were initially localised in the mid-2000s under programmes led by international firms including then market leaders Vestas and Gamesa; component producers subsequently sold components to domestic turbine manufacturers. See Keith Bradsher, 'To conquer wind power, China writes the rules', *New York Times*, 14 December 2010.

<sup>153</sup> Turbine size had to be a minimum 0.6MW.

From 2004, the State Council mandated different groups to begin preparatory work for the REL. Consistent with good practice in the analytical framework of this thesis, the Environmental and Resources Protection Committee of the National People's Congress, in charge of drafting the law, consulted with domestic manufacturing firms on its content, while NDRC researchers continued to visit foreign wind turbine makers, as well as foreign government agencies with renewables experience.<sup>154</sup> In an instance of low-cost regulatory borrowing, the REL was based on German legislation (as were subsequent environmental regulations, including those governing distributed solar power). The law set targets for renewables capacity, created a national reserve to subsidise the cost of renewable energy, and mandated grids to connect and buy renewable power; it came into force at the beginning of 2006.

In 2007, the NDRC published its Medium- and Long-Term Plan for Renewable Energy Development in China, which provided the first comprehensive set of targets, including 30GW of grid-connected wind power by 2020. (The target was revised only five years later, in 2012, to 200GW.) The 2007 Plan also stipulated that electricity generating companies must generate at least 8 percent of their power from renewables by 2020, a stipulation that became a major driver for the growth of the wind industry (Lewis, 2012:54). The 2007 Plan included a first mention of China's strategy to develop multi-gigawatt wind power 'bases'.

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<sup>154</sup> W1, 27 May 2013. GE and Suzlon were among foreign firms studied by the NDRC.

In 2009, as a result of operating experience, the REL was amended. Changes included regulations to address delays in providing grid connectivity (Schuman and Lin, 2012). The same year, the NDRC moved from a tendering process for wind projects to a four-category national feed-in tariff (FIT), creating an operating environment in which central government decided demand for wind power by setting medium- and long-term targets for its generation, and leaving developers to decide when and how to build wind farms.

Table 25 shows the impact of the successive government policy initiatives from 2003 on the Chinese wind turbine market. Installations approximately doubled each year from 2003 to 2009, hitting a peak of almost 19 gigawatts in 2010. From 2009, China constituted the largest wind turbine market in the world. What was more telling, however, was that the signalling effect of government industrial policy was such that production capacity for turbines increased faster than demand. Until 2006, when the REL came into force, capacity utilisation for wind turbine assembly in China was close to 100 percent. In 2007, when the Medium- and Long-Term Plan for Renewable Energy Development mandated targets for renewables generation, capacity utilisation fell to 75 percent as factory construction accelerated. In 2008, capacity utilisation fell to 54 percent.<sup>155</sup> The learned responsiveness of manufacturers to state policy echoed the developmental experiences of Japan, South Korea,

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<sup>155</sup> Data on capacity utilisation are taken from a 2009 report by the European Chamber of Commerce in China in conjunction with Roland Berger Strategy Consultants: 'Overcapacity in China: causes, impacts and recommendations'. Available at [http://173.254.52.9/~undersx4/wp-content/uploads/2013/10/European-Chamber-of-Commerce-\\_Overcapacity-in-China\\_Dez09.pdf](http://173.254.52.9/~undersx4/wp-content/uploads/2013/10/European-Chamber-of-Commerce-_Overcapacity-in-China_Dez09.pdf) Accessed 12 January 2017.

and Taiwan (Johnson, 1982, Amsden, 1989, Wade, 1990, Gold, 1986, Woo, 1991).

**Table 25. Annual installed and cumulative wind generating capacity in China, 2001-13. MW**

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
New Installed Capacity (MW)	42	66	98	197	507	1288	3311	6154	13803	18928	17631	12960	16089
Cumulative Installed Capacity (MW)	381	448	546	743	1250	2537	5848	12002	25805	44733	62364	75324	91413

Source: CWEA

Manufacturing capacity was constructed at an extraordinary pace. In August 2009, the State Council listed wind turbine production as an ‘excess capacity sector’, causing the Ministry of Land and Resources to deny applications for new manufacturing facilities. Some 80 firms had already entered the business (Zhou et al., 2016:292).

The rush to enter the market combined with the government’s withdrawal from central bargaining for technology to produce a new phenomenon: the tendency for technology costs to be bid up. In 2009, the Ministry of Finance published a report in which it claimed that unrestricted entry into the wind business caused prices of production licences for foreign-designed 1-1.5MW turbines to increase from US\$1.4-2.8 million in 2005 to US\$11-12.4 million in 2007 (Tan and Seligsohn, 2010a).

Data for technology expenditure from Mingyang (see case study) showed in detail how small- and mid-size European design firms were able to extract hefty upfront payments as well as royalties with minimum charges per megawatt of turbine produced. Within

government there was criticism that the move to a more *laissez-faire* approach to technology transfer mostly benefited foreign technology owners.<sup>156</sup> The anxiety echoed that 40 years earlier within the Japanese government when central bargaining for technology by MITI gave way to decentralised firm-level negotiation in sectors including electronics (Gregory, 1985, Lynn, 1982, Peck and Tamura, 1976).

Nonetheless, Chinese firms were quick to absorb imported wind turbine designs and to modify them sufficiently to be able to claim ‘independent’ design capabilities. A 2009 survey of 120 turbine models available in China found that the number claimed to be of ‘independent design’ more than doubled, to 51, compared with 25 in 2008. The number of turbines constructed under a basic foreign licence halved to less than 10 in 2009, while the number designed on the basis of ‘joint development’ with a foreign technology provider, under which IP rights were shared, increased from 10 to 25 (Wang et al., 2012).

In the supply chain, by 2009 Chinese component providers achieved full localisation of blades, gearboxes, and generators, while domestic capabilities in bearings, converters and control systems progressed markedly.<sup>157</sup> Chinese firms scaled up the size of the turbines they produced fast, in line with the key NDRC metric for technological progress. The average size of wind turbines installed in China doubled between 2000 and 2010, from 600KW to 1.3MW (Lewis, 2012, Ru et al., 2012). What was striking in terms of the analytical framework of this

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<sup>156</sup> W2, 30 July 2012.

<sup>157</sup> See: Li Junfeng et al, *2010 China Wind Power Outlook*, Beijing: CREIA & GWEC. Available at <http://gwec.net/wp-content/uploads/2012/06/wind-report0919.pdf> Accessed 18 January 2017.

thesis was that if there was inflation of technology costs compared with centrally bargained outcomes, this was compensated by greater technological competition and greater variety in technological paths.

The scale of domestic investment, the capability by the 2000s of Chinese manufacturers to produce most mechanical (as opposed to electronic) wind turbine components from wholly-domestic inputs, and project bidding based on headline price without independent quality certification, meant that international firms were barely able to compete.<sup>158</sup> The foreign firm bid prices reported by the China Wind Energy Association (CWEA) were, on average, 13 percent and 20 percent higher than those of domestic firms in 2004 and 2005, when early concession projects were tendered. From 2006 to 2011, as domestic production capacity mushroomed, average foreign firm bids were one-quarter to one-third higher than domestic ones (Figure 6).<sup>159</sup> Consequently, the foreign turbine makers' share of the Chinese market fell, according to the CWEA, from 75 percent in 2004 to 70 percent in 2005, 55 percent in 2006, 43 percent in 2007, 25 percent in 2008, and 10 percent in 2010, a level at which it stabilised.

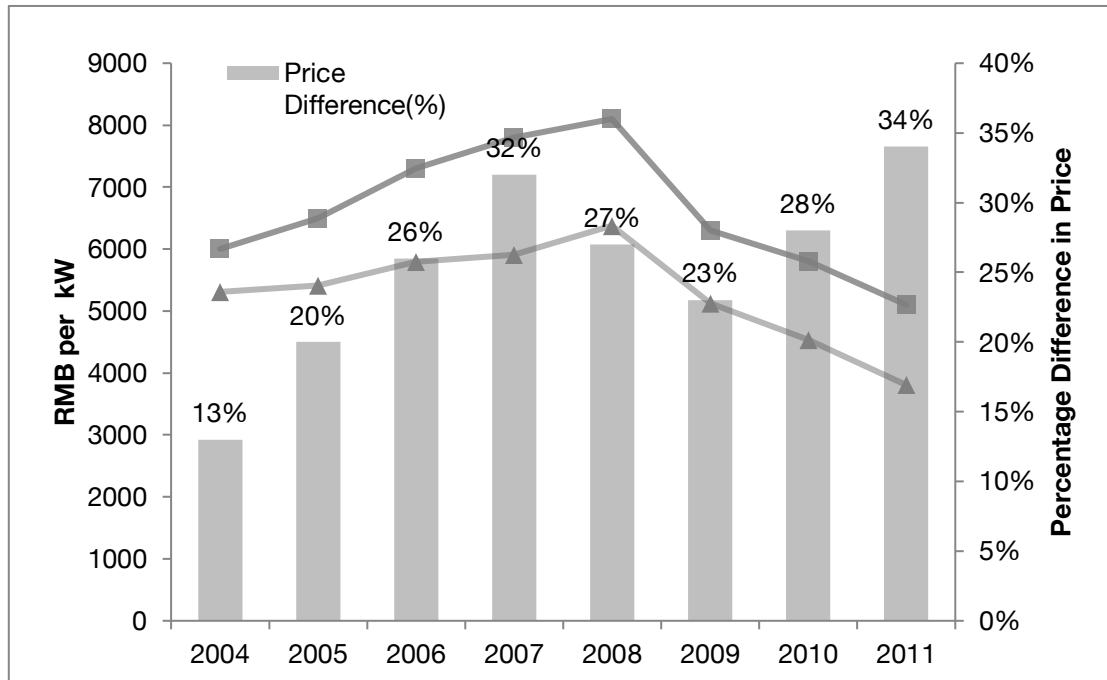
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<sup>158</sup> It was also alleged that during the concession project era, foreign firms were denied timely access to bidding information while domestic firms were sometimes allowed to raise their prices after they were awarded bids. Such allegations were raised in author interview W2, 30 July 2012, and are noted in Lewis (2012).

<sup>159</sup> The price difference between tenders inside and outside China was greater. When Suzlon subsidiary Repower Systems announced its withdrawal from China in 2011, CEO Andreas Nauen stated that the price per KW for onshore turbines in China that his firm experienced in 2011 was around Rmb4,800; the price in tenders elsewhere in the world averaged Rmb11,000. Sara Knight, 'Repower announces withdrawal from China', *Windpower Monthly*, 23 September 2011.



**Figure 6. Chinese and foreign average wind turbine prices in the Chinese market, 2004-2011. (Chinese turbine prices marked with triangles, foreign turbine prices with squares)**



Source: reported prices bid to concession and wind base projects. CWEA data

The early market leaders through 2010 were Sinovel, a start-up of state-owned heavy equipment maker Dalian Heavy Industry Group Co.; Goldwind, the domestic firm with much the longest experience with wind turbines; and Dongfang (Table 26). Dalian Heavy and Dongfang used similar strategies to leapfrog Goldwind. Early movers in creating production capacity when the NDRC began to tender concession projects, they both possessed engineering capabilities that enabled them to quickly localise (both internally and through suppliers) the production of mechanical wind turbine parts, and they focused on the 1.5MW turbines that NDRC bureaucrats favoured in the first years of

market expansion.<sup>160</sup> As large state-owned firms, Dalian Heavy and Dongfang enjoyed good lines of communication to government policymakers. The founder of Dalian Heavy subsidiary Sinovel, Han Junliang, knew NEA Director and wind industry promoter Zhang Guobao personally.<sup>161</sup>

Dalian Heavy purchased a licence for a 1.5MW turbine from German design house Fuhrländer at the end of 2004. When the NDRC issued the notice in July 2005 that wind projects required a minimum 70 percent local content by value, Dalian Heavy was already localising major components, including a gearbox, generator, yaw system and tower.<sup>162</sup> Sinovel was incorporated in February 2006. While many observers regarded Sinovel as a state company, only 20 percent of its equity was owned by Dalian Heavy, both pre- and post- a 2011 initial public offering (IPO).<sup>163</sup> Other substantial shareholders included a subsidiary of New Horizon Capital, a private equity firm co-founded by a son of premier (2003-13) Wen Jiabao; Wei Wenyuan, former general manager of the Shanghai stock exchange; Sinovel chairman Han Junliang; and other senior Sinovel managers.<sup>164</sup> Sinovel was a complex mix of state and

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<sup>160</sup> NDRC officials consistently pushed firms to produce larger turbines, as their metric of technical progress. W1, 27 May 2013.

<sup>161</sup> The perceived significance of the relationship between Zhang Guobao and Han Junliang was mentioned by several interviewees, including W1, 27 May 2013 and W2, 30 July 2012. See also references to the relationship in media reports including Pu Jun and Yu Ning, 'Post-boom blowdown for wind energy's Sinovel', *Caixin*, 11 July 2013, and Michael Riley and Ashlee Vance, 'Inside the Chinese boom in corporate espionage', Bloomberg, 15 March 2012. Zhang and Han's relationship was believed by interviewees to date from Zhang's NDRC work in north-east China.

<sup>162</sup> Securities Review (*Zhengquan Daobao*), 24 August 2012. In Chinese. Available at [http://zqdb.hinews.cn/html/2012-08/24/content\\_518332.htm](http://zqdb.hinews.cn/html/2012-08/24/content_518332.htm) Accessed 13 January 2017. Further background is contained in Pu Jun and Yu Ning, 'Post-boom blowdown for wind energy's Sinovel', *Caixin*, 11 July 2013.

<sup>163</sup> Sinovel annual report 2010, pp5-6. The report stated that Sinovel had no controlling shareholder.

<sup>164</sup> *Caixin* reported that there were five original Sinovel shareholders in 2006, amongst whom a subsidiary of Dalian Heavy, New Horizon Capital, and Wei Wenyuan, constituted three. Pu Jun and Yu Ning, 'Post-boom blowdown for wind energy's Sinovel', *Caixin*, 11 July 2013.

private interests; the firm's core production base was in Dalian, but its headquarters were in Beijing.

Dongfang also concluded a licence deal for a 1.5MW turbine in 2004, with German manufacturer and design house REpower (with which Goldwind already worked). Like Dalian Heavy, Dongfang began to localise component manufacture in 2005, assembling its first turbine at the end of 2006. By mid-2007, when Sinovent claimed a local content rate of 85 percent for its 1.5MW turbines, Dongfang reported 70 percent.<sup>165</sup> Both companies established dedicated wind power research institutes, backed by central government grants.<sup>166</sup>

In 2008, Sinovent emerged as China's biggest wind turbine manufacturer (Table 26). Goldwind was second, and Dongfang third. That year, Sinovent won much the biggest slice of the first tender for one of China's multi-gigawatt wind bases, Jiuquan in Gansu province, securing 1.8GW of orders for the 3.8GW first phase of the project (Backwell, 2014). That mammoth order, and other large ones for wind bases, set Sinovent up to pull further ahead of Goldwind in 2009 and 2010, delivering 3.5GW and 4.4GW of turbines respectively. In January 2011, Sinovent completed an IPO in Shanghai, raising Rmb9.45bn.

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<sup>165</sup> The local content claims were not audited. See p18-19 of Li Junfeng and Gao Hu, *2007 China Wind Power Report*, available at <http://gwec.net/wp-content/uploads/2012/08/wind-power-report.pdf> Accessed 16 January 2017.

<sup>166</sup> W3, 5 May 2010.

**Table 26. Market-leading Chinese wind turbine manufacturers, 2008-13. MW of annual installations and () rank**

	<b>Sinovel</b>	<b>Goldwind</b>	<b>Dongfang</b>	<b>United Power</b>	<b>Mingyang</b>
2008	1403 (1)	1132 (2)	950 (3)	24	146
2009	3495 (1)	2722 (2)	2036 (3)	768 (4)	749 (5)
2010	4386 (1)	3736 (2)	2624 (3)	1643 (4)	1050 (5)
2011	2939 (2)	3200 (1)	946 (5)	2847 (3)	1178 (4)
2012	1203 (3)	2522 (1)	467 (9)	2029 (2)	1134 (4)
2013	896 (7)	3750 (1)	574 (9)	1488 (2)	1286 (3)

Source: CWEA

By the time of the Sinovel IPO, however, both Sinovel and Dongfang were experiencing equipment performance problems. The gearbox on Sinovel's 1.5MW turbine was susceptible to damage from gusting wind. Anonymous internet postings warned of sub-standard and rusting components in Sinovel turbines. A windmill in Kulun county in Inner Mongolia, stated online to be a Sinovel product, lost an entire blade in May 2010.<sup>167</sup> In spring 2011, technical failures at wind bases in Jiuquan in Gansu and Zhangjiakou in Hebei that threatened serious damage to local grids were reported in the Chinese press.<sup>168</sup> In October 2011, five people died in an accident at a Sinovel assembly plant in Gansu.<sup>169</sup>

<sup>167</sup> W4, 3 May 2011. Claims of technical failures and poor quality in Sinovel turbines were previously posted and were viewed at <http://bbs.simol.cn/archiver/tid-10279.html> and <http://www.windpower-china.com/node/411> in 2011. At the time of writing these pages can no longer be accessed. Images of the purported fallen blade in Kulun county in Inner Mongolia were posted on a Chinese blog and can still be viewed at [http://blog.sina.com.cn/s/blog\\_4cf4ed770100mkgu.html](http://blog.sina.com.cn/s/blog_4cf4ed770100mkgu.html) Accessed 16 January 2017. The blade is not explicitly identified as a Sinovel product in the posted photographs.

<sup>168</sup> Securities Review (*Zhengquan Daobao*), 24 August 2012. In Chinese. Available at [http://zqdb.hinews.cn/html/2012-08/24/content\\_518332.htm](http://zqdb.hinews.cn/html/2012-08/24/content_518332.htm) Accessed 13 January 2017.

<sup>169</sup> Pu Jun and Yu Ning, 'Post-boom blowdown for wind energy's Sinovel', *Caixin*, 11 July 2013.

The reports of technical failures came on top of increasing problems with the dispatch of electricity from wind bases in north China. Transmission capacity was inadequate. Increasing numbers of turbines were denied connection to the grid.

Central government and the NEA therefore decided to slow the pace of wind power expansion and recentralise control of all wind farm development. In mid-2011, the NEA issued a game-changing regulation that made approval of small wind farms under 50MW – which previously required only local government permits – an NEA function.<sup>170</sup> In effect, local governments lost their capacity to protect and subsidise favoured local firms. The new regulations came six months after the retirement of NEA head Zhang Guobao, in January 2011.

Wind turbine installations fell by 7 percent in 2011, and by more than one quarter in 2012 (Table 25). The firm-level effect of the slowdown was to return manufacturing over-capacity to very high levels, just as turbine failures focused wind farm operators on variations in the performance of turbines, and on the different break-down service responses from manufacturers. Sinovel and Dongfang were perceived poorly, on both counts. In 2011, Sinovel's orders fell by one-third, and then by a further 59 percent in 2012, far more than the market. Dongfang, whose service response to breakdowns in 2010 had been particularly slow, was hit even harder. Sales fell 64 percent in 2011 and a further 51 percent in 2012. Dongfang's sales then stabilised (Table 26); however Sinovel's kept falling.

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<sup>170</sup> 'Wind farm development interim rules and regulations,' NEA, 2011. Unapproved wind farms were not eligible for the FIT, or for grid connection.

Sinovel created two more problems for itself. In 2011, the firm was caught bribing an employee of its American electronic controls supplier to steal a copy of its source code.<sup>171</sup> And in May 2013, Sinovel came under investigation by the China Securities Regulatory Commission (CSRC), accused of overstating its revenues and profits in 2011 by 10 percent. Sinovel chairman Han Junliang resigned in March 2013, shortly before the investigation was publicly announced. By 2015, Sinovel disappeared from the top ten list of Chinese turbine manufacturers, while Dongfang retained a domestic market share of 4-5 percent, placing it eighth among manufacturers in 2015.

#### **4.4. Stage 3: Manufacturing of current technology; and incremental modification of current technology**

The 2011-12 period marked the end of the first phase of a new industrial policy approach in China's energy sector. The opening of competition to all firms, government withdrawal from central bargaining for technology, and the use of laws and regulations, rather than fiat, to frame industrial policy had created new challenges. Open admission to the market produced a large and diverse range of entrants, but not all of them were, in hindsight, desirable. Sinovel, in particular, combined the political inside track of a large state firm with a majority non-state equity structure that encouraged what Kroeber (2016:chapter 5) described as a Chinese variant on crony capitalism. Sinovel delivered neither the stolid manufacturing reliability of the state sector, nor the value-adding

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<sup>171</sup> The US supplier, AMSC, secured a conviction for distribution of trade secrets against the employee, Dejan Karabasevic, in court in Austria in September 2011; he was sentenced to one year in jail. Legal action in China was unresolved at the time of writing. Michael Riley and Ashlee Vance, 'Inside the Chinese boom in corporate espionage', Bloomberg, 15 March 2012.

flexibility and resourcefulness of the private sector. Dongfang was a more traditional, centrally-controlled state firm, but also disappointed after a flying start, not least because it failed to compete on service aspects of the wind business.

A different state firm now became the number two player to Goldwind, following a later entry into the market. United Power was from the China Guodian group, one of the 'big five' power utilities created under a government restructuring in 2002, which had inherited a small number of state wind farm assets. Guodian controlled the Longyuan group, whose Longyuan Power operated the wind farms, and added more capacity through the 2000s and early 2010s to become China's leading wind farm developer. United Power, the turbine manufacturer, was a former service joint venture of the Longyuan group with Westinghouse, set up in 1994 with a remit to improve performance of China's fleet of aging 200MW thermal turbines. Siemens took over Westinghouse's interest in the business in 1998, but by 2006 there was no more work upgrading 200MW units. The Beijing joint venture was dissolved and the Chinese side, looking to deploy around 100 trained engineers, started to manufacture wind turbines.<sup>172</sup>

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<sup>172</sup> China Guodian Corp., a holding company, was one of the big five power generators created from the former State Power Corporation (SPC) in 2002. China Guodian absorbed the Beijing-based Longyuan group as part of the same restructuring. Most wind farm assets, which came originally from SPC, were held through Longyuan Power. In December 2009, Longyuan Power listed in Hong Kong as a dedicated wind farm developer, and by end 2013 accounted for 11.8GW of 17.5GW of installed wind farms in China. Other Longyuan group companies included Longwei Power Generation Technology Service Co., the 50:50 joint venture with Westinghouse set up in 1994, which was restructured and renamed Guodian United Power Technology (United Power) in 2007. In 2010, United Power was authorised and funded to set up a State Key Laboratory for Wind Power Equipment at its base in Beijing. Sources: United Power web site at <http://www.gdupc.com.cn/newsContentEN.aspx?catald=41&id=13334> Accessed 18 January 2017. Fang Tiantian, 'The Past and Present of United Power' (*Lianhe Dongli de qianshi jinsheng*), *21<sup>st</sup> Century Business Herald*, 24 January 2011.

In November 2006, United Power engaged German design house Aerodyn to develop a 1.5MW turbine. Rather than manufacture an established model, the firms' engineers worked through a joint development arrangement and created a windmill with longer blades than was then the norm in China, yielding more power from lower wind speeds. The Chinese firm recruited a deputy general manager, Sun Lixiang, who worked for six years with Germany's Nordex, a partner in one of the original two wind turbine joint ventures. United Power was able to use the Guodian group's wind farms to test prototypes in different climatic conditions; the parent group also provided a captive market in the early years of development.

United Power became the most vertically integrated wind turbine producer in China, entering blade manufacture from 2007 and making gearboxes, generators and control systems. Its first turbine was installed in 2008. In 2009 and 2010, United Power became the fourth biggest player in the market based almost entirely on sales to its own group. The quality of its machines was confirmed in 2010 when one-third of orders came from other developers. Thereafter, United Power rose to second place (Table 26, above), the majority of its sales consistently outside its group.<sup>173</sup>

In the second phase of wind industry development, United Power consolidated its number two position. It was followed in third and fourth

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<sup>173</sup> See: Li Junfeng et al, 2014 China Wind Power Review and Outlook, Beijing: CREIA & GWEC. Available at <http://www.gwec.net/publications/country-reports/> Accessed 18 January 2017. Fang Tiantian, 'The Past and Present of United Power' (Lianhe Dongli de qianshi jinsheng), *21<sup>st</sup> Century Business Herald*, 24 January 2011.



places by two private sector firms, Mingyang and Envision (Table 27). Mingyang, based in Guangdong province, entered the market at the same time as United Power, in the second half of 2008, coming from a background in low-voltage electrical equipment manufacturing. Envision, headquartered in Shanghai, entered the market only in 2012, and was started by Chinese former finance and private equity professionals who had worked abroad.

Envision represented a new model inasmuch as its founders came from outside manufacturing and sought to assemble a globally-integrated business from the outset, with key design resources outside China, manufacturing in China, and an immediate focus on service aspects in the forward part of value chain. Mingyang and Envision are addressed in case studies below, following the Goldwind case study.

Goldwind, the earliest entrant in wind turbine manufacturing, secured clear market leadership in the second phase of development of the wind turbine sector, with an estimated market share of 27 percent in 2016 (Table 27).<sup>174</sup> In the process, Goldwind transitioned from state-owned work unit to a firm with diversified ownership and no controlling shareholder, and a global design capability split between China and Germany. As noted, the opening of the wind sector to all types of firm produced a broad array of contenders, from pure state to pure private, with many variants in between. Among the top four turbine makers, with more than half the Chinese market between them, private

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<sup>174</sup> Market share data for 2016 were not confirmed at the time of writing.

shareholder interests were in the ascendancy by 2015; only United Power could be described as a traditional state firm.

**Table 27. Market-leading Chinese wind turbine manufacturers since 2014. MW of annual installations and ( ) rank**

	<b>Goldwind</b>	Goldwind China market share	<b>United Power</b>	<b>Mingyang</b>	<b>Envision</b>
2014	4434 (1)	19%	2582 (2)	2058 (3)	1962 (4)
2015	7749 (1)	25%	3065 (2)	2510 (3)	2510 (4)
2016	6363 (1)	27%	1908 (4)	1959 (3)	2003 (2)

Source: CWEA

The second phase of manufacturing development was characterised by the production of wind turbines close to the global technological frontier and by more competition through differentiation and incremental innovation. As noted, state-owned United Power led in the most important area of early hardware differentiation, entering the market in 2008 with a 1.5MW turbine driven by 82m diameter blades when the largest blade sets in use in China were 77m. Low wind-speed turbines were popular not in the wind base areas identified by NDRC planners -- regions that were constrained by power distribution limitations -- but in central and southern China. In 2009, Mingyang and Envision began to mould 1.5MW turbine blade sets with, respectively, 83m and 87m diameters.<sup>175</sup> Other manufacturers followed the trend. By 2011, Goldwind modified its 1.5MW turbines to work at 'ultra-low' wind speeds with 93m diameter blades sets (Wang et al., 2012). By 2013,

<sup>175</sup> China Mingyang Wind Power form 20-F 2010, filed with the United States Securities and Exchange Commission 11 April 2011. W13, 23 October 2014.

United Power's ultra-low wind turbines were deploying 97m blade sets.<sup>176</sup>

United Power set the pace in the hardware area of competition -- larger blade sets, and turbines and generators adjusted to work with them. A main board member at Goldwind noted that the 'cut-in' wind speed for leading Chinese turbine makers fell from 9 metres per second in the mid-2000s to 5 metres per second in 2013. 'Bigger blades,' he observed, 'operating at slower wind speeds, made the market larger.'<sup>177</sup> However, as reflected in the analytical framework of this thesis, as time went on competition through turbine and blade size was only one aspect of broader competition. Service provision, project management skills and asset-light structures became increasingly important. In these dimensions, state-owned United Power was less able to compete successfully. The shape of evolving competition in the second stage of development becomes clearer as we examine the case studies.

### **Three case studies**

#### **4.5. Case study: Goldwind**

In line with empirical regularities set out in Chapter 1, Goldwind showed that technological learning is cumulative. The firm was the earliest learner in the wind turbine sub-sector and built up manufacturing capabilities step by step to a point where it was able to digest and

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<sup>176</sup> The trend continued with longer blade sets fitted to larger turbines. In 2014, Goldwind marketed a 2MW turbine with 115m blades. For further details of the development of low wind-speed turbines in China, see pp6-7 of Li Junfeng, *2014 China Wind Power Review and Outlook*, available at <http://www.gwec.net/publications/country-reports/> Accessed 16 January 2017.

<sup>177</sup> W1, 27 May 2013.

commercialise a non-mainstream wind turbine technology – Direct Drive Permanent Magnet (DDPM) electricity generation -- that marked out its superior manufacturing credentials. In the long run, however, the extension of Goldwind's competitive advantage was not so much through its narrow manufacturing capabilities as through its development of dynamic capabilities when the firm moved to systems integration in manufacturing, combined with a quest for high-margin, downstream activities that delivered Chandlerian economies of throughput (Chandler, 1977) to its assembly plants. Goldwind made and implemented these entrepreneurial, strategic choices earlier and faster than other Chinese companies.

Goldwind grew out of Xinjiang Wind Energy Co. (XWEC), a state research work unit created in 1986 in Urumqi, Xinjiang. XWEC was a vehicle to receive, operate, test and study imported wind turbines. The first two turbines were imported from Denmark in late 1986. In 1989, a US\$3.2m grant from the Danish government paid for 13 more turbines, forming the then largest wind farm in China.<sup>178</sup>

More turbines were added through the 1990s. It appears that XWEC employees, including current Goldwind chairman Wu Gang, then in his late 20s, learned a great deal from this experience. They worked alongside Danish (and later other) engineers to set up the turbines and, by the time the first turbine assembly was undertaken in China, they acquired a decade's experience of siting, maintaining and repairing turbines.

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<sup>178</sup> Xinhua 2 October 2010. Available at [http://www.china.org.cn/environment/2010-10/02/content\\_21055057.htm](http://www.china.org.cn/environment/2010-10/02/content_21055057.htm) Accessed 3 February 2017.

In 1996, the Xinjiang provincial branch of MOST provided XWEC with a grant to support the local assembly and component localisation of 600kW turbines, then a globally mature but still popular product. XWEC leaders decided to license a design from German turbine manufacturer Jacobs Energie. Goldwind was incorporated as a manufacturing company in 1998. After some calamitous early mechanical failures and breakages, Goldwind slowly mastered the wind turbine assembly process.<sup>179</sup> From 1998 through 2001, the firm assembled between two and nine 600kW turbines a year. Component inputs were around one-third localised by value at the end of the period (Lewis, 2012:123pp).

In 2001, Goldwind signed a licence for a 750kW wind turbine with REpower, now merged with Jacobs Energie. Goldwind interviewees recounted that a first substantial, purpose-built factory was opened in Urumqi in 2002, with capacity to assemble up to 200 wind turbines per annum. Production increased to 25 600kW turbines in 2002, and 40 turbines in 2003, when the first 750kW units were assembled.<sup>180</sup>

In 2003, the NEA tendered the first two, 100MW wind farm concession projects. A senior executive noted that, at this point, Goldwind's domestic competition consisted of the two fractious and unsuccessful joint ventures sponsored by the NDRC, and Windey, a Zhejiang province-based firm that grew out of a wind turbine research unit set up by that

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<sup>179</sup> Wu Gang said in 2009: 'Whole blades dropped off... The main shafts broke. It was really very dangerous.' Evan Osnos, 'Letter from China: Green Giant', *The New Yorker*, 21 December 2009.

<sup>180</sup> W1, 27 May 2013; W5, 12 December 2012; W6 1 August 2012; Goldwind annual reports, various years.

province's government.<sup>181</sup> Goldwind was the most capable domestic player, and was granted the tender for one of the two farms, in Huilai county, Guangdong province. Goldwind's Urumqi production increased further in 2004, and in 2005 hit the full capacity of its original facility, with 200 turbines manufactured. The local content of the turbines was around half by value.<sup>182</sup>

### **An early thirst to move towards incremental manufacturing innovation**

While the learning process with mature, geared wind turbine technology supplied by REpower was ongoing, Goldwind management actively engaged with other developers of technologies with a near-term possibility of commercialisation. In particular, in the period immediately prior to the launch of China's first concession projects, Goldwind developed a relationship with a spin-off firm from the Wind Energy Research Group of Germany's Saarland University of Applied Sciences. The firm, Vensys, was working on a non-mainstream but promising technology: Direct Drive Permanent Magnet (DDPM) wind turbines.

The attraction of DDPM was that, like other direct drive technologies, it dispensed with the gearbox and other friction-creating mechanical components that increased servicing requirements or led to outright mechanical failure. In Germany, Enercon won the largest share of the national market with direct drive technology based around a large,

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<sup>181</sup> Windey, called Yunda (运达) in Chinese, began to produce 200kW turbines in 1997 and subsequently also licensed REpower's 750kW model. The firm is based in Hangzhou and in 2015 ranked the 9<sup>th</sup> Chinese producer by volume; it has always been state-owned.

<sup>182</sup> Data provided by Goldwind show that output was 40MW in 2004 and 132MW in 2005; most turbines produced in these years were the 600kW model. W1, 27 May 2013.

annular generator.<sup>183</sup> The Enercon turbines, however, were the heaviest in each power class and hence relatively expensive to build and install. Globally, at the start of the 2000s, direct drive turbines accounted for less than one-tenth of the turbine market. A generator based on permanent magnets could potentially deliver all the benefits of direct drive while being much lighter.

The problem with DDPM, which was first conceptualised and researched in Europe in the early 1980s, was the high cost of the magnets. These required so-called ‘rare earth’ materials such as Neodymium, of which there was little production.<sup>184</sup> From 1990, when researchers at the University of Saarland began to develop DDPM prototypes, however, the cost of rare earth materials fell. The reason was vastly expanded rare earth mining in China, whose share of global production increased from 27 percent in 1990 to nearly 95 percent in 2010 (Tse, 2011). Between 1995 and 2005, prices of rare earths used in magnets dropped by a factor of ten (Mueller and Polinder, 2013).

This was the context in which Wu Gang and Goldwind recognised that DDPM technology, first worked on by Danish engineers at Vestas and Bonus in the 1980s, could now be profitably exploited. When Vensys was established in 2000, its engineers had tested a 600kW DDPM wind turbine for several years; in 2000-2, Vensys developed a 1.2MW

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<sup>183</sup> The annular generator was connected directly to the rotor hub in the Enercon system. The rotations of the generator were far slower than in a geared turbine, which reduced wear and tear. The annular generator required a large ring, accommodated in the widest part of the distinctive Enercon tear-drop nacelle. In a permanent magnet generator there was no direct connection to the rotor hub. For a detailed comparison of the two main direct drive technologies, see Bang et al. (2008).

<sup>184</sup> The term is misleading in that rare earth elements are not particularly rare (Chen, 2011).

prototype. A manager engaged in strategic planning stated it was this model that, in 2003, Goldwind licensed for development and commercial production.<sup>185</sup>

The risk was a calculated but considerable one, observed a main board director at Goldwind. The firm produced mature technology licensed from a substantial European manufacturer, REpower. Vensys was a group of academic researchers who spun off a small design firm and had no experience in manufacturing. Goldwind needed to be confident it could test and commercialise a raw design concept for a new type of turbine-generator set.<sup>186</sup>

Goldwind installed its first DDPM 1.2MW turbine two years after signing the Vensys licence, in 2005. The firm then moved on to jointly develop a 1.5MW DDPM turbine with Vensys, which began commercial production in 2008. Throughout this period, Goldwind maintained its licensing relationship with REpower for geared turbines, which were the firm's source of cash flow and profits as China's concession programme expanded. In 2006, however, when Goldwind sought to sign an additional licence with REpower for a 1MW turbine, the German firm declined. REpower had decided to enter the China market directly and did not wish to compete against licensed versions of its larger turbines. Later the same year, REpower was taken over by the fast-growing Indian turbine maker Suzlon, which had even greater ambitions in China.<sup>187</sup> At

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<sup>185</sup> W5, 12 December 2012. Vensys CEO Jurgen Rinck and Director responsible for production Stefan Gross were both former researchers from the Wind Energy Research Group.

<sup>186</sup> W1, 27 May 2013.

<sup>187</sup> W4, 24 October 2014. REpower entered China only to withdraw in 2011 after losses. Subsequently the firm's China CEO, Wolfgang Jussen, and several other key employees, joined Goldwind.



this point, with its 1.2MW DDPM turbine in full production and a growing order book for it, and a 1.5MW DDPM turbine nearing production, Goldwind decided to go all-in with permanent magnet technology. In 2008 the firm bought a 70 percent interest in Vensys for Euro41.24m. There were other bidders but, as a senior Goldwind manager noted, Goldwind had the deepest working relationship with Vensys while Vensys was overwhelmingly dependent on the Chinese firm for licensing revenues.<sup>188</sup>

When Goldwind took control of Vensys, the firm made a technological choice that leading multinational manufacturers would follow. In 2009 Siemens began to develop a DDPM prototype that was quickly commercialised. The same year GE acquired Scanwind in Norway in order to access DDPM technology (Mueller and Polinder, 2013).

Whereas direct drive turbines accounted for 12 percent of global wind turbine installations in 2008, the share rose to 21 percent in 2011 and in 2016 was around 30 percent.<sup>189</sup> The cost-benefit case for DDPM turbines was not overwhelming, but has been strong enough to ensure steady market growth both in China and globally.<sup>190</sup>

Goldwind's progress through the first stage of manufacturing capability building was not quick; this began with the first turbine assembly in 1998 and continued until Goldwind's first substantial factory reached full capacity utilisation in 2005. The tendering of concession projects from

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<sup>188</sup> W6, 1 August 2012. The interviewee stressed that, apart from Goldwind, Vensys had achieved only small licensing deals as an independent firm, including one deal in Brazil.

<sup>189</sup> BTM Consult data.

<sup>190</sup> Goldwind claimed in its marketing materials that DDPM wind turbines offered 20 percent less maintenance, 20 percent more reliability, and 3-5 percent more output versus geared machines. Goldwind presentation, 17 July 2012.

2003, and the large increase in wind turbine demand, accelerated the learning process.<sup>191</sup> It was a clear case of learning more by doing more, familiar from the experience of the thermal power equipment firms.

In Goldwind's case, however, the learning acceleration that occurred in 2003-5 not only brought the firm to the beginning of the second stage of manufacturing capability building, but also created the path to an innovation capacity.<sup>192</sup> The licensing relationship for DDPM technology with Vensys demanded, and generated, a new level of dynamic capabilities required to take prototypes and technical specifications from a design house and turn them into commercial wind turbines suited to the needs of the different segments of China's market. A further reason for the emergence of an incipient innovation capability was that Goldwind began at an early stage to develop dynamic capabilities in the management of its value chain.

### **Manufacturing capability *and* value chain leverage**

In 2003-4 and in 2007, Goldwind made two strategic business decisions that had a defining impact on the firm's success. The first was to move to an asset-light, outsourcing-focused, system integrator (Prencipe et al., 2003) approach to wind turbine manufacture based on analysis of how GE won and implemented the second of the original concession projects in 2003. The second decision came in 2007, when Goldwind -- this time

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<sup>191</sup> After the tendering of the first two 100MW wind farms in 2003, 700MW of projects were tendered in 2004, 500MW in 2005, 1000MW in 2006 and 950MW in 2007 (Steinhilber, 2016).

<sup>192</sup> As of 2008, when it acquired control of Vensys, Goldwind operated three R&D centres around the world: the Vensys design centre at Neunkirchen, Germany; a Chinese government-funded 'national' research centre close to its original production base in Urumqi; and an electronics and control systems research centre in Beijing.

influenced by the global and China strategies of Spanish wind turbine maker Gamesa -- began to invest its cash flow surplus in wind farm development, several years ahead of the competition. The two strategic choices were of course related. A manufacturing strategy based on outsourcing meant that Goldwind had more cash available for project development as compared with its more vertically integrated peers.

GE only entered the wind industry in 2002, through its purchase of Enron Wind in the US. Nonetheless, the firm was an aggressive bidder in the second of the original Chinese concession tenders in 2003, for a 100MW farm at Rudong in Jiangsu province. GE brought to the wind business what management believed was a disruptive and high-margin strategy: to build wind turbines with an asset-light, system-integrator approach. GE Wind managers identified leading multinational wind turbine firms as unnecessarily vertically integrated, and hence capital inefficient, mainly for reasons of historical legacy. In a maturing industry, the better strategy was to design wind turbines and assemble them almost entirely from outsourced components. China's 2003-7 concession programme provided an opportunity to test this model.

A main board director at Goldwind noted that GE's interest in China was such that the firm partnered with seven different Chinese firms in seven different bids for the Rudong 1 concession. In each case the Chinese firm was the project developer and GE the turbine supplier. Six of the bids were with state-owned enterprises;<sup>193</sup> the seventh was with a private Chinese firm called Huarui, which earlier profited from hydropower

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<sup>193</sup> W1, 27 May 2013.

investments.<sup>194</sup> Consistent with the NEA's policy that the wind sector was open to firms of all ownership types, Huarui won.

The NEA demanded 50 percent local content in its first two tenders. GE, pursuing the system integrator model, sought to identify and certify the largest possible number of domestic Chinese suppliers. The multinational had a network of sourcing, service and manufacturing operations around China that supported products from gas turbines and medical diagnostic devices to white goods and consumer electrics. A team of wind turbine engineers at GE's China Technology Center in Shanghai used the network to identify, and upgrade, suppliers using GE's global Six Sigma certification standard. The result was that GE was able to assemble a 1.5MW wind turbine in 2004 that comprised almost 90 percent, by value, domestic Chinese components (Lewis, 2012).

The GE turbine was testament to how far China's manufacturing capability had risen, but also to GE's sourcing and supplier management capability. The Goldwind main board director said no company paid closer attention to GE's achievements in the Rudong 1 concession than Goldwind. The firm's parochial, Xinjiang base meant it had a fraction of GE's knowledge about Chinese outsourcing capabilities. He noted: 'We learned from GE.'<sup>195</sup>

As Goldwind ramped up production in 2004 and 2005, the firm determined to follow GE in using the system integrator approach. Within

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<sup>194</sup> This Huarui is not to be confused with Sinovel, whose Chinese name rendered in Roman letters is also Huarui. The Huarui that won the Rudong 1 concession was a forerunner of the firm that became solar energy business Hanergy; Rudong 1 was the only wind project it undertook. W1, 27 May 2013.

<sup>195</sup> W1, 27 May 2013.

Goldwind, the strategy was termed ‘two ends inside and the middle outside’, meaning the firm focused on design at one end and quality control, final assembly and service at the other, while outsourcing component production (Huo et al., 2012). The strategy set Goldwind apart not only from most Chinese turbine manufacturers, but also from the European firms they tended to emulate. The director quoted above observed: ‘In our peak year [in the 2000s], we went on to produce 3.7GW of turbines with 4,500 people. At that time, Vestas was doing 5-6GW with 20,000 people.’<sup>196</sup> From the time of Goldwind’s IPO in 2007 until the completion of a major cost-cutting exercise and strategic overhaul by Vestas in 2014, the former’s return on assets was consistently higher than that of the world’s leading wind turbine producer (Table 28, below).<sup>197</sup>

**Table 28. Return on assets, Goldwind and Vestas, 2007-2015. %**

	2007	2008	2009	2010	2011	2012	2013	2014	2015
Goldwind	18.87	11.06	13.45	10.66	2.02	0.48	1.29	4.57	5.79
Vestas	7.32	10.64	9.86	2.31	-2.25	-13.14	-1.3	6.2	8.79

Source: Bloomberg

Goldwind managers were encouraged towards the system integrator approach to the supply chain by GE’s example. The main board director cited above noted they became interested in forward integration into

<sup>196</sup> W1, 27 May 2013. The contrast is perhaps even more striking than indicated. The peak global headcount at Vestas was an average 22,926 in 2011, when the Danish company shipped 5.05GW of wind turbines. In the early 2010s, Vestas followed GE and Goldwind towards less integrated operations, cutting its workforce by one quarter from 2011 to mid-2013. Email communication from William Lim, Global Marketing, Communications and Corporate Relations, Vestas, 12 July 2013.

<sup>197</sup> GE did not break out data for its wind turbine business that would allow for a comparison.

wind farm development based on the strategy of Gamesa.<sup>198</sup> Since it entered the wind business in Europe in 1994, Gamesa's strategic idiosyncrasy was its deployment of capital in wind farm management and development as an equity investor. The approach reassured co-investors and utility operators in a then-nascent industry; it provided an investment opportunity with potentially good margins for cash generated from manufacturing; and it could be used to smooth demand for turbines from Gamesa's factories through the business cycle.

Gamesa brought the strategy it developed in Spain and Portugal to China. In 2005, Gamesa took on a first maintenance contract for a concession project, Nanridao in Fujian province, set up a project development team, and signed to co-invest in several wind farms with Longyuan. Co-investment deals with other utilities followed and by August 2010 Gamesa had a wind farm pipeline in China of 3,185MW. In terms of turbine deliveries, by the end of 2009 China accounted for 2GW of Gamesa's global accumulated deliveries of 18GW.<sup>199</sup>

Gamesa's strong performance compared with most other foreign wind turbine makers drew Goldwind's attention. In 2007, the Chinese firm set up a wind farm development subsidiary, and introduced what it termed a 'total solution' capability offering wind farm services. These moves were several years ahead of domestic competitors.

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<sup>198</sup> W1, 27 May 2013.

<sup>199</sup> Jorge Calvet, Gamesa Chairman, presentation at Shanghai Expo, 14 September 2010. Slides available at <http://www.gamesacorp.com/recursos/doc/accionistas-inversores/presentaciones/english/2010/committed-to-developing-the-wind-industry.pdf> Accessed 28 February 2017. Gamesa China sales in the initial period of market expansion were as follows: 2003: 24MW; 2004: 71MW; 2005: 231MW; 2006: 237MW; 2007: 498MW; 2008: 498MW; 2009: 479MW.

However, where Gamesa combined more vertically-integrated manufacturing typical of Europe with forward integration in the value chain, Goldwind combined an outsourced manufacturing system with forward integration.<sup>200</sup> By end 2009 (Table 29), Goldwind had Rmb3bn (US\$438m) of wind farm assets on its balance sheet. At the same time, noted the Goldwind main board director, the firm's focus on service for third-party developers -- also influenced by Gamesa -- enabled it to win business from small private investors who lacked power generation experience but who had moved into wind farm investment after China introduced its first, quite generous national feed-in tariff (FIT) in 2009.<sup>201</sup>

### **Full focus on the value chain**

According to a manager engaged in strategic planning, Goldwind embraced the system integrator approach to its supply chain and entered the wind farm development business as strategies to win at *manufacturing*. It was only when the Chinese turbine market contracted in 2011-12, and acute overcapacity (temporarily) drained all margin from manufacturing, that management recognised it had laid the foundations for the service-oriented strategy it now needed to build up. In this period, the interviewee said, management began to distinguish between Goldwind's 'product chain' (*chanwu lian*), which produced wind turbines, and its 'business chain' (*yewu lian*), which developed wind farms and offered value-added services to connect to and to support

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<sup>200</sup> The Goldwind wind farm development company set up in 2007 was called Tianrun; Goldwind's separate services division was called Tianyuan. Gamesa's vertically-integrated manufacturing was brought to China; it established wholly-owned subsidiaries to make blades, gear boxes and generators, among other components.

<sup>201</sup> W1, 27 May 2013.

end-customers. ‘We started thinking more like the IT industry – that we needed “architecture expertise” and to be close to customers.’<sup>202</sup>

Wind farm development expanded rapidly. From Rmb3bn at the end of 2009, wind farm assets more than quadrupled during the period of market slowdown and contraction, to Rmb13.2bn at the end of 2012 (Table 29). By that point, Goldwind had more than 1GW of its own wind farms under construction, boosting utilisation rates at its assembly plants.

**Table 29: Goldwind manufacturing assets, wind farm assets, wind farm capacity under construction. Year-end, 2009-15.**

	<b>Manufacturing assets. Rmb</b>	<b>Wind farm assets. Rmb</b>	<b>Wind farm capacity under construction. MW*</b>
2009	12.9bn	3.0bn	Na
2010	26bn	4.8bn	306MW
2011	29bn	9.0bn	558MW
2012	27bn	13.2bn	1030MW
2013	29bn	16.1bn	553MW
2014	36bn	18.1bn	1500MW
2015	44bn	27bn	1640MW

\*Capacity attributable to Goldwind. In some years a small amount of aggregate capacity under construction was attributable to minority partners; such capacity is not included.

Sources: Goldwind annual reports

Gains from wind farm disposals and sales of electricity generated by the farms became a major component of aggregate profits. In 2012, when China’s wind turbine installations contracted by more than a quarter, pre-tax profits from disposals of wind farms and electricity exceeded

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<sup>202</sup> W6, 1 August 2012.



aggregate pre-tax profits, reflecting a loss on manufacturing operations (Table 30). In 2013 and 2014, pre-tax profits from disposals and electricity sales were over 40 percent of aggregate profits. The share only fell back in 2015 as China's wind turbine installations recovered to a new record of more than 30GW.

**Table 30: Goldwind pre-tax gains from disposals\* and pre-tax profits from electricity sales versus total pre-tax profits, 2012-15. Rmb m**

	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>
Pre-tax gains from disposals	290	220	454	174
Pre-tax profits from electricity sales	22	17	470	290
<b>Sub-total</b>	<b>312</b>	<b>237</b>	<b>924</b>	<b>464</b>
Total pre-tax profits	207	506	2109	3247
<b>Pre-tax profit from disposals and electricity sales as % of total pre-tax profit</b>	<b>151%</b>	<b>47%</b>	<b>44%</b>	<b>14%</b>

\* Gains from disposals of subsidiaries, joint ventures and investments, the great majority of which were wind farm assets.

Sources: Goldwind annual reports

At the end of 2015, Goldwind's retained wind farm assets amounted to Rmb27bn (Table 29, above), a sum equivalent to more than 60 percent of its manufacturing assets. The earnings from electricity sales at the farms were a source of frustration as delays to grid connection and curtailment of uptake due to grid system inadequacies reduced receipts. In 2014, investments in new grid capacity appeared to be paying off as, nationally, curtailment fell, to an average 8 percent of wind turbine output; Goldwind reaped record profits from electricity sales (Table 30). However, curtailment worsened again in 2015; the NEA reported curtailment of 15 percent of wind-generated power. Goldwind retained wind farm assets in the belief that the curtailment problem would

eventually be resolved, and that this would contribute to higher wind farm prices. Even with the curtailment problem, disposals through 2015 rendered attractive returns.

Curtailment encouraged Goldwind to experiment with off-grid projects, building capabilities that co-evolved with its changed operating environment (Jacobides and Winter, 2005). The firm established demonstration wind power heating projects in Inner Mongolia and Hebei province. In Jiangsu province, Goldwind set up a wind-powered desalination plant for sea water. In Jilin province, Goldwind established a demonstration project for wind-powered production of hydrogen, which variously could be mixed with China's (largely imported) natural gas supplies, used in industrial production processes, or deployed for hydrogen-based fuel cells in vehicles. In 2015, Goldwind was approved to construct a first, 200MW commercial wind-powered hydrogen plant in Jilin, a substantial project.

Goldwind continued to add service capabilities to support third party purchasers of its turbines. These included wind resource assessment and project design; financing consultancy; engineering, purchase and construction (EPC) services; wind farm management; grid connectivity management; and overall project and investment management.

Revenues attributable to new services offerings rose faster than those from wind turbine sales – by 3.3 times from 2012 to 2015 compared with 2.8 times respectively (Table 31). However, such services were still only 4 percent of total company revenues in 2015. Vestas, the global industry leader, derived 14 percent of revenues from services that year.

Goldwind management noted that substantial numbers of Chinese turbines began to exit their warranty periods in 2012-13, making paid maintenance of turbines a new industry in China relative to Europe. It was also argued that two cuts in China's feed-in tariff scheduled for 2016 and 2018 would focus developers more closely on operations and maintenance (O&M) services that optimised turbine performance.<sup>203</sup>

**Table 31: Goldwind revenues from manufacturing versus third-party services (excluding wind farm development), 2012-15. Rmb bn**

	2012	2013	2014	2015
Manufacturing	10.6	11.2	17.6	29.8
Services	0.39	0.59	0.65	1.3

Sources: Goldwind annual reports

### **Yet-to-be-disputed dominance**

Goldwind's dynamic capabilities, reflected in its system integrator approach, its forward focus in the value chain, its expanding wind farm development unit, and its efforts to provide value-added services to third-party developers, were the background to consistent market share gains in 2012-16. By 2016, Goldwind's 27 percent wind turbine market share in China exceeded that of its next three competitors combined (Table 27).

<sup>203</sup> Note that the service income comparison with Vestas is not a precise one since Goldwind's services revenue does not include services revenues that result from its wind farm development activities (which Vestas does not have). Cuts to wind power feed-in tariffs in 2016 and 2018 were announced by the NDRC on 22 December 2015; depending on the wind category region, the effect is to reduce purchase prices by up to 15 percent. Data from Goldwind and Vestas annual reports, various years.

The firm's exports – 189MW in 2015 and an accumulated 864MW at the end of 2015 – were still modest, but they far exceeded the exports of any other Chinese wind turbine manufacturer and included sales to both developed and developing countries.<sup>204</sup> In 2016, Goldwind acquired a new, 160MW development project in Texas, and contracted to deliver the first 32.5MW of a potential 1,870MW project in Wyoming.<sup>205</sup> The fact that Goldwind built and operated successful wind farm projects in Australia and the United States, and the certification of its turbines by global quality benchmarking agencies like DNV-GL and TÜV Nord, suggested it had the potential to expand into international markets more aggressively.<sup>206</sup>

Overall, Goldwind's success derived from a combination of a conservative, step-by-step approach to building manufacturing capabilities and its bolder strategic choices that reflected growing dynamic capabilities. In the manufacturing dimension, in the 2000s Goldwind trailed well behind its peers in terms of the average size of the turbines the firm produced as it moved cautiously from 600KW to 750KW to 1.2MW to 1.5MW units (Table 32). There was no rush to match competitors that entered the market directly with 1.5MW turbines, in line with the NDRC's bigger-is-better metric. Goldwind's calculated manufacturing risk was instead to produce DDPM turbines, hedged by continuing to manufacture geared turbines until the new

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<sup>204</sup> Goldwind accounted for more than half of the total cumulative wind turbine exports by Chinese firms. Goldwind annual report 2015, p27. Major export destinations were Australia, the United States, South Africa, and countries in south-east Asia and Latin America.

<sup>205</sup> The Texas investment was the Rattlesnake Wind Project; it was expected to expand to 300MW in a second phase. The Wyoming development was being developed by Viridis Eolia, with which Goldwind signed an agreement to supply up to 1,870MW of turbines in November 2016.

<sup>206</sup> For example, in 2014 Goldwind sold most of its interest in a 165.5MW Australian wind farm, Gullen Range, for Rmb1,855m and a pre-tax profit of Rmb333m. Goldwind annual report 2015.

technology was proven. The bolder strategic risks were the embrace of an asset-light, system integrator manufacturing strategy and the move into wind farm development. Senior Goldwind interviewees stressed that it was these early, integrated choices that assured Goldwind unmatched value-chain leverage when the market slowed and consolidated, before beginning to grow again.<sup>207</sup>

**Table 32. Wind turbine sales by units, rated output, and rated output per turbine. Goldwind, Sinovel, United Power, 2008-12.**

	Goldwind			Sinovel			United Power		
	Units	Rated output (MW)	Output per turbine (MW)	Units	Rated output (MW)	Output per turbine (MW)	Units	Rated output (MW)	Output per turbine (MW)
2008	1246	1132	<b>0.91</b>	935	1403	<b>1.5</b>	16	24	<b>1.5</b>
2009	2355	2722	<b>1.2</b>	2307	3495	<b>1.5</b>	512	768	<b>1.5</b>
2010	2648	3736	<b>1.4</b>	2903	4396	<b>1.5</b>	1623	2435	<b>1.5</b>
2011	2370	3200	<b>1.4</b>	1831	2939	<b>1.6</b>	1876	2847	<b>1.5</b>
2012	1600	2522	<b>1.6</b>	699	1203	<b>1.7</b>	1302	2029	<b>1.6</b>

Source: CWEA

Dynamic capabilities were reflected in superior profitability. Like Gamesa, whose forward integration into wind farm development the firm copied, Goldwind posted higher gross margins than Vestas in the period after 2011. Indeed, Goldwind's net margins were superior to those of both Gamesa and Vestas. Goldwind's gross and net margins moved far ahead of those of the only other listed, top-four Chinese wind turbine maker, Mingyang (Table 33).

<sup>207</sup> W1, 27 May 2013; W5, 12 December 2012; W6, 1 August 2012.

**Table 33. Gross and net margins, Goldwind, Vestas, Gamesa, Mingyang, 2011-15.**

	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>
Goldwind gross margin	16.6	15.4	21.2	27	26.5
Vestas gross margin	12.4	11	14.7	17	17.9
Gamesa gross margin	23.4	31.5	40.5	29.9	29.3
Ming Yang gross margin	18	12.8	9.2	13.9	16.2
Goldwind net margin	4.7	1.4	3.5	10.3	9.5
Vestas net margin	-2.84	-13.35	-1.35	5.67	8.13
Gamesa net margin	1.69	-24.75	1.93	3.23	4.86
Ming Yang net margin	5.3	-9.7	-17.7	6.1	2.4

Source: Morningstar data

In terms of scale, Goldwind's revenues in 2015 were US\$4.6bn compared to Vestas' US\$9.3bn and Gamesa's US\$4.6bn and Mingyang's US\$1.05bn.<sup>208</sup> In 2016, Siemens agreed to merge its wind turbine unit with Gamesa; that year the combined business would have been slightly smaller than Goldwind's in volume terms, but larger in revenue terms. The merger made Vestas, GE Wind, Goldwind and Siemens-Gamesa the big four global players.<sup>209</sup> Goldwind is the only Chinese wind turbine company with an R&D budget comparable with those of the other big four firms. In 2014 and 2015, Goldwind spent, respectively, 2.4 and 2.1 percent of revenues on R&D, compared with 3.1 and 2.5 percent at Vestas.

<sup>208</sup> Conversions to US dollars at average 2015 exchange rates, US\$1:Rmb6.48 and US\$1:Euro1.11.

<sup>209</sup> According to Bloomberg New Energy Finance, Vestas sold 8.7GW of wind turbines in 2016, GE 6.5GW, Goldwind 6.5GW, and Gamesa and Siemens combined sold 6.0GW.

#### 4.6. Case study: Mingyang

Mingyang Wind Power, a private firm headquartered in Guangdong province, was the strategic opposite of Goldwind – focused on winning through manufacturing technology alone and late, and less effective, in pursuing forward integration and value chain leverage.

Mingyang grew out of an electrical components and switchgear business established by Zhang Chuanwei in Zhongshan in 1993. Like several other Chinese entrants into the wind turbine business, Zhang contracted with German firm Aerodyn to license designs, in April 2006.<sup>210</sup> Zhang sought a full range of necessary technologies, including turbines, blades, towers and electronic control systems. His original firm, Mingyang Electrical, did not state publicly what upfront licence fees were paid to Aerodyn; however, when the licences for a 1.5MW turbine and its blades were transferred to the firm that became Mingyang Wind Power in 2008, the valuation was Rmb25.5m (US\$3.7m). The upfront charges for the licences were in addition to minimum annual consultancy fees and royalties on each wind turbine and blade-set sold.<sup>211</sup>

Mingyang delivered its first wind turbines in May 2008. A senior manager described how the firm's manufacturing was more vertically integrated than Goldwind's, but less so than United Power's. Mingyang manufactured all of its own blades from 2009, and put together gearbox sub-assemblies instead of buying finished units.<sup>212</sup> Some sense of

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<sup>210</sup> Aerodyn's China clients included: CSIC Haizhuang (joint development); Dongfang (joint development); United Power (licence); Hewind (joint development); Mingyang (joint development); Shanghai/Sewind (joint development).

<sup>211</sup> Mingyang annual report 2010.

<sup>212</sup> W8, 7 June 2013.

Mingyang's more integrated manufacturing process versus Goldwind's was revealed in their 2015 balance sheets, where the firms reported almost identical inventories, despite Goldwind's more than three times greater wind turbine sales.<sup>213</sup> Mingyang gained a reputation for relatively reliable machines combined with aggressive pricing, becoming one of China's top four suppliers (Tables 26, 27, above). The company was among the first to meet demand for longer bladed turbines suitable for southern markets.

What set Mingyang apart from other Chinese companies which licensed mature technology from Aerodyn was that the firm also invested to license Aerodyn technology that was in the initial design stage. This was not the same risk as taken by Goldwind in 2004 to license a 1.2MW DDPM turbine from Vensys. In the Goldwind case, Vensys tested and made commercial sales of a 600KW DDPM turbine in the late 1990s.<sup>214</sup> Mingyang agreed to pay Euro19m, beginning in July 2008, for China rights to a technology for which Aerodyn had not yet tested a prototype.<sup>215</sup> The technology in question, 'Super Compact Drive' (SCD), was an attempt to combine a two-stage gear system with a permanent magnet generator to produce a turbine that was smaller, lighter and more efficient than anything on the market.<sup>216</sup>

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<sup>213</sup> Goldwind and Mingyang's inventory values at the end of 2015 were Rmb3.04bn and Rmb3.05bn respectively. Their turbine sales in 2015 were 7,749MW and 2,510MW, respectively.

<sup>214</sup> The Vensys 600KW prototype was tested from 1995 and found an early commercial partner in Germany. The 1.2MW prototype was in development from 1999, four years before Goldwind licensed it.

<sup>215</sup> The licence fee was Euro7m for a 2.5/3MW SCD turbine and Euro12m for a 6MW turbine; if the technology worked it would be most valuable for larger turbines, particularly those installed offshore. The fees were paid in installments.

<sup>216</sup> For an outline of SCD technology, see <http://www.aerodyn-engineering.com/scd-technology/vision/> Accessed 10 March 2017.



Mingyang's licences also required royalty fees with minimum payments per MW, and unpublished, non-refundable minimum annual payments when commercial production began (Table 34). Aerodyn's first SCD prototype was completed in 2010, when two versions were installed in China. A 6MW prototype began development in 2010. At this point, Mingyang set up SCD production lines in Zhongshan and Tianjin, with combined annual capacity of 400 2.5/3MW turbines.<sup>217</sup>

**Table 34. Aerodyn royalties for SCD turbines.**

	Share of sales price	Minimum royalty payment
First 100 units	2%	> Euro16,000 per MW
Next 400 units	1.5%	> Euro8,000 per MW
Next 500 units	1%	> Euro4,000 per MW
Next 1000 units	0.5%	> Euro2,000 per MW

Source: Mingyang annual report 2010

Despite trials of several SCD prototypes in China, by the end of 2015 Mingyang had not put one into commercial production. It became clear that the cost of SCD technology would not be economic for any but the largest turbines. Mingyang continued to suggest that a long-delayed 6MW SCD prototype would secure sales in the offshore market, though none materialised.<sup>218</sup> At the start of 2016, the company's exclusivity rights to technology for 2.5/3MW SCD turbines in China expired.<sup>219</sup>

<sup>217</sup> 'China Mingyang Wind Power Group Ltd, 2010 Q4 and Full Year Earnings Presentation', March 2011. Mingyang reported that it expected full commercial production to begin in Q2 2011.

<sup>218</sup> The 6.0/6.5MW SCD prototype that began development in 2010 was not completed until 2014 and only underwent testing in China in 2015. Mingyang was sufficiently invested in the belief that SCD would allow it to capture a large offshore market that by 2013, when the author visited, it had moved its Zhongshan production facilities to a shorefront location. W8, 7 June 2013.

<sup>219</sup> Mingyang annual report 2015.

Mingyang's strategy to break through the global technology frontier via its relationship with Aerodyn was a bust. Moreover, the outlays of cash and management time on the Aerodyn relationship undermined efforts to build internal technology acquisition capabilities. In 2009, Mingyang signed a research and cooperation agreement with the Technical University of Denmark (DTU) and opened an R&D subsidiary in Denmark's wind turbine capital, Aalborg. But the subsidiary peaked at only 4 employees. By 2014, a Mingyang technical specialist described how there was one, Chinese employee conducting liaison work, mostly with suppliers.<sup>220</sup> In 2012, Mingyang opened what it called a 'US R&D centre' at North Carolina State University in Raleigh with plans to recruit 10 employees. The operation remained a shell.<sup>221</sup>

While Mingyang waited for the manufacturing technology magic bullet of SCD to arrive, the firm did not integrate forward in its value chain or develop new services to bring it closer to customers. Only in late 2011, as the Chinese wind turbine market contracted, did Mingyang enter its first wind farm development projects. It chose a joint venture, build-operate-transfer (BOT) model in which local governments and state firms contracted to buy Mingyang equity in joint ventures at specified times after wind farms were operational. Prior to this, the joint ventures were not required to make payments to Mingyang based on electricity sales. As curtailment of wind power worsened and wind farm revenues

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<sup>220</sup> W10, 2 July 2014. The interviewee described the Danish office as 'standing by' because of 'financial issues'. Mingyang was still involved in a research project with DTU for control systems for low-speed wind turbines.

<sup>221</sup> See <http://www.windpowermonthly.com/article/1124469/chinese-firm-bets-r-d-us-market> Accessed 10 March 2017. An interviewee at Mingyang stated that the 'centre' did not become an active R&D operation. W8, 7 June 2013.

fell short of expectations, most of Mingyang's partners were unable or unwilling to meet their contractual obligations to buy Mingyang's shares. After several years of booking revenues from its seven joint ventures as receivables, in 2015 Mingyang began to record impairment charges.<sup>222</sup> From 2014, the firm scrapped the joint venture model and switched to a wind farm investment model similar to Goldwind's.

By the end of 2015, Mingyang was developing and operating a fraction of wind farm capacity relative to turbine production capacity that Goldwind boasted.<sup>223</sup> The firm had around 600MW of capacity spread across its joint ventures and more recent investments. Goldwind, which manufactured just over three times more turbines than Mingyang in 2015, reported a cumulative 3,290MW of developed wind farms on its books and a further 1,747MW of wind farms under construction – a combined total eight times that of Mingyang.<sup>224</sup>

Similarly, Mingyang's service revenues were relatively much smaller than those of Goldwind, and growing more slowly. In 2015, service revenue of Rmb118m at Mingyang amounted to 1.7 percent of total revenues, compared with service revenue of Rmb1.3bn, or 4 percent of revenue, at Goldwind. Service revenues at Mingyang increased 1.8 times

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<sup>222</sup> In 2015 Mingyang recorded an impairment charge of Rmb46.5m across its seven joint ventures, and did not record a further Rmb12m of revenue it was owed, due to 'operating results... below our expectation'. Annual report 2015, pp84.

<sup>223</sup> Mingyang carried enormous manufacturing overcapacity. At a peak in 2013, the firm's factories were capable of making 3,396 wind turbines per year; less than one-third that number were actually produced. A lack of effective forward integration meant a lack of throughput optimisation, per Chandler (1977). Annual report 2015, pp51.

<sup>224</sup> Mingyang's seven joint venture projects involved a combined total of approximately 350MW of capacity. The firm's Jieyuan wind farm investment subsidiary had five projects under development involving a combined 250MW capacity. Mingyang annual report 2015, p21, p42. Goldwind's cumulative 3,290MW of developed wind farms at the end of 2015 comprised 3,044MW domestic and 246MW international. Goldwind annual report 2015, p30.

in 2015 compared with 2012, versus 3.3 times at Goldwind (Table 35; compare Table 31, above).

**Table 35: Mingyang revenues from manufacturing versus services operating segments, 2012-15. Rmb m**

	2012	2013	2014	2015
Manufacturing	2775	2754	5775	6678
Services	67	91	97	118

Sources: Mingyang annual reports

Overall, Mingyang's narrow focus on manufacturing technology meant that it was poorly placed to compete after 2011 when higher margins depended on wind farm development capabilities and value-added services that both wooed and supported manufacturing customers. When the Chinese turbine installation market recovered in 2014-15, Mingyang's margins remained depressed, while those of Goldwind hit new highs (Table 33). The divergence in fortunes was further reflected in return on assets and return on equity at the two firms across the 2011-15 period (Table 36). Mingyang paid the price for focusing on a competitive advantage based entirely on manufacturing technology.

**Table 36. Return on assets and return on equity, Goldwind versus Ming Yang, 2011-15.**

	2011	2012	2013	2014	2015
Goldwind return on assets	2.0	0.5	1.3	4.6	5.8
Ming Yang return on assets	3.1	-2.5	-4.3	3.0	1.6
Goldwind return on equity	4.6	1.2	3.3	13.0	18.1
Ming Yang return on equity	8.1	-7.7	-15.4	11.1	6.0

Source: Morningstar data

#### **4.7. Case study: Envision**

Envision Energy was, along with Mingyang and United Power, another 2008 entrant to the Chinese wind industry, but one that disrupted the sector as an outsider and exhibited striking dynamic capabilities. The firm took the system integration approach pursued by Goldwind to a new level, combining aggressive outsourcing with lean production and logistics techniques imported from the automotive sector. Envision grew more slowly than Mingyang or United Power (Table 37), refusing to open the multiple manufacturing sites demanded by local governments as the price of support for local wind farm developments. Instead, Envision aggressively integrated forward into software services to both support its own hardware sales and to win service business through the optimisation of existing installed wind turbines, in China and overseas. Envision did not invest in wind farm development in China, but rather in wind farm assets in Latin America and, latterly, Europe. By end 2016, Envision was a partner in overseas wind farms totalling 1.5GW.

Main board directors described how Envision was founded in 2007 by entrepreneurs who studied and worked overseas in financial services. CEO Zhang Lei was a former energy analyst at French oil company Total and a trader in structured financial products at Barclays' energy division in London. Felix Zhang Xuyu, responsible for international operations, worked in energy trading and invested in renewables firms at investment banks and at a hedge fund in Toronto and London.<sup>225</sup>

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<sup>225</sup> W13, 23 October 2014, W15, 30 June 2016.

In 2005-6, prior to starting the business, the founders researched the Chinese wind industry, concluding that local content requirements for foreign wind turbine manufacturers and the first rounds of concession projects already created an almost complete domestic supply chain. The modular nature of much of the supply chain meant they could pursue a system integrator approach. A 1.5MW turbine was designed through recruitment of experienced technical personnel, rather than paying for licences. In 2007, Envision hired two key, ethnic Chinese engineers from GE Wind in China, as well as a retired manager from Toyota expert in lean production techniques.

Envision interviewees described how a small team worked out of the metal casting factory of Zhang Lei's parents in Jiangyin, Jiangsu province and, supported by engineers from the casting business, completed a prototype in April 2008. This was installed at a Longyuan wind farm. After several months' operation, the performance of the turbine was such that Longyuan ordered 33 of them for a farm in Gansu province.<sup>226</sup>

The total expenditure to fund the initial team and produce the prototype was given as Rmb10m (US\$1.4m), considerably less than firms taking the licensing route were paying and with no ongoing royalty obligations.<sup>227</sup> Klagge et al. (2012) reported that a venture capital firm connected with Longyuan subsequently invested in Envision. A European

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<sup>226</sup> W11, 2 July 2014, W15, 30 June 2016, W16, 21 July 2016.

<sup>227</sup> 'Zhang Lei: a paranoid ex-Barclays financial engineer of energy takes on the wind' (*Zhang Lei: yige pianzhi de qian bakelai jinrong gongchengshi ni feng er shang*), *Global Entrepreneur (Huanqiu qiyejia)*, 11 January 2011.

new energy investment fund, Swiss Re's European Clean Energy Fund, was another early investor.<sup>228</sup>

Envision's initial development was based entirely on contracts with Longyuan. The firm received and delivered three 50MW orders in 2008 and 2009, for wind farms in Fujian and Hainan, in addition to the first one in Gansu. The first 100 turbines were assembled by a team of only 20 people, including more specialists recruited from the automotive sector. Zhang Lei claimed that using Envision's system integrator, lean production approach, 20 people could put together 250 turbines per year.<sup>229</sup> The order from southernmost Hainan province led Envision to work with large blade, slow speed turbines from an early stage, honing a capability that defined each of the most successful Chinese firms as curtailment increased in high wind speed areas in the north.<sup>230</sup>

**Table 37. Goldwind, United Power, Mingyang, Envision, annual wind turbine installations, 2008-16. MW**

	2008	2009	2010	2011	2012	2013	2014	2015	2016
Goldwind	1132	2722	3736	3200	2522	3750	4434	7749	6363
United Power	24	768	1643	2847	2029	1488	2582	3065	1908
Mingyang	146	749	1050	1178	1134	1286	2058	2510	1959
Envision	13	137	250	348	544	1128	1962	2510	2003

Source: CWEA

<sup>228</sup> Interviewees declined to confirm the Longyuan investment. The Swiss Re fund, which raised US\$329m in 2007, was publicly acknowledged as an investor at the time, but with no further details.

<sup>229</sup> Ada Qin, 'Vision of windpower' (*Fengneng yuanjing*), *Forbes China*, October 2009.

<sup>230</sup> In 2009 Envision became the first Chinese firm to deliver 87m diameter turbine sets. W12, 23 October 2014.

An Envision technical director observed that the former GE wind engineers and other technical personnel recruited in China not only developed a 1.5MW turbine that was scaled up to 1.6MW and 1.8MW, but also subsequently created a 2MW platform. These two platforms accounted for the vast majority of Envision sales through 2016.<sup>231</sup> As noted, however, unlike at Mingyang and United Power, Envision management did not rush to maximise production capacity (Table 37, above).

Instead, Envision settled on a strategy of steady manufacturing growth and, from 2010, a drive to differentiate itself through software capabilities including monitoring and control applications; performance analytics and turbine optimisation programs; operations and maintenance data that supported ‘predictive maintenance’ before breakages occurred; investment management tools; and more. Data was derived not only from wind turbines, but also from sensors introduced to monitor other physical phenomena. The aims were to bolster Envision turbine sales, to add new service revenue streams from those sales, and to profit from the large Chinese and worldwide stock of installed turbines whose financial return could be improved. It was a natural focus for disruptive entrepreneurs from a different business sector, financial services (Jacobides and Winter, 2005).

Between 2010 and 2013, Envision opened software development operations in Shanghai, in Nanjing (where China’s key State Grid research institute is located), and in Houston, Texas, a global centre of

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<sup>231</sup> W11, 2 July 2014.



energy trading and investment as well as energy-related software development. By 2013, when the firm launched its Wind Operating System (WindOS), 100 of its 600 employees worked in software development.

Strikingly, it was Envision's US subsidiary, where key software design occurred, that secured the first clients of WindOS. In 2013, Atlantic Power contracted to use the system for a 300MW wind farm in Oklahoma, and Pattern Energy puts its entire wind portfolio, then 1.04GW, on the platform.<sup>232</sup> Chinese clients including China Guangdong Nuclear Power (CGN) followed. In 2015, a platform for solar farms was introduced; the solar and wind platforms were subsequently combined and rebranded EnOS. In 2016 in Europe, where Envision's software business expanded much more slowly than in the US, the firm bought the number two European renewables data management firm, Bazefield, based in Norway.<sup>233</sup>

By 2016, Envision claimed to have 50GW of renewable energy resources under management on its EnOS platform, including 7GW acquired with Bazefield. The firm stated that it employed 400 software engineers, around one-third of its workforce. However, no financial details for the software business were released. CEO Zhang Lei said only that total revenues in 2015 at unlisted Envision were 'about US\$2 billion'

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<sup>232</sup> The Atlantic Power wind farm in Oklahoma was called Canadian Hills. In 2014-15, Envision's US subsidiary reported that it added clients including Duke Energy and EverPower. The US subsidiary's Chief Software Architect was Tony Chen, a graduate of Tsinghua and former IBM employee.

<sup>233</sup> W12, 23 October 2014; W15, 30 June 2016. Envision management stated that the solar platform, introduced in 2015, was employed at 120 sites in 15 provinces in China by late 2016. The acquisition price for Bazefield was not revealed.

(Rmb13.5bn).<sup>234</sup> If correct, this figure meant that Envision's total revenues per kilowatt of wind turbines installed in 2015 were one-third higher than Goldwind's, and almost double Mingyang's (Table 38), implying substantial software revenues. A senior Envision software manager said of Zhang Lei in 2014: 'He is betting the company on doing software.'<sup>235</sup>

**Table 38. Total revenues per reported kilowatt of installed wind turbines. Goldwind, Mingyang, Envision, 2015. Rmb per kw**

Goldwind	3,852
Mingyang	2,708
Envision*	5,163

Source: CWEA, company reports and announcements, author calculations

\* No audited financial statements. Revenues as stated to Reuters, 27 September 2016.

In the period when Envision built up its software development capability in the US and China, the firm also established a 'Global Turbine Innovation Centre' in Denmark. The objectives were to provide cutting-edge technical support to optimise wind turbines developed in China, to design new offshore models, and to design larger onshore platforms for the Chinese and global markets. Envision built up the centre by recruiting Anders Rebsdorf, who had previously developed a Danish design office for Gamesa. A technical director stated that the Envision Innovation Centre opened in 2010, employed 20 people after a year and

<sup>234</sup> Christoph Steitz, 'Envision Energy to spend US\$1.1bn on European expansion: CEO', Reuters, 27 September 2016. The *China Daily* reported that Envision revenues in 2015 were Rmb16bn, without citing a source. 'Smart vision at the core of company's leading role in energy internet sector, *China Daily*, 28 October 2016. See [http://www.chinadaily.com.cn/m/jiangsu/wuxi/2016-10/28/content\\_27208053\\_2.htm](http://www.chinadaily.com.cn/m/jiangsu/wuxi/2016-10/28/content_27208053_2.htm) Accessed 17 March 2017.

<sup>235</sup> W14, 24 October 2014.

35 by 2014.<sup>236</sup> In November 2015, Envision opened a 'Global Blade Innovation Centre' in Boulder, Colorado, close to the US National Wind Technology Centre; by mid 2016 there were 12 employees, led by a former Siemens executive.

Envision's international wind farm development strategy began in 2014 with the first of two small projects in Chile.<sup>237</sup> Following an energy sector deregulation initiative in Mexico, in 2015 Envision purchased a controlling interest in a 600MW pipeline of projects from Mexican wind farm developer Vive Energia. The first two projects, totalling 160MW, began construction on the Yucutan pensinsula in 2016.<sup>238</sup> That year, Envision also secured the largest share of Argentina's first national wind project auction, involving 185MW across four projects. By the end of 2016, Envision claimed to have a 1GW pipeline of projects in Latin America.<sup>239</sup>

In July 2015, Envision bought a small, 25MW wind farm project in Sweden to be used as a European demonstration site for its larger platform onshore turbines designed in Denmark. Envision's stated intention was to become a 'top five' wind turbine supplier in Europe, the world's most competitive market.<sup>240</sup> A new sales and project management office was opened in Hamburg. In December, Envision's

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<sup>236</sup> W11, 2 July 2014.

<sup>237</sup> The two projects totalled 22MW.

<sup>238</sup> See <http://www.viveenergia.com/> Accessed 21 March 2017. And Mao Pengfei, 'China, Mexico to partner on wind farms', *China Daily*, 9 May 2016, available at [http://usa.chinadaily.com.cn/world/2016-05/09/content\\_25144579.htm](http://usa.chinadaily.com.cn/world/2016-05/09/content_25144579.htm) Accessed 21 March 2017.

<sup>239</sup> See <http://www.envision-energy.com/2016/10/13/envision-energy-leading-quest-unlock-argentina-wind/> Accessed 21 March 2017.

<sup>240</sup> Andrew Lee, 'Envision's plan to conquer Europe', *Recharge*, 6 October 2015. In late 2016 it was reported that the Swedish wind farm near Eskilstuna was delayed by an environmental challenge to its planning application. Envision aimed to showcase its 2.3MW and 3.0MW onshore turbines.

European team made a first substantial investment when it bought over a 453MW pipeline of wind projects in north-east France from Velocita Energy.<sup>241</sup> Zhang Lei said he expected Envision to invest Euro1 billion in Europe over three to five years.<sup>242</sup>

Even more than its US and European software development businesses, which were combined with a software business in China, Envision's substantial investments in wind farm development in Latin America and Europe reflected a 'born global' (Knight and Cavusgil, 2004, Cavusgil and Knight, 2009, Zhou et al., 2007) strategy that was markedly more aggressive than Goldwind's international expansion. Main board directors referred several times in interviews to Envision as a 'human resource-driven' company, arguing that Chinese management talent had reached a level where it could be combined with foreign talent in a new type of cosmopolitan, though ultimately Chinese, enterprise. Envision's early recruitment of Chinese personnel, interviewees noted, hired only those with experience at multinationals, including GE, Vestas, Siemens, IBM, Ford, GM, Boeing, McKinsey and investment banks and hedge funds.<sup>243</sup> Senior management believed that successful ethnic Chinese employees at multinationals often sought greater meaning in their careers and that Envision could offer that.<sup>244</sup> In addition, said a senior

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<sup>241</sup> See <http://www.velocitaenergy.com/about-us/history.html> Accessed 21 March 2017. By mid-2016 there were some 20 employees at Envision's Hamburg project management office. W16, 21 July 2016.

<sup>242</sup> Christoph Steitz, 'Envision Energy to spend US\$1.1bn on European expansion: CEO', Reuters, 27 September 2016. Available at <http://www.reuters.com/article/us-europe-windpower-envision-idUSKCN11X1MV> Accessed 21 March 2017.

<sup>243</sup> W12, 23 October 2014; W13, 23 October 2014; W15, 30 June 2016.

Interviewees also referred to a Harvard Business Review article about talent-led firm-building that briefly discussed Envision (Ready et al., 2014).

<sup>244</sup> An early hire of Zhang Lei recalls he was asked directly about his dreams: 'He asked me "What is your dream?" The boss in China doesn't ask you that question. He just asks you about your capabilities.' W16, 21 July 2016.

manager for strategy, the firm self-consciously pursued the ‘Huawei’ model, offering equity participation to all senior management while stating it had no plans for an IPO.<sup>245</sup>

Without financial data, and particularly margin and profit data, however, it is impossible to judge how successful Envision is. A strategy of lean production in China, an emphasis on software, and R&D centres in key technology hubs around the world saw the firm rise to second place by installations among Chinese firms in 2016. However, this was partly due to a substantial fall in sales by United Power, while Envision was not far ahead of Mingyang, and Goldwind retained three times Envision’s market share in China (Table 37, above). Where Envision appeared to lead all Chinese firms was on turbine output per employee (Table 39). An interviewee at the firm’s Jiangyin production base noted that the Supplier Quality Engineer (SQE) team that manages suppliers is one of the largest groups at the factory: ‘The key is to make suppliers do as much as possible,’ he said.<sup>246</sup>

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<sup>245</sup> ‘The model is Huawei.’ W12, 23 October 2014. It should be noted that while Huawei is commonly perceived in China to offer senior employees equity participation, what they actually receive is profit sharing. Envision, by contrast, granted equity to senior employees.

<sup>246</sup> W16, 21 July 2016.

**Table 39. Wind turbine installations per employee. Goldwind, Mingyang, Envision, 2015. MW**

	<b>Turbine installations. MW</b>	<b>Employees</b>	<b>Turbine installations per employee. MW</b>
Goldwind	7,749	6,526	1.19
Mingyang	2,510	4,379	0.57
Envision*	2,510	1,200	2.09

Source: CWEA, company reports and announcements, author calculations

\* No audited financial statements.

Goldwind management acknowledged that Envision had outpaced it in developing software capabilities. Goldwind reacted to Envision's software product launches in 2013-14 by licensing an off-the-shelf platform from HP. However, one senior Goldwind manager conceded in late 2014 that the product was inferior to Envision's and would need considerable customisation. Nonetheless, the same Goldwind manager asserted that having by far the biggest installed wind turbine base among Chinese firms gave Goldwind a big advantage, because competition in software and services would be partly determined by who had a deeper well of accumulated data to work with. 'They are cutting-edge, but we are on the same track with 16 years' experience,' he said. 'We are capitalising our history, getting data from 10,000 machines.'<sup>247</sup>

#### **4.8. Discussion**

Within the analytical framework of this thesis, the Chinese developmental state continued in the wind turbine sub-sector to support the acquisition of manufacturing capabilities. The acceleration

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<sup>247</sup> W4, 24 October 2014.

in the pace of manufacturing capability development was far quicker than it had been in the thermal equipment sector because firms built on a much-expanded economy-wide foundation of capabilities. The state also enhanced its contribution to the process.

The developmental state performed its core role by maintaining a close focus on product evolution. The integration of component supply chains was ensured by the application of local content rules. Technical progress was benchmarked, albeit crudely, by progress in turbine sizes. Turbine quality was upheld by centralising all subsidised wind farm approvals such that local governments could not favour lower quality products from local firms.

Additionally, the developmental state expanded and refined institutional and policy inputs that supported the technology learning process. Publicly-funded S&T and R&D programmes were enlarged, institutional linkages between firms and universities and research institutes were improved, and new state- and outsourced-research capabilities were employed to support the industrial planning process. New state-sponsored industry associations were promoted in order to facilitate communication between government and decentralised firms. Overall, support for manufacturing capability acquisition became multi-layered compared with the early learning period in the thermal sub-sector.

The critical *differential* contribution from the developmental state in the wind sub-sector, however, was that it created conditions for a transition to a competitive environment in which the dominant firms were those

that exhibited the strongest dynamic capabilities, reflected in strategic business choices. Three policy changes informed this transition: the opening of competition to firms of all ownership types, the devolution of all technology bargaining to the firm level, and the use of laws and regulations rather than government fiat to establish the industry operating environment.

The transition to a competitive environment in which firm-level dynamic capabilities had greater room to develop brought some unwanted, but temporary, side effects, notably the bidding up of technology licensing fees. However, what proved more enduring, and more important, was the blossoming of technological and strategic variation at the firm level. Product prices in the wind sub-sector were reduced below international levels, but this was accompanied in the most successful firms by the emergence of *strategic* competitive advantages. Notable examples from the case studies include the systems integration, project development and software capabilities of Goldwind and Envision.

Consistent with the theoretical framework of vertical scope that is highly dynamic in high-technology firms (Jacobides and Winter, 2005), the most successful wind turbine companies were ones that rapidly adjusted their vertical scope in the light of rapidly evolving industry conditions. As in the global high technology sector, the pace of change in China's wind sub-sector was relentlessly quick, with the FDC developmental state driving very rapid acquisition of manufacturing capabilities. Goldwind and Envision, the most successful firms, were the ones that most dynamically adjusted to this change, disintegrating their production



chains as outsourcing possibilities emerged and becoming the most capable systems integrators. A combination of dynamic capabilities manifested in strategic initiatives such as forward integration into high-margin service activities, and asset-light business structures associated with systems integration, enabled Goldwind, and probably Envision (audited financial data were not available), to match the profit margins of leading multinational peers, something that no firm achieved in the thermal sub-sector.

Evidence in the thermal sub-sector suggested that state ownership of firms inhibited the development of dynamic capabilities. Evidence in the wind sub-sector broadly supported this finding. State firms in the wind sub-sector were as quick as private firms to build manufacturing capabilities, typified by the cases of Dongfang and United Power. However, firms that remained state-owned did not exhibit the dynamic capabilities associated with the most successful private firms.

The Goldwind case study suggested that while state ownership typically might not be conducive to the growth of dynamic capabilities, there are conditions under which the correlation is more nuanced. Not only was Goldwind's origin as a state-owned research unit associated with impressive early learning of manufacturing capabilities, but the firm made some bold strategic decisions in this period. These included the 2003 licensing of DDPM technology from Vensys, and the 2004-5 move to a systems-integrator manufacturing model. The explanation for these early dynamic strategic moves under state ownership may be that the original work unit, XWEC, was established as an entirely new operation

in 1986, becoming in turn a new state manufacturing company in 1998. As a result, there were no legacy structures and interests that created path dependencies for Goldwind while Wu Gang, the firm's visionary chairman, rose to lead the firm through meritocratic selection based on his track record of entrepreneurship. In such special circumstances, levels of entrepreneurship and dynamic capabilities not encountered in other state firms were apparent at Goldwind in its state-owned incarnation.

Goldwind's privatisation, involving IPOs in Shenzhen in 2007 and Hong Kong in 2010, was the background to the firm's service-oriented forward integration, the growth of its export activity, and its large domestic market-share gains after 2012. This was also the period in which Goldwind matched or exceeded the profit margins of leading multinational peers. Through privatisation, Goldwind acquired a diversified investor base with no majority shareholder, although the firm still has strong indirect links to the state.<sup>248</sup>

The case study of Envision, according to the theoretical framework of this thesis, represents a new stage in China's development. As posited by Jacobides and Winter (2005), the growth and diffusion of capabilities in an industry and the vertical disintegration of production tasks eventually opens the way for disruption by firms entering the market from other sectors. In the case of Envision, entrepreneurs from the

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<sup>248</sup> Goldwind's largest investor as of 2016 was another 'new' state enterprise, China Three Gorges Corp. (CTG), established in the 1990s to operate the world's largest hydropower facility. CGT invested in wind farms in China and overseas from 2007, the same year that Goldwind established its wind farm subsidiary, and became a strategic investor in Goldwind, holding 43 percent of equity at the end of 2015. Anbang Insurance Group was the second largest shareholder, with 15 percent.

financial services sector disruptively entered the wind turbine industry with a new focus on complementary software. The case study showed both the extent to which industry-wide manufacturing capabilities had reached a level where they alone could not provide clear competitive advantage and the growth of entrepreneurial talent in China to a point where a new firm, defined by its dynamic capabilities and without any manufacturing history, could take a leadership position in an unfamiliar industrial sector. It was, of course, the developmental state that had opened up the policy space that allowed this to occur.

## Chapter 5

### Solar power: the private sector sets off without national government

#### 5.1. Background

At the industrial policy planning level, the Chinese developmental state's treatment of the nascent solar sector in the early 2000s appeared to be fundamentally different from its approach to wind turbines. National government made a clear decision to support domestic demand for wind turbines, but not for crystalline silicon photovoltaics, principally because unit costs for wind power equipment were much lower and because the perceived risk of technological disruption in photovoltaics was higher.

When the tendering of wind farm concessions began in 2003 there was no equivalent policy for solar farms. The result was that, until central government policy changed in the late 2000s, the photovoltaic industry developed based on export demand alone.<sup>249</sup> The photovoltaics sub-sector therefore should, in respect of the analytical framework of this thesis, have provided a test of firms' capacity to develop manufacturing and dynamic capabilities in the absence of national industrial policy support on both the supply side and the demand side.

In practice, however, the development of the photovoltaics sector was accompanied by heavy support on the supply side. First, despite the absence of NDRC/NEA backing for the solar sector, local governments provided significant subsidies for the development of photovoltaics firms. This support included equity investment, free or cheap land,

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<sup>249</sup> The NDRC's 2006 Medium- and Long-Term Development Plan for Renewable Energy set a 2020 target for installed wind capacity of 30GW, compared with a target of 1.8GW for photovoltaics.

infrastructure, subsidised utilities, and more. Second, after Chinese solar firms listed on US stock markets in the mid-2000s, state-owned commercial banks lent aggressively to photovoltaics firms, even though this was not in line with national industrial policy. Third, the Ministry of Science and Technology (MOST), whose policy choices were poorly integrated with those of other national bureaucracies, unilaterally pursued efforts to promote domestic manufacturing of high-purity crystalline silicon, the feedstock for that part of the photovoltaics sub-sector. The result was that MOST helped unblock the key bottleneck in terms of manufacturing capabilities.

National industrial policy denied photovoltaics demand-side support in the form of a subsidised market. However, despite the NDRC's early intentions, supply-side support for the sector was enormous. When the world's solar industry went into recession in 2011-12, the supply-side support from local governments and state banks was so great that it was difficult for national government not to step in to create subsidised domestic demand for photovoltaics and prevent Chinese firms going bankrupt. Fortunately for central government planners, by the end of the 2000s the photovoltaic firms reduced their unit costs by more than wind turbine manufacturers, bringing the per unit capital equipment cost of solar power from four times that of wind in 2005 to twice as much in 2010 (Table 40).

**Table 40. Prices of Chinese-made wind turbines versus solar modules, in China, 2005-2010. Rmb/KWp**

	2005	2006	2007	2008	2009	2010
WTG	9,000	8,000	7,000	6,500	6,000	5,000
Solar module	36,000	35,500	37,000	30,000	16,000	10,000

Source: WTG prices from CWEA, solar module prices averaged from annual reports of case study firms

The NEA reacted to massively reduced photovoltaic unit prices, and a crisis of overcapacity and falling export demand after 2009, with a two-phase policy to subsidise and develop a domestic solar market similar to that pursued in the wind sub-sector. Where the wind industry was offered an annual quota of concession projects from 2003, there were two rounds of concession projects for photovoltaics producers, beginning in 2009. And where the wind market moved to development under a quota-free, geographic zone-based feed-in tariff (FIT) in 2009, this occurred for photovoltaics from July 2011 (Zhang et al., 2013, Liu and Shiroyama, 2013).<sup>250</sup>

**Table 41. Growth of the domestic Chinese photovoltaic market, 2008-16. Annual installations, MW**

2008	2009	2010	2011	2012	2013	2014	2015	2016
40	160	500	2,600	5,000	12,900	10,600	15,100	34,500

Source: IEA

The creation of a substantial, rapidly growing domestic market (Table 41), however, did not have the same qualitative impact, or the same

<sup>250</sup> The main solar concession programme, named Golden Sun, began in July 2009. It continued after the launch of the solar FIT and took its last applications in March 2013.

timeframe for impact, on the competitive landscape of photovoltaic firms as it had on that of wind turbine firms. One reason was that the value chain structure of the photovoltaic business was different to the wind business. Barriers to entry in the three middle segments (Figure 7) of the photovoltaic chain – wafers, cells, and modules – were low, and successively lower. Much of the production technology for wafers, cells and modules was embedded in manufacturing equipment. As a result, the capacity of wafer, cell, and module manufacturers to differentiate their products was significantly less than it was for wind turbine makers.

The creation of a domestic market ought to have allowed the best manufacturers to differentiate themselves through dynamic capabilities reflected in forward integration into solar farm development and services. In the United States, the most successful photovoltaics manufacturer, First Solar, swiftly refocused its business in the late 2000s on project development as module prices fell. The number two US solar panel manufacturer, Sunpower, followed a similar strategy. Within China, however, the forward segments of the solar value chain contained greater, albeit ultimately transient, obstacles to profitable development. There were two main impediments.

The first was that the market for utility-scale solar projects was highly fragmented and dominated by locally- rather than nationally-tendered projects. This echoed the situation in the early years of the domestic wind market, when many projects were locally authorised and driven by local vested interests; the NDRC only brought the situation under control in 2011, mandating that all wind projects must receive central

**Figure 7. The photovoltaic value chain (multi-crystalline)**





government approvals.<sup>251</sup> In the solar sector, however, the problem was more egregious and compounded by the fact that subsidy payments, which were a relatively larger part of developers' revenues than in the wind business, were subject to greater payment delays. A locally-driven, sometimes chaotic utility business characterised by much-delayed subsidy payments was not an easy market in which to build a differentiated, large-scale, high-margin firm.<sup>252</sup> The utility solar environment began to change in 2015-2016, with the NDRC moving to centralise control and approvals and to encourage projects of higher technical standards via its Top Runner programme. However, market maturation required time.

A second obstacle to profitable forward integration and differentiation in the solar sector was that China faced high barriers to the development of a distributed generation (DG) market. DG solar projects are ones that are normally connected to the grid, but in which electricity is used close to where it is produced, whether by individual or multiple households or by commercial entities. In this respect, solar divides into two markets where wind power is a single, utility-scale market.

In developed countries, DG accounted for the bulk of installations soon after solar deployment began.<sup>253</sup> However, in China, issues ranging from divided ownership of roof spaces and legal system immaturity;

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<sup>251</sup> Prior to 2011, projects under 50MW were licensed at the provincial level. The requirement for national approval in order to obtain FIT subsidies, as a senior manager at Goldwind noted, raised concentration by putting local government-favoured firms out of business. W4, 24 October 2014.

<sup>252</sup> China's big five utilities, with the exception of State Power Investment Corporation, were reluctant to invest in solar farms for many years, preferring to concentrate their renewables projects in wind.

<sup>253</sup> According to the International Energy Agency (IEA), at the end of 2016, DG accounted for 54 percent of installed global photovoltaics; 86 percent in Japan, 74 percent in Germany, 42 percent in the United States, and 9.2 percent in China.

unfamiliarity of financial institutions with DG projects and unwillingness to lend to them; absence of 'net-metering' technology that typically manages DG system connections to the grid; and general grid company resistance, all combined to impede the growth of the DG market (Zhang et al., 2015). Despite numerous regulatory adjustments designed to promote DG projects, the NEA reported that in 2016 they constituted only 12.25 percent of that year's solar installations. The DG market tripled in China in 2016 – from 1.39GW in 2015 to 4.23GW -- but the low base of growth meant that large-scale manufacturers were just beginning to experience an environment in which they might differentiate themselves through their DG strategies.

Initially weak central government management of the utility scale solar tendering process, and slow development of DG solar power, meant that mid-stream photovoltaics firms were unable to emulate US peers by creating high-margin, forward-integrated project development businesses. Instead, China's dominant multi-crystalline silicon producer, GCL, became the largest and most profitable solar company, using its sector-beating cashflows to expand opportunistically into every segment of the value chain. At the time of writing, Longi Green Energy was attempting to follow a similar strategy based on the world's largest scale production of mono-crystalline silicon.

It remained to be seen whether the silicon producers would dominate once forward, service-oriented parts of the solar value chain matured. From the perspective of the analytical framework of this thesis, the key point is that the developmental state has not yet created necessary

conditions in the photovoltaics sub-sector for a transition away from competition based on manufacturing capabilities. The evidence has implications for the improvement of industrial policymaking that are discussed at the end of this chapter and in Chapter 6.

## **5.2. Stage 1: Search without central government consensus**

China's first S&T programmes focused on solar cells began in the 1970s alongside incipient satellite, and broader space, programmes (Fraas and Partain, 2010). In the 1980s and 1990s, research programmes expanded as solar power was deployed for rural off-grid use as part of anti-poverty work and for specialist functions such as power for remote weather monitoring stations and military communications. Some of the funding for anti-poverty solar installations came from foreign aid and from the World Bank's Global Environment Fund (Li et al., 2007). More than 30 universities and research institutes were involved in solar R&D by the end of the 1990s. Funding was thinly spread and technological standards were generally well behind the global frontier.

Officially, MOST was responsible for the solar research strategy. However, as with the wind turbine sector in the search stage, multiple other agencies, including the State Economic and Trade Commission (SETC) and the Chinese Academy of Sciences (CAS), pursued their own agendas. The difference was that whereas in wind all government agencies were working with the same fundamental technology, in the solar sector multiple competing technologies – including sub-categories of crystalline silicon, thin-film and concentrating solar -- were under consideration (Fraas and Partain, 2010). A 1999 report by Tsinghua researchers observed: 'Because so many government agencies

participate in the policy making and implementation, there exist many problems under such an inefficient multi-institution management system for developing Chinese PV industry.’(Dai et al., 1999).

The Chinese market for photovoltaic modules at the end of the 1990s was 2MW per year and most modules were manufactured domestically (Dai et al., 1999). In the late 1970s, three state-owned semi-conductor plants had been converted to production of photovoltaic cells; in the 1980s three more state enterprises began production of different types of cell; all used imported production lines. The six state enterprises had a combined installed manufacturing capacity of 5MW a year, but produced less than half this volume (Marigo, 2007). Most output in the late 1990s comprised mono-crystalline silicon cells.<sup>254</sup> Mono-crystalline cells render higher solar conversion rates; however, when predominantly private-sector, export-oriented investment in photovoltaics took off in China in the 2000s, it focused on multi-crystalline silicon cells with slightly lower conversion rates, but production costs that were lower still (Li et al., 2007, Dai et al., 1999).<sup>255</sup>

As the export-oriented photovoltaic industry grew through the 2000s, China’s S&T solar research budget was increased, but remained widely distributed across many technologies. Photovoltaics research was included in MOST’s 863 and 973 programmes beginning in the 10th Five-Year Plan (2001-5) (Fraas and Partain, 2010). Marigo (2007) estimated

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<sup>254</sup> Of the six production units, four manufactured mono-crystalline cells, one multi-crystalline cells and one amorphous silicon cells.

<sup>255</sup> Both China’s manufacturing and much of its photovoltaic research were out of kilter with the incipient commercial dominance of multi-crystalline silicon cells in the late 1990s. When researchers from Tsinghua asked 10 Chinese solar experts which technology would dominate the future in a 1999 report, five said mono-crystalline, three said amorphous silicon, and only two said multi-crystalline (Dai et al, 1999).

that in this period MOST invested Rmb50-60m in photovoltaics, or about one-quarter of public sector R&D investment in Germany in a single year, 2004. It was estimated that in the 11<sup>th</sup> Five-Year Plan (2006-10) MOST funding for photovoltaic research increased to Rmb210m (Huo and Zhang, 2012).

When the private sector photovoltaic industry took off in the 2000s, it was difficult to observe connections with China's historic national research programmes. The most advanced technical capabilities in the early development of the country's solar industry were supplied by entrepreneurs who had studied, researched and worked in photovoltaic science overseas.<sup>256</sup> Other successful early solar entrepreneurs had little technical training, but a practical understanding of the solar business from involvement with China's 1990s rural anti-poverty investments in photovoltaics (following section).

The exception to the rule of no connections between national S&T programmes and industry development was the area where S&T efforts and import substitution strategy had greater focus: production of high purity crystalline silicon feedstock. China had a long history of crystalline silicon production because of the material's strategic importance to the semiconductor industry, including for military applications. However, in the early 2000s Chinese technology was energy inefficient and sub-scale, leading to high-cost output. In 2006, China had only 400 tonnes of capacity, and produced 300 tonnes (Li et al., 2007). Through the 1990s,

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<sup>256</sup> In the sense that Chinese governments after 1978 encouraged promising students to study abroad as part of national capability building, and then sought to lure them back, this phenomenon can be viewed as a sub-set of broad S&T policy (Zweig, 2002); but it was also distinct from activities under the domestic S&T budget discussed here.

the waste material from this production – whose primary focus was the electronics industry -- was enough to satisfy the raw material needs of photovoltaic cell production of around 2MW per annum. However, as private sector investment took off in the early 2000s, increasing aggregate output of cells to 50MW in 2004 and 200MW in 2005 (Table 42), almost all feedstock was imported. MOST therefore focused China's long-established silicon research infrastructure on updating crystalline silicon production technology.

**Table 42. Chinese photovoltaic cell production, 2004-2017 (forecast). MW and share of global output**

	2004	2005	2006	2007	2008	2009	2010
China output. MW	50	200	370	1,100	2,600	4,700	9,000
Share of global output. %	4	11	15	27	33	38	43

	2011	2012	2013	2014	2015	2016	2017F
China output. MW	17,000	20,000	23,000	29,000	37,000	48,000	50,000
Share of global output. %	57	58	55	59	63	62	60

Source: (Jäger-Waldau, 2017).

The key vehicle for the research, included in the 10<sup>th</sup> Five-Year Plan (2001-5), was the Emei Semiconductor Research Institute of China's General Research Institute for Non-Ferrous Metals (GRINM), located at Leshan in Sichuan province.<sup>257</sup> The aim was for Emei to ingest

<sup>257</sup> Emei was a 'third line' unit set up in rural Sichuan that began silicon research in 1957. In the 1960s, after the Sino-Soviet split, researchers opened a small crystalline silicon production line. Emei continued as a combined research and production facility.

contemporary best practice in ‘Siemens process’ technology (developed by the German firm in the 1960s and still the dominant production method) and then diffuse the learning to domestic silicon producers (Huo and Zhang, 2012). The project also included the localisation of technology for furnaces used to cast multi-crystalline silicon ingots (Fraas and Partain, 2010).

According to De la Tour et al. (2011), analysis of 2006 and 2007 patent applications related to silicon technology showed that the MOST campaign led to China receiving 36 percent of worldwide innovation patents in those years, compared with 17 percent or less in other segments of the solar value chain. The vast majority of silicon patents were filed by state research agencies; the authors described MOST’s approach as ‘a massive domestic effort to break a technological lock in a strategic segment where the Chinese industry is still dependent on a small number of foreign suppliers’ (De La Tour et al., 2011).<sup>258</sup>

In 2007, the NDRC endorsed the push on crystalline silicon technology by approving and publishing the notice ‘Major Projects on the Industrialisation of High-Purity Silicon Material Technology’ (Zhou et al., 2016). This conveyed official support for firm-level entry into manufacturing and for state bank credit supporting that production. MOST was already working with two state-owned companies to expand production of multi-crystalline silicon using updated technology. The first was Luoyang China Silicon in Henan province, one of two existing small-scale (300 tonne) crystalline silicon producers; the second was Leshan Xinguang Silicon, a new, green-field, state-owned producer

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<sup>258</sup> Despite the large number of silicon-related innovation patent filings, official data only showed MOST making silicon technology research grants of Rmb20m in 2006-10 (Huo and Zhang, 2012).

established by state sector investors in the Sichuan city where the Emei research institute was located.<sup>259</sup>

In 2005, Luoyang China Silicon began construction of a new 1,000-tonne per annum facility, and Leshan Xinguang Silicon a 1,260 tonne facility. Xinguang completed first, beginning production in February 2007, while Luoyang China Silicon's added capacity became operational in the second half of 2007. Other Chinese firms supported by MOST began to manufacture 500kg multi-crystalline ingot furnaces (Fraas and Partain, 2010).<sup>260</sup>

In terms of the analytical framework of this thesis, the continuing importance of the developmental state's role in supporting the acquisition of manufacturing capabilities was demonstrated clearly. However, state-owned manufacturers were not, ultimately, the major beneficiaries of this programme. Spiralling crystalline silicon prices in 2005-7 attracted both state-owned and private sector firms to invest in the sub-sector and the winner in this competition was an uninvited private sector entrant.<sup>261</sup>

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<sup>259</sup> The controlling shareholders of Leshan Xinguang Silicon were a Sichuan province state enterprise, Sichuan Chantou, and a Hebei province state enterprise, Baoding Tianwei, that was in turn an early investor in Yingli (see below). The Sichuan provincial government aimed to leverage MOST's crystalline silicon upgrading drive to make the province the world's leading manufacturer of multi-crystalline silicon. In addition to the Xinguang project, in 2006 centrally-controlled, Sichuan-based big three thermal power equipment firm Dongfang acquired Emei's 200 tonne per annum manufacturing operation, announcing a Rmb4bn investment to expand capacity. However, Dongfang and Emei were slow to deliver, not completing an expansion project until 2009 and missing out on much of a spike in silicon feedstock prices.

<sup>260</sup> High-purity crystalline feedstock is *all* initially purified as multi-crystalline material. This feedstock is then either melted and block cast to produce multi-crystalline ingots that are sliced into multi-crystalline solar wafers; or the feedstock is extruded, using the more costly Czochralski process, to become the highest purity mono-crystalline ingots, which are sliced either as solar wafers or for use in the electronics industry.

<sup>261</sup> In 2001-3 the price of solar grade crystalline silicon feedstock had been US\$25/kg; it surpassed US\$100/kg in 2005, and US\$200/kg in 2006. As of 2006, there were seven silicon projects under construction in China and eight more seeking state approvals (Li et al., 2007:17).



Jiangsu province-based GCL acquired manufacturing capabilities for silicon feedstock in part by poaching a key technical manager from MOST-supported Leshan Xinguang Silicon, who brought with him blueprints. GCL was sued for this, but a court sanction did not impede the development of its silicon business (see case study). Instead, GCL constructed and ramped up production at a pace that state firms could not match. GCL built its initial production line in only 15 months, opening in late 2007 at the same time as Luoyang China Silicon, despite the state firm having begun construction a year earlier. As occurred in the wind sub-sector, private firms brought to bear competitive weapons beyond narrow manufacturing capabilities – in this case economies of speed.

### **5.3. Stage 2: Manufacturing of mature technology without central government support**

As noted, the earliest successful entrepreneurs in the cell and module part of the value chain had one of two origins. The first group were returnee technical specialists with training and working experience in photovoltaics in economically advanced countries. The most important connection was with the photovoltaics department of the University of New South Wales (UNSW) in Australia, from which a number of Chinese graduates involved in starting businesses in China hailed.<sup>262</sup>

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<sup>262</sup> <https://www.engineering.unsw.edu.au/energy-engineering/what-we-do/about-the-school/arc-photovoltaics-centre-of-excellence> Accessed 5 June 2017. UNSW was the first university to offer a dedicated undergraduate degree in photovoltaics, although most Chinese students were post-graduates.

Best-known of these was Shi Zhengrong, who founded Suntech in Wuxi, Jiangsu province, in 2001. A main board director at Suntech described how Shi completed a doctorate at UNSW supervised by the university's leading photovoltaics scholar, Martin Green, and went on to work for Green's thin-film photovoltaics firm, Pacific Solar.<sup>263</sup> Shi's contemporary at UNSW, Zhao Jianhua, established photovoltaics business Sunergy in Nanjing, Jiangsu province, in 2004 (Zhou et al., 2016).<sup>264</sup> Other Chinese graduates of UNSW worked in senior positions for these and other Chinese start-ups.

A senior manager at Canadian Solar explained how founder Shawn Qu, whose main manufacturing site was established in Suzhou, Jiangsu province, completed a doctorate in materials science at the University of Toronto in 1995. He worked for the photovoltaics subsidiaries of the Ontario electric utility and of private-sector Automation Tooling Systems (ATS) before returning to China to set up Canadian Solar in 2001.<sup>265</sup>

The prominent entrepreneurial role of returnee technical specialists occurred in a period in the 2000s when the Organisation Department of the CPC led a campaign to woo more Chinese students with foreign doctorates to return to China to start businesses (Zweig and Wang, 2013). Jiangsu province, which became the national centre of photovoltaic investment, was a regional frontrunner in this campaign

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<sup>263</sup> S1, 11 December 2012. Shi lived and studied in Australia from 1987-2001. The interviewee stated that Shi obtained 15 patents while at UNSW. Martin Green's Pacific Solar, founded in 1995, operated on research grants in the late 1990s rather than commercial revenues.

<sup>264</sup> Zhao continued to work at UNSW's Centre of Excellence for Advanced Silicon Photovoltaics and Photonics as deputy director until 2006.

<sup>265</sup> S2, 15 October 2013. The ATS subsidiary where Qu worked was Photowatt International S.A.

under the leadership of Party Secretary Li Yuanchao.<sup>266</sup> Cities such as Wuxi co-funded business start-ups by returnees such as Suntech's Shi Zhengrong. When Li launched China's national '1,000 Talents' programme as head of the CPC's Organisation Department in 2008, with the aim of luring back 2,000 foreign doctorate holders over five to ten years, Canadian Solar's Shawn Qu was in the first batch announced (albeit he had already been settled back in China for several years).<sup>267</sup> It is difficult to assess how important official efforts to bring back Chinese photovoltaic specialists were, given that people like Shi Zhengrong and Shawn Qu were already interested in returning. What was more important was the provision of credit and subsidy.

Local government support for photovoltaic start-ups was also made available to non-returnee entrepreneurs without the same technical accomplishments. This was the second category of early photovoltaic entrepreneurs. Trina, founded by Gao Jifan in Changzhou, Jiangsu province, in December 1997, was a photovoltaic business launched three years before Suntech and Canadian Solar to undertake trading and installation work related to China's small-scale, rural, mostly off-grid projects. Yingli, founded by ex-army officer Miao Liansheng in the garrison town of Baoding in Hebei province in 1998, sprang from a long-time trading business that progressed from cosmetics to neon lighting to photovoltaic products.<sup>268</sup> Miao entered discussions with the Hebei branch of MOST and the Baoding city government in 1998 with the aim

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<sup>266</sup> Li was Deputy Party Secretary of Jiangsu 2001-2 and Party Secretary 2002-7.

<sup>267</sup> S2, 15 October 2013. The interviewee said that the practical impact of the status for Canadian Solar was that it facilitated applications for MOST R&D grants. Separately, Zhang Lei of Envision was also included on the 1,000 Talents roster when setting up his Jiangsu-based firm (Chapter 4).

<sup>268</sup> Miao Liansheng came across solar lighting on a business trip to Japan in the late 1990s (Gallagher, 2014); at the time Japanese firms dominated the photovoltaics industry.

of securing funding for a first, demonstration photovoltaic module production line, but the project did not go ahead (Gallagher, 2014). Yingli eventually started module production in 2003, the year after returnee-led firms Suntech and Canadian Solar. Trina followed in 2004.

Support from local governments was what united the returnee and local entrepreneur firms. Suntech interviewees explained how Wuxi led the way after founder Shi Zhengrong circulated a 200-page business plan for a 3MW cell and module manufacturing line among several local governments in 2001. Wuxi, which already supported a number of returnee-led businesses, offered to invest US\$6m -- sourced from a mix of local government funds and state-connected firms in the city and province -- for a 75 percent stake. Shi himself was allowed to contribute most of his equity in the form of technological know-how. Wuxi also provided land for the business at below market cost, and initial free office space.<sup>269</sup> Suntech opened its first production line in 2002, manufacturing 2MW of modules that year and 8MW in 2003 (Ahrens, 2013). Germany, where solar subsidies were introduced in 2000 and increased in 2004, became Suntech's dominant market.<sup>270</sup> In 2004, Suntech quadrupled its output to 35MW.

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<sup>269</sup> There were seven shareholders in the business, including a provincial-level state venture capital fund, a city-level state venture capital fund, and local state-controlled white goods firm Little Swan. Shi Zhengrong's nominal US\$2m investment for a 25 percent stake comprised only US\$400,000 cash. Moreover, Shi was able to earn a further 5 percent stake in the business through sweat equity. S1, 11 December 2012; S3, 11 December 2012.

<sup>270</sup> Germany's revised solar tariff of 2004 guaranteed prices as high as US\$0.60 per KW-hour for photovoltaic power when retail prices for thermal electricity were around US\$0.12. See Schwartz, Evan, 'The German Experiment', *MIT Technology Review*, June 22, 2010. Available at <http://www.technologyreview.com/review/419464/the-german-experiment/>. Accessed 9 May 2017. Italy and Spain followed Germany in introducing similar subsidies.

At this point, a new component was added to China's evolving private sector template for photovoltaic manufacturing. Shi Zhengrong negotiated with Goldman Sachs to obtain US\$80m bridging finance that allowed him to buy out the Wuxi investors and purchase capital equipment for expansion, as well as raw material inventory, such that Suntech could undertake an offshore IPO. This in turn repaid the bridging finance.

A Suntech executive stated that it was not easy to convince the investors organised by the Wuxi government to sell their equity, but in April 2005 they did so.<sup>271</sup> Production capacity was rapidly increased in 2005, with 82MW of modules shipped that year. In December 2005, Goldman led the Suntech IPO on the New York Stock Exchange (NYSE), raising US\$396m (Table 43).

A pattern was established. A Yingli interviewee explained how, in Hebei province, Miao Liansheng tapped one of Baoding's key state enterprises, electrical transformer maker Tianwei Baobian, to invest in Yingli's solar manufacturing business in 2002. Local government provided additional support, including free land.<sup>272</sup> Miao then obtained private equity investment, and bridging finance secured against his own shares, to pay for expansion, while reducing Tianwei Baobian's 51 percent controlling stake to, successively, 49 percent, 46 percent, and 38 percent.<sup>273</sup> Further investment in wafer production lines and silicon inventory formed the

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<sup>271</sup> S3, 11 December 2012.

<sup>272</sup> S4, 8 August 2011.

<sup>273</sup> A banker who worked with Miao noted that he could not raise bank loans to support expansion because Chinese state banks required physical assets as collateral. This was the bottleneck that foreign providers of private equity and bridging loans overcame. S5, 7 October 2014.

basis for necessary sales forecasts for an NYSE IPO in June 2007, which raised US\$319m and diluted Tianwei Baobian' interest to 26 percent.

Like Shi Zhengrong, Miao tapped city-level state interests for start-up capital which put him in a minority shareholding position; but he secured majority control prior to listing, and control thereafter.<sup>274</sup> Yingli expanded aggressively from 2005, anticipating that increased German subsidies would create a market for its output and developing wafer, cell and module production lines. By 2009, Yingli was the world's fifth biggest photovoltaics firm, and Suntech the second (Table 44).

**Table 43. Chinese photovoltaic firm IPOs and follow-on equity issues, 2005-11. US\$m**

	Market	IPO date	Gross funds raised in IPO	Follow-on equity issues through 2011	Total equity funds raised
Suntech	NYSE	Dec' 2005	\$396m	1	\$673m
Canadian Solar	NASDAQ	Nov' 2006	\$116m	1	\$219m
Trina	NYSE	Dec' 2006	\$98m	3	\$543m
LDK	NYSE	May 2007	\$469m	2	\$833m
JA Solar	NASDAQ	June 2007	\$225m	1	\$491m
Yingli	NYSE	June 2007	\$319m	1	\$546m
GCL	HKSE	Nov 2007	\$151m	2	\$1,335m
Renesola	NYSE	Jan 2008	\$130m	2	\$388m
Jinko	NYSE	May 2010	\$64m	1	\$190
Totals	--	--	\$1,968	14	\$5,218

Sources: company public documents, author calculations

<sup>274</sup> Tianwei Baobian was Miao's proposed partner for the 1998 prototype photovoltaic line which never went ahead. An interviewee at Yingli said that Miao's working relationship with Tianwei Baobian was extremely complex and he was able to make use of some of the state firm's manufacturing assets without paying for them; S4, 8 August 2011. After raising loans to buy Tianwei shares in Yingli, Miao controlled 60 percent of the firm's equity immediately prior to listing; Shi Zhengrong secured loans to hold 54 percent of Suntech equity prior to listing. Yingli's main private equity investments came from Inspiration Partners, in September 2006, and the Temasek investment arm of the Singapore government, in December 2006. Data from Yingli's and Suntech's SEC 20-F filings and F-1 Registration statements.

**Table 44. Top 10 global photovoltaic firms by module shipments, 2006-12. Chinese firms in bold**

	2006	2007	2008	2009	2010	2011	2012
<b>1</b>	Sharp	Sharp	Q-Cells	First Solar	<b>Suntech</b>	<b>Suntech</b>	<b>Yingli</b>
<b>2</b>	Q-Cells	Q-Cells	<b>Suntech</b>	<b>Suntech</b>	First Solar	First Solar	First Solar
<b>3</b>	Kyocera	<b>Suntech</b>	Sharp	Sharp	Sharp	<b>Yingli</b>	<b>Suntech</b>
<b>4</b>	<b>Suntech</b>	Kyocera	First Solar	Q-Cells	<b>Yingli</b>	<b>Trina</b>	<b>Trina</b>
<b>5</b>	Sanyo	First Solar	Kyocera	<b>Yingli</b>	<b>Trina</b>	<b>Canadian</b>	<b>Canadian</b>
<b>6</b>	Mitubishi	Motech	Motech	<b>JA Solar</b>	<b>Canadian</b>	Sharp	Sharp
<b>7</b>	Schott	Sanyo	Sanyo	<b>Trina</b>	Hanwha	Sunpower	<b>Jinko</b>
<b>8</b>	Motech	SolarWorld	Sunpower	Sunpower	Kyocera	<b>Jinko</b>	<b>JA Solar</b>
<b>9</b>	BP	Mitsubishi	<b>JA Solar</b>	Kyocera	Sunpower	Hanwha	Sunpower
<b>10</b>	Sunpower	Sunpower	BP/Mitsubishi	Motech	SolarWorld	Kyocera	Hanwha

Sources: PV Tech web site; Solarbuzz web site.

The most extreme case of local government support was for Peng Xiaofeng's LDK. Peng, like Envision's Zhang Lei, was from an already wealthy business family. He initially determined to base his solar business in Suzhou. However, in 2005 the government of Xinyu city, in inland Jiangxi province, offered a degree of support so great that Peng decided to build a facility 500km from the coast.<sup>275</sup> A private equity financier to Peng described how the support provided by Xinyu included free land; construction of certain factory buildings at local government expense; a three-year free lease of one factory unit; construction of supporting infrastructure such as roads; rebates on utility costs including electricity; tax holidays and exemptions; loan guarantees from the Xinyu government and provincial government-controlled investment firms; guarantees that labour required by LDK would be readily available; and construction of a new polytechnic institute in Xinyu that specialised in

<sup>275</sup> Jiangxi was the original home of the Peng family; however, its substantial business interests, in latex glove manufacturing and real estate, were in Fujian province.

solar technology and graduated 2,000 students per year.<sup>276</sup> When the European Union (EU) launched anti-dumping investigations against Chinese solar firms in 2012, LDK was assessed to have benefitted more than any other investigated firm from land-related subsidies, while no other investigated firm was found to have received electricity rebates.<sup>277</sup>

Peng Xiaofeng used Xinyu's vast non-cash subsidies to concentrate his family's investment funds, and state bank credit, on the imported machinery for a specialist solar ingot-casting and wafer-cutting business located upstream from most early Chinese solar investment. LDK listed on the NYSE in June 2007, after only four quarters of production, raising US\$469m, the largest photovoltaic IPO (Table 43, above).<sup>278</sup> The funds raised, plus two follow-on equity issues, bond issues and bank debt, were deployed to enter silicon feedstock production, and later cell and module manufacturing. LDK thereby covered every segment of the solar manufacturing value chain. Peng claimed to a business partner who was interviewed that the Xinyu government pressed him to expand faster than he did, requesting simultaneous development of six square kilometres of production facilities.<sup>279</sup> After listing, LDK was required to

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<sup>276</sup> S5, 7 October 2014; S6, 26 September 2013; *China Economic Weekly* (*Zhongguo jingji zhouban*), 31 July 2012, available at <http://finance.sina.com.cn/roll/20120731/002712710715.shtml> Accessed 10 May 2017. One interviewee who worked closely with Peng estimated that Xinyu city and provincial loan guarantees were extended to one-third of LDK's eventual Rmb30 billion of debt. The interviewee said the electricity subsidy alone was worth Rmb100-120m per year, with LDK paying a rate in the mid-20s of Chinese cents per kwh, versus a commercial rate around Rmb0.40.

<sup>277</sup> The EU investigation determined that LDK's receipt of cheap and free land use rights was equivalent to an ad valorem subsidy of 4.28 percent to the ex-factory price of its goods, while Xinyu's electricity rebates were equivalent to a subsidy of 2.45 percent. See Council Implementing Regulation (EU) No1239/2013, 2 December 2013, in the Official Journal of the European Union.

<sup>278</sup> LDK's temporary competitive advantage was that the firm had ordered almost the entire available supply of silicon ingot saws for cutting solar wafers from the only two manufacturers then in existence: Meyer-Burger and HCT (subsequently acquired by Applied Materials of the US), both in Switzerland. The firm's F-1 Registration statements showed it had 27 wafering saws in operation, 40 on order from Meyer Burger, and 170 on order from HCT.

<sup>279</sup> S5, 7 October 2014.



identify all ongoing local and national *cash* grants and subsidies in its annual financial statements and these, like its non-cash local government subsidies, reflected the largest scale support relative to revenues of any of the major Chinese photovoltaics firms (Table 45).

**Table 45: Revenues versus cash grants and subsidies reported in annual financial statements, selected Chinese photovoltaics firms, 2007-12.**

**Rmb m**

	2007	2008	2009	2010	2011	2012
Suntech revenues	9,347	13,132	11,472	18,856	19,804	NR
<b>Suntech cash grants and subsidies</b>	11.8	15.0	4.7	7.8	12.6	NR
Yingli revenues	4,059	7,553	7,255	12,500	14,678	11,392
<b>Yingli cash grants and subsidies</b>	NR	NR	23.7	102.5	125.6	214.0
LDK revenues	3,632	11,220	7,439	16,305	13,581	5,376
<b>LDK cash grants and subsidies</b>	24.0	134.3	182.4	36.5	212.1	26.4
Canadian Solar revenues	2,099	4,813	4,275	9,717	11,952	8,067
<b>Canadian Solar cash grants and subsidies</b>	0	0	0	0	0	0
GCL revenues	1,845	3,693	4,337	16,241	21,159	18,120
<b>GCL grants and subsidies</b>	42.7	60.5	93.2	253.8	162.2	231.8

NR: not reported

Sources: company reports

The final component in the photovoltaic boom was that, in the wake of six successful US IPOs between December 2005 and June 2007 (Table 43), China's state-owned commercial banks lent aggressively to photovoltaics firms. This was despite the solar sector not yet being identified as an NDRC industrial policy target. Four state banks -- China Merchants Bank, Everbright Bank, Industrial and Commercial Bank of China (ICBC) and Bank of China -- were particularly aggressive in lending and underwriting bond issues after their headquarters marked

photovoltaics as a sector for credit growth. LDK's Peng Xiaofeng told the private equity counterparty cited above that 'banks were so desperate to see him that he had to pick between them'.<sup>280</sup> In effect, local government support, short-term foreign bridging finance for offshore IPOs, and Chinese commercial bank lending short-circuited the NDRC's industrial policy prioritisation process. Four Chinese firms were among the world's top ten producers of solar modules by 2009, a number that rose to six three years later (Table 44, above).

### **Unplugging the bottleneck**

The value-chain bottleneck for the Chinese solar industry through the mid-2000s was the supply of silicon feedstock, whose price increased from a historic average US\$25-30/kg in the 1990s and early 2000s to a peak of US\$450/kg in 2008 (Paulson, 2014). As noted, the pricing tempted many firms to enter the market. However, while it was not difficult to produce energy-intensive solar-grade silicon at high prices, it was difficult to produce at anything near the long-run historical price achieved by multinationals. The spike in prices from 2008 before they declined to US\$30/kg by end 2011, and a new low of US\$17/kg in late 2012, created a competitive environment in which economies of speed were the critical variant.

GCL (see case study) was the Chinese firm that added capacity faster than multinationals and drove down production costs faster than the fall in unit prices when new capacity at the multinationals came on line. Other Chinese firms were unable to do this.

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<sup>280</sup> S5, 7 October 2014.

LDK, which announced it would enter crystalline silicon feedstock production following its 2007 IPO, hired foreign project managers to plan, and US engineering, procurement and construction (EPC) firm Fluor to build, its plant.<sup>281</sup> Construction time, and the ramping up of production, were too slow. Silicon spot prices were already falling precipitously when LDK's 10,000 tonne per annum line opened in 2009. A senior technical specialist at LDK stated that the firm's cost of production reached a lowest level of \$30/kg in 2012, while the market price fell more than 50 percent further. LDK invested over US\$1bn in silicon feedstock operations and lost money on all but the earliest batches it produced.<sup>282</sup>

Yingli's performance was relatively worse, but on a smaller investment. The firm constructed a 3,000 tonne per annum facility that cost US\$400m and opened in 2011. The plant never produced more than 1,000 tonnes of silicon in a year because of high production costs and quality problems. At the time of a visit in July 2012, a manager stated that the plant's 500kg reactors were yielding only 300kg of silicon; the cash production cost was stated as US\$40/kg, versus a market price already under US\$20/kg.<sup>283</sup> As with LDK's facility, Yingli's was shut down when it became clear it would never produce at under US\$20/kg.

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<sup>281</sup> LDK consultants included the former CEO of Norwegian silicon manufacturer REC, Goran Bye, who in turn brought in a team of foreign technicians. Peng Xiaofeng already used a team of foreigners led by Nick Sarno, a former manager at US MEMC Electronic Materials, to establish LDK's ingot casting and wafering operations. S6, 26 September 2013.

<sup>282</sup> S6, 26 September 2013.

<sup>283</sup> S7, 16 July 2012. Yingli purchased the highest purity crystalline silicon manufacturing line in China but could not ingest the advanced technology.

At Suntech, a senior manager estimated the firm lost in excess of US\$250m through failed minority investments in crystalline silicon manufacturers in 2006-8, designed to secure raw material supplies when these were scarce. Suntech, like Yingli, locked itself into long-term supply contracts of up to 10 years with third-party producers, never imagining that prices would fall far below the contracted ones.<sup>284</sup>

Failed silicon investments dealt a mortal blow to many large Chinese photovoltaic firms. Nonetheless, the extraordinary success of GCL, and the ability of a few other Chinese silicon manufacturers to reduce costs close to market levels, enabled the downstream sectors of the photovoltaics industry to continue to drive down module prices.

Interviewees noted that a major contributor to the cost reductions was production equipment prices that declined in every solar segment, from silicon feedstock, through ingot casting and wafer slicing, to cells and modules. In silicon feedstock production, the LDK technical specialist cited above observed that capital expenditure per kilo of silicon feedstock capacity in China declined from US\$90 in 2007 to US\$40-45 in 2013; in other words, the cost of a 10,000 tonne per annum facility such as LDK built fell from around US\$1bn to less than half that in six years.<sup>285</sup> Lower costs were partly related to the use of larger reactors and Chinese firms' gradual mastery of a new, modified chemical process. The

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<sup>284</sup> S8, 24 September 2012. Suntech made investments in active and planned crystalline Silicon producers Asia Silicon, Shunda Holdings, Xi'an Longji, Hoku Scientific and Nitel Solar. The first three were China-based producers; Hoku was a consortium of Chinese investors with a silicon project in the United States; Nitel was a Russian firm.

<sup>285</sup> S6, 26 September 2013. A 2013 report by CLSA found that Chinese silicon plant construction costs had fallen to around one-third of what multinationals spent in developed countries in 2010 (Yonts, 2013).

overarching theme, said the LDK technical specialist, was that every piece of manufacturing equipment localised by Chinese suppliers was at least 30 percent cheaper than recent world prices.<sup>286</sup>

In 2006, furnaces for creating multi-crystalline ingots from silicon feedstock were still imported (Li et al., 2007). By 2008, they were localised and Chinese equipment firms like Jinggong, in Zhejiang province, began to develop furnaces larger, as well as cheaper, than those manufactured in developed countries. Chinese multi-wire saws for wafer cutting were available by 2008 and quality improved quickly.<sup>287</sup> In solar cell production, Chinese firms reverse engineered diffusion furnaces, plasma etchers, sintering ovens and semi-automatic screen printers (Fraas and Partain, 2010). Plasma Enhanced Chemical Vapour Deposition (PECVD) equipment, wet-etching benches and fully automatic screen printers followed.

The impact on specialist foreign equipment firms, including Europe's Meyer Burger and Centrotherm, whose businesses boomed in the mid-2000s, was consistent: share prices fell by more than four-fifths as China localised equipment manufacturing.<sup>288</sup> The photovoltaics equipment experience was consistent with a general trend in China in the 2000s

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<sup>286</sup> S6, 26 September 2013. The new chemical process was energy-saving hydrochlorination, rather than the older direct chlorination process. For a technical discussion, see <http://www.renewableenergyworld.com/articles/2010/05/advancements-in-the.html> Accessed 12 May 2017. GCL was the first Chinese company to master hydrochlorination. S9, 16 August 2010.

<sup>287</sup> Yingli, for example, reported that it was buying Jinggong furnaces in 2011 at a price 30 percent below that of its previous supplier, GT Advanced Technologies of the US, as well as Chinese-made wire cutters. S4, 8 August 2011.

<sup>288</sup> Applied Materials of the US, which made acquisitions of firms including Swiss wire saw maker HCT Shaping Systems (US\$475m in 2007) and Italy's Baccini screen printer manufacturer (US\$330m in 2008), reversed course and began a gradual exit from the photovoltaics business as Chinese equipment vendors came on line. The Chinese leader in fully automatic screen printing, one of the last core technologies to be localised, was Wujiang Maxwell Technologies, based in Suzhou.

whereby purchases of foreign equipment, which accounted for the majority of Chinese spending on technology in the 1990s, were only one-tenth of technology expenditure by the end of the 2000s (Watanabe, 2014:chapter8).

Falling production equipment prices exacerbated the problem of low barriers to entry in the photovoltaics sector for all but silicon manufacturers. The strongest Chinese brand, Suntech, enjoyed technological leadership, manifested in slightly higher solar conversion rates for its cells. However, noted a manager responsible for strategic planning, the firm could never convert this into a pricing premium of more than 5 percent over other Chinese manufacturers.<sup>289</sup>

In line with the analytical framework of this thesis, manufacturing capabilities alone could not secure clear competitive leadership. Dynamic capabilities recommended forward integration into project development to achieve higher margins. This is what manufacturers in the United States pursued from the mid-2000s: as photovoltaic unit prices fell precipitously, market leaders First Solar and SunPower moved into utility solar, and subsequently distributed solar, project development. SunPower also started a successful residential leasing business. First Solar's revenues from project development were 5 percent those of its component sales in 2009; in 2011, they were one-third; and in 2013, project revenues were almost twice as much as module sales. The overwhelming majority of the projects were in the

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<sup>289</sup> S8, 24 September 2012.

United States.<sup>290</sup> Chinese firms, however, had to try to replicate this strategy in foreign markets, since there was no Chinese solar market to speak of.

The impulse to dynamic capabilities was certainly present among the leading Chinese firms. They tried to develop offshore downstream businesses. Suntech established regional business development hubs for the Americas and Europe as early as 2007, with headquarters in San Francisco and Geneva. In 2008, the firm committed Euro258m to a Global Solar Fund (GSF), initially focused on project development in Europe. In the US in 2008, the company formed a joint venture to develop solar projects, and purchased a California-based solar EPC firm. In 2010, Suntech invested in a trial residential solar leasing business in the US.<sup>291</sup> However, the complexity of developing offshore installation businesses without any domestic experience, the challenge of managing far-flung international teams, inadequate cash flows to see overseas businesses through to maturation, and a large-scale alleged fraud at Suntech's GSF all contributed to a failure to move directly to international forward integration (see case study).

LDK failed with a similar strategy. The firm entered a 2009 joint venture with German photovoltaics manufacturer Q-Cells to develop solar

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<sup>290</sup> First Solar reported revenues in two segments: components and systems. The former covered module sales to third parties while systems included modules used in projects developed by the firm. Revenues in 2009, 2011, 2013 were, respectively, US\$1,965, US\$2,068, US\$1,174 for components and US\$101m, US\$698m, US\$2,136m for systems. In 2011, when First Solar had 2,082MW of projects under development, only 100MW were outside the United States. Company annual reports.

<sup>291</sup> The joint venture, Gemini Solar Development, was formed with MMA Renewable Ventures. The EPC was EI Solutions, renamed Suntech Energy Solutions. The residential leasing business was BriteLease. Company public documents; S3, 11 December 2012; S10, 5 June 2013.

projects, but pulled back after a first, loss-making project in Germany.<sup>292</sup> In 2011, LDK acquired a US EPC, Solar Power Inc., but could not develop a profitable downstream business in the US. Even GCL, with its large cash flows from silicon sales, struggled to build an overseas installation business after entering a US joint venture with SolarReserve in 2010. GCL sold down most of its US project pipeline when silicon prices hit record lows in 2012-13. The one Chinese firm that was able to move directly to build up a substantial sustained overseas development business was Canadian Solar. However, even this was a relatively much smaller part of its business than was the case with First Solar and Sunpower in the US. Canadian Solar's revenue from project development and services was never more than half its total revenue (see case study).

Chinese solar firms' inability to develop profitable project development businesses overseas did not become an existential problem through 2011 because module exports continued to grow strongly. Exports rose through the global financial crisis in 2008-9, jumped with the opening of new subsidised markets in Europe and the US in 2010, and established a peak value of US\$35.8bn in 2011 (Table 46). Moreover, from 2010 China's key policy bank, China Development Bank (CDB), began to lend aggressively to photovoltaics firms. By 2011, it was reported that CDB had US\$7bn of credit outstanding to the sector.<sup>293</sup> Zhang et al. (2014) reported that CDB's decision to commit to the solar sector was connected to its involvement in preparatory work for the State Council's

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<sup>292</sup> S6, 26 September 2013.

<sup>293</sup> Wayne Ma, 'Chinese solar approach faces test', *Wall Street Journal*, 6 March 2013. Separately, an interviewee at Suntech stated that 2010 was the first time that competitor LDK received funding from CDB. S11, 15 May 2013.



October 2010 ‘Decision on Accelerating the Development of Strategic Emerging Industries’, which identified photovoltaics as part of a ‘new energy’ emerging industry. Whatever CDB’s motivation, it was out of kilter with policy at the NDRC and NEA, which began to develop new solar subsidy programmes much more tentatively. Beginning in 2009, the NEA was party with other ministries to the Solar Roofs programme, the Golden Sun Demonstration programme and a small number of other utility-scale projects (Huo and Zhang, 2012). The aggregate subsidies funded only a few hundred megawatts of installations in 2009-10.

**Table 46. Exports of photovoltaics products, 2008-2016. US\$ bn**

2008	2009	2010	2011	2012	2013	2014	2015	2016
4.4	13.7	30.5	35.8	23.3	12.3	14.4	15.5	14

Sources: Chinese customs data (Zhao et al., 2015)

The year 2011 proved a turning point. The latest surge of bank credit, led by CDB, made possible exponential capacity expansion accompanied by rapidly falling profit margins as production ran far ahead of demand (Table 47). For its part, the NEA maintained a measured transition to larger domestic solar subsidies. The Golden Sun programme was switched to a fixed tariff arrangement and expanded. In July 2011, the NEA introduced a first national feed-in tariff for other solar projects.

China’s domestic market expanded, from 0.5GW in 2010 to 2.6GW in 2011 (Table 41, above). However, this was far from enough to absorb output from module manufacturing capacity, estimated to have increased from 9GW per annum in 2009 to 55-70GW in 2011; 55GW was

1.5 times global demand in the latter year.<sup>294</sup> Prices spiralled down and photovoltaics firms in China and overseas started to lose money. In the US and Europe, solar manufacturers lobbied for anti-dumping tariffs on Chinese imports. The US Department of Commerce started an investigation in October 2011, leading to a provisional minimum import tariff of 31 percent from May 2012. The EC introduced a provisional minimum import tariff of 37 percent from June 2013.

**Table 47. Gross margins of selected photovoltaics firms, 2006-15. %**

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Suntech*	24.9	20.3	17.8	20	18.7	12.3	na	na	na	na
Yingli	23.84	23.57	23.4	23.63	33.22	16.69	-3.24	10.87	17.31	11.91
Trina	26.24	22.41	19.77	28.06	31.46	16.24	4.41	12.29	16.87	18.67
Canadian	18.09	18.85	10.07	12.38	15.3	9.6	6.98	16.66	19.62	16.63
GCL	na	19.65	72.55	30.15	36.87	33.19	7.83	11.91	23.12	26.54
First Solar	40.19	49.88	54.43	50.56	46.22	35.13	25.32	26.12	24.33	25.69
Sunpower	21.3	19.1	24.3	18.6	23	9.5	10.2	19.6	20.6	15.5

na: not available

\*Suntech's last filing of 20-F annual accounts was 2011; the firm declared bankruptcy in March 2013.

Sources: company reports

Against this background, Chinese exports of photovoltaic products decreased by about half in 2012, and by more in 2013, before stabilising (Table 46, above). The government was left with a simple choice: either subsidise a much larger domestic market or accept widespread bankruptcies and related state bank losses. By early 2012, the ten largest Chinese photovoltaic firms reported combined debts of US\$17.5bn.<sup>295</sup>

Fortunately, the remarkable reduction in ex-factory solar module unit prices – from approximately US\$4/W in 2007 to US\$1.3/W in 2011

<sup>294</sup> The higher module manufacturing estimate was from Nomura. See Bruce Einhorn, 'The fall of China's solar power king', Bloomberg, 6 March 2013. Available at <https://www.bloomberg.com/news/articles/2013-03-06/the-fall-of-chinas-solar-power-king> Accessed 16 May 2017. A lower estimate of 55GW is given by Zhang et al (2014).

<sup>295</sup> Wayne Ma, 'Chinese solar approach faces test', *Wall Street Journal*, 6 March 2013.

(Table 48) – made the government’s choice relatively easy. In the course of 2012, the NEA’s target for installed solar generating capacity in 2015, which was 5GW as of 2011, increased to 10GW at the start of the year, 15GW in May, and 21GW in time for the 12th Five-Year Plan for Renewable Energy Development in China, published on 1 January 2013 (Liu and Shiroyama, 2013). A GCL interviewee said that, privately, NDRC officials told Chinese solar firms in late summer 2012 that 30-40GW per annum was possible by 2015, which was what occurred (Table 41).<sup>296</sup>

**Table 48. Ex-factory module prices in China, 2007-15. US\$ per watt**

2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
3.75	4.23	2.13	1.8	1.34	0.77	0.67	0.67	0.58	0.51

Source: Canadian Solar

Despite the government’s actions, a number of bankruptcies could not be avoided because of the scale of over-capacity. The first was Suntech, in March 2013. Notably, Suntech was less indebted than LDK and Yingli. However, state banks removed support after founder Shi Zhengrong refused to provide personal guarantees for the firm’s debts. The requirement for heavily indebted entrepreneurs to pledge personal, and often family, assets is a common state bank requirement in China to attempt to reduce the moral hazard that accompanies industrial policy-determined lending. According to one interviewee familiar with the matter, Shi first refused to provide personal guarantees to CDB in June 2012, and subsequently repeated the refusal with other banks.<sup>297</sup>

<sup>296</sup> S8, 24 September 2012.

<sup>297</sup> S12, 16 May 2013. The refusal to provide the personal guarantees demanded by the banks in turn undermined the Wuxi city government’s support for Suntech, according to the interviewee.

At LDK, Peng Xiaofeng pledged both personal and family assets, with banks locking down his family's bank accounts, according to a financier who worked with him. In return, the interviewee explained, CDB led a group of 20 creditors which rolled over outstanding loans and interest each quarter beginning February 2012; CDB even extended a new, Rmb440m (US\$71m) loan in January 2013 in an effort to upgrade LDK's silicon feedstock manufacturing operation. All efforts failed, and different LDK units entered bankruptcy in 2014 and 2015, with net liabilities around US\$2.7bn; Chinese banks lost about 80 percent of their loans.<sup>298</sup> Yingli, whose founder Miao Liansheng pledged personal assets to state banks, was also kept alive by a creditor group led by CDB.

#### **5.4. Stage 3: Manufacturing of current technology, and incremental modification of current technology, with government support**

As in the wind industry, the basis for a substantial domestic solar market was the introduction of a feed-in tariff (FIT), in July 2011. In the wind industry, however, the NEA made only one major change to its management of the subsidy regime after the wind FIT was launched in 2009, when the approval of all wind farm projects was centralised from mid-2011.<sup>299</sup> In the solar sector, the subsidy regime underwent a number of major changes, reflecting a more challenging NEA task to frame a regime that could lead to concentration and reward those firms exhibiting dynamic capabilities.

The initial expansion of the domestic market in 2011 and 2012 (Table 49) was based on a uniform FIT, which led to a rush of investment in

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<sup>298</sup> The new CDB loan to LDK was for hydrochlorination equipment. S5, 7 October 2014.

<sup>299</sup> 'Wind farm development interim rules and regulations,' NEA, 2011.

western provinces with good solar resources and low land costs. This worsened curtailment problems, already plaguing wind farms in these areas, due to inadequate distribution infrastructure (Wang et al., 2016). The NDRC and NEA therefore coordinated a series of regulatory changes through 2012 and 2013 that sought an even balance between utility-scale projects and DG projects that create less stress for electricity infrastructure (Zhang et al., 2014). In addition, the uniform FIT was changed to a three-zone FIT that paid lower tariffs in western provinces with higher rates of curtailment. A DG tariff paid on both electricity consumed by a project's developer and on surplus electricity sold to the grid was added.<sup>300</sup>

**Table 49. China's photovoltaic market, and distributed generation component, 2008-16. MW**

	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total	40	160	500	2,600	5,000	12,900	10,600	15,100	34,500
- of which DG						800	2,050	1,390	4,230

Source: NEA

Despite the changes, DG project development increased slowly. In 2014, the NEA targeted 8GW of DG installation, but only 2.1GW was completed. Local electricity grid offices resisted connecting DG projects, banks were unwilling to finance them, and rights to roof space in shared

<sup>300</sup> The three-zone utility-scale FIT was made up of two components: the local rate for thermal electric power, paid by the grid, and the balance, paid by the Ministry of Finance from its Renewable Energy Development Fund. The DG tariff was a uniform tariff of Rmb0.42/KWh from its inception in 2013, on all electricity self-consumed and on surplus electricity sold to the grid; in addition, a DG project owner received the local wholesale rate for thermal electric power for electricity supplied to the grid. Several provinces, led by Zhejiang, started to offer additional provincial subsidies around Rmb0.1/KWh for DG projects from 2012.

accommodation were unclear and difficult to assert legally (Zhang et al., 2015). These problems could not be quickly addressed. In September 2014, the NEA raised the upper limit for DG projects from 6MW to 20MW and allowed developers to sell all output to the grid at an alternative, higher tariff. However, DG installations in 2015 fell to 1.4GW. The figure increased to 4.2GW in 2016, but only in the context of record overall solar installations of 34.5GW.

The NEA focused promotion efforts on several dozen DG demonstration zones around the country, in which half of all roofs were targeted to carry solar installations, and more than 80 percent on new buildings. Through 2017, the main DG tariff was maintained at its 2013 level while the utility scale FIT, which began at a unified Rmb1.15/KWh in 2011, was steadily reduced (Table 50). The NEA aim was to increase the DG share of total installations to 45 percent by 2020. However, China had yet to develop the financing and leasing firms for DG projects that facilitated rapid expansion in countries like the US.<sup>301</sup>

**Table 50. Wind utility-scale, solar utility-scale, solar distributed tariffs, 2017. Rmb/KWh\***

Wind FIT category 1	0.4	Solar FIT region 1	0.65
Wind FIT category 2	0.45	Solar FIT region 2	0.75
Wind FIT category 3	0.49	Solar FIT region 3	0.85
Wind FIT category 4	0.57	Solar DG tariff**	0.42

\*Geographic categories/zones for wind and solar were not the same and hence not directly comparable, but they broadly reflected the most/least favourable wind and solar resource locations.

\*\* In addition to the local thermal electricity tariff when power is supplied to the grid. The average local thermal tariff in China in 2017 was around Rmb0.38.

Source: NEA data

<sup>301</sup> In the US, leasing firms like SolarCity, Vivint and Verengo accounted for two-thirds of residential solar installations by 2013-14, before their market shares began to decline.

The NEA also experimented with new policies in the utility-scale market to reward firms with the best products and services, rather than the lowest prices. In 2015, the NEA introduced a quota programme called Top Runner that required minimum solar conversion rates. After completing 1GW of demonstration projects, Top Runner expanded to 5.5GW of utility-scale projects in 2016. The programme was designed to favour the largest manufacturers using the latest technology. The programme's introduction coincided with the stabilisation of the group of largest Chinese photovoltaics firms (see below). However, the analytical framework of this thesis suggested that an industrial policy based narrowly on manufacturing capabilities reflected in solar conversion rates -- recalling the NEA's earlier focus on turbine size in the wind sector -- would not be enough to hone truly world-class firms.

Overall, curtailment and late payment of subsidies remained major problems through 2016, increasing investment risk and driving down rates of return. Low utilisation and curtailment in Xinjiang and Gansu reduced project internal rates of return to around 5 percent – below the cost of Chinese bank credit. This was before delayed FIT subsidy payments by the Ministry of Finance, which commonly took 1-3 years to remit, further increased investors' effective cost of capital (Yeung et al., 2016, Shen, 2016).<sup>302</sup> The NEA hoped that the completion of a series of ultra-high voltage (UHV) power lines between remote wind- and solar-intensive regions and more populous areas would relieve the curtailment problem; UHV lines with annual transmission capacity up to

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<sup>302</sup> As of 2015, Rmb20-30bn of solar FIT subsidy payments were more than one year overdue. The renewable energy surcharge on all electricity consumption, which funds the FIT subsidies for renewables, increased from Rmb0.2 cents per KWh in 2006 to Rmb 1.9 cents in December 2015, but remained insufficient.

53GW were due to be completed in 2017.<sup>303</sup> In the meantime, the NEA in 2016 introduced guarantees of minimum hours of wind and solar output that must be purchased by utilities; it was not clear if these could be enforced.<sup>304</sup>

As of 2017, the best Chinese solar firms could not differentiate themselves clearly and capture significantly higher margins by forward integration in the domestic market. Nonetheless, as the NEA scrambled to adjust its DG policy mix, built out the Top Runner programme, and experimented with utilisation guarantees, a group of six photovoltaics firms started to bed down as the industry's vanguard. Four of these firms were the largest surviving mid-stream producers of wafers, cells, and modules: Jinko, Trina, Canadian Solar and JA Solar. Notably, all of the big six firms began to cut costs by outsourcing cell and module production to smaller, weaker manufacturers; in 2016, outsourcing accounted for more than one-third of big-six module production.<sup>305</sup> Only the strongest firms could afford the outlays to support constant technology upgrades to raise cell conversion rates, while a trailing group of producers became either their captive suppliers, and/or own-brand manufacturers of lower-margin products.

The other two firms among the big six were the fully integrated producers of silicon, wafers, cells and modules. GCL was the first firm to follow this strategy as it progressed, opportunistically, from silicon to

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<sup>303</sup> The first UHV line, between Gansu and Hunan provinces, opened in 2015; two more followed in 2016; eight were due for completion in 2017.

<sup>304</sup> Announced 31 May 2016, the guarantees were significantly higher than actual utilisation rates recorded in 2015.

<sup>305</sup> See PV Tech, 31 January 2017, at <https://www.pv-tech.org/editors-blog/top-10-solar-module-suppliers-in-2016> Accessed 5 June 2017.



wafers to cell and module production. More recently, Longi Green Energy, which further refined multi-crystalline feedstock into the highest purity mono-crystalline ingots at unparalleled scale, replicated GCL's strategy. Among the big six Chinese firms, only Longi was not among the world's top 10 module producers in 2016 (Table 51); it was expected to be so in 2017.

**Table 51. Largest solar module manufacturers by output, 2016.**  
(Chinese firms in bold)

Rank	Company
1	<b>Jinko</b>
2	<b>Trina</b>
3	<b>Canadian Solar</b>
4	Hanwha Q-Cells (ROK)
5	<b>JA Solar</b>
6	<b>GCL</b>
7	First Solar (US)
8	<b>Yingli</b>
9	<b>Talesun</b>
10	<b>Risen</b>

Source: PV-Tech & Solar Media, January 2017.

Although it was sometimes slow to do so, once the NEA came to terms with the idiosyncrasies of the solar business the agency was tenacious in pursuing strategies to increase concentration and reduce subsidies to weaker firms. In line with the analytical framework of this thesis, the solar sub-sector, like the thermal and wind sub-sectors, highlighted that effective industrial policy could not be limited to narrow manufacturing capability development. Policy needed to facilitate a transition to

competition through firms' strategic dynamic capabilities. What became clear in the photovoltaics sub-sector, however, was that this required sufficient maturity in domestic product markets. When market maturity was insufficient, there were no quick remedies.

### **Three case studies:**

#### **5.5. Case study: Suntech**

Among Chinese photovoltaics firms, Suntech was the leader in manufacturing technology and it was the first firm to complete private equity fund raising and an IPO, and hence the leader in scaling up production. Despite these advantages, Suntech was also the first Chinese solar firm to file for bankruptcy, in March 2013.

Suntech's founder, chairman and CEO Shi Zhengrong, was the most technologically accomplished leader of any of the wind and solar case study firms. Shi was a research colleague of photovoltaic industry founding father Martin Green, and named on 15 patents while living in Australia (Vietor, 2011). He recruited other accomplished scientists to Suntech, including Stuart Wenham, a former colleague at UNSW and Pacific Solar, who helped design the first production lines and in 2005 joined as Chief Technology Officer.

Leadership in manufacturing technology, however, only gave Suntech a small competitive advantage. As a senior manager responsible for

strategy noted, in 2012 Suntech achieved unit prices just 3-5 percent higher than competitors.<sup>306</sup>

This small premium was more than offset by Suntech's poor strategic choices. Unlike Goldwind and Envision in the wind sector, Suntech did not restrict itself to investment in ready-to-market technologies, such as Goldwind's commercialisation of DDPM, or Envision's investments in software. Suntech made large investments in a Japanese developer of thin-film and built-in photovoltaic (BIPV) products, and a German developer of thin-film technology. Neither Japan's MSK, nor Germany's CSG Solar, possessed products which were commercially proven. Suntech attempted to leapfrog in manufacturing capabilities. The manager cited above said the strategy led to combined write-offs in BIPV and thin-film activities in excess of US\$200m.<sup>307</sup>

Suntech's first mover role in raising finance also offered it potential competitive advantage. Shi accessed private equity finance in 2004, completed a US\$396m IPO in December 2005, sold US\$1,075m in bonds in 2007 and 2008 and completed a US\$277m follow-on equity issue in 2009.<sup>308</sup> This flow of low-cost equity and debt allowed Suntech to increase cell and module capacity from 6.4MW in 2003 to 363MW in 2007 and 1,540MW in 2010, at which point it was the largest solar firm in the world. Revenues rose from US\$13.9m in 2003 to US\$1.35bn in 2007 and US\$2.9bn in 2010.

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<sup>306</sup> S3, 11 December 2012; S11, 15 May 2013.

<sup>307</sup> Suntech's last 20-F report, for 2011, recorded accumulated write-downs of US\$126m against MSK, and a US\$14.1m write-down against CSG, which declared bankruptcy in 2011. A Suntech interviewee stated that total thin-film losses, across CSG and production facilities the firm set up in China, were around US\$100m. S8, 24 September 2012.

<sup>308</sup> The bonds were sold in tranches of US\$500m in February 2007 and US\$575m in March 2008.

Investment choices beyond basic capacity expansion, however, were deeply flawed. In addition to losses on unproven technologies, Suntech miscalculated badly during the industry's silicon feedstock shortage of 2004-08. Shi did not consider that Chinese firms might cut the production cost of silicon feedstock. As noted earlier, Suntech lost around US\$250m in minority investments in silicon producers undertaken to ensure supplies when feedstock was scarce. Most of the firms were bankrupted when GCL mastered hydrochlorination technology and combined this with unprecedented economies of scale (see case study). Shi not only backed the wrong firms, he locked Suntech into expensive long-term, fixed-price contracts in the belief that China could not become a low-cost silicon producer. The largest contract was a US\$6bn, 10-year 'take or pay' agreement with US-based MEMC Electronic Materials in July 2006; in 2011, Suntech compensated MEMC US\$120m to terminate the agreement.<sup>309</sup>

Despite the missteps, Suntech carried less debt than peers LDK and Yingli, and might have survived if its early strategic move into project development had been successful. A comparison with the leading multi-crystalline photovoltaic firm in the US, SunPower, shows that Suntech's operating margins in 2009-10 were superior to the American firm's. More important, because Suntech integrated forward into international project development before any other Chinese manufacturer, beginning 2006-7, the firm was able to report net margins higher than operating margins in 2010 as it booked US\$251m of investment gains from solar

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<sup>309</sup> Recorded in Suntech's 2011 20-F statement.

projects (Table 52).<sup>310</sup> SunPower began to book gains the same year from its move into domestic US project development work and leasing. The difference was that Suntech's early moves into project development in Japan, the US and Europe stretched its management capabilities too far, too soon.

**Table 52. Suntech, SunPower and First Solar operating and net margins, 2008-2015. %**

	2008	2009	2010	2011	2012	2013	2014	2015
Suntech operating margin*	9.5	10.3	6.8	-20.5	na	na	na	na
Suntech net margin*	4.6	5.1	8.2	-32.4	na	na	na	na
SunPower operating margin	10.7	4.1	6.3	-22.5	-11.9	6.3	8.3	-13.1
SunPower net margin	6.4	2.2	8.05	-26.1	-14.6	3.8	8.1	-11.9

\*2011 was the last year that Suntech filed annual financial statements.

Sources: company financial statements

Although Suntech's US\$300m acquisition of MSK Corp. in Japan in 2006 was principally motivated by technology targets, it also brought a national distribution network and the basis for a growing residential and commercial solar installation business. However, the integration of MSK, including the cultural challenges of Chinese and Japanese workforces operating together, was fraught. Suntech was unable to develop a downstream business in Japan and had to write off the MSK investment (Li, 2013).

In the US, Suntech's 2008 move into project development via its Gemini Solar Development joint venture encountered complaints from domestic developers which it supplied with modules that Suntech was creating

<sup>310</sup> Suntech 20-F, 2010. The figure is shown under 'equity in net earnings of affiliates' and relates to investment profits on projects of the Global Solar Fund. Suntech reported that it shipped US\$313m of modules to its own projects in 2009 and 2010.

‘channel conflict’ – in other words, that Suntech was competing with them. The firms threatened to buy their modules from other suppliers. Although the notion of channel conflict would disappear as more manufacturers entered the project development business, a Suntech manager stated that at this early stage the firm was sufficiently concerned to scale back its US ambitions.<sup>311</sup>

In Europe, there were fewer objections from developers. However, Suntech was unable to find an equity partner for its Global Solar Fund (GSF) project business. The former Spain sales manager of Suntech, Javier Romero, raised 10 percent of the equity for GSF, Shi Zhengrong invested 10 percent personally, and Suntech held 80 percent, much more than balance sheet prudence recommended. GSF was then undermined by two problems. First, GSF was indicted over a series of solar farm investments in southern Italy, accused of circumventing requisite project approvals.<sup>312</sup> Second, German government bonds pledged by GSF manager Romero as collateral for a Euro560m loan from China Development Bank for Italian projects turned out to be fake. Suntech alleged that Romero defrauded GSF and launched legal proceedings, which were never concluded.<sup>313</sup>

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<sup>311</sup> S3, 11 December 2012.

<sup>312</sup> The 20MW of projects were located in the province of Puglia. The main accusations were that GSF managers illegally declared five larger projects as a series of 1MW projects in order to qualify for expedited approval, and that construction work was declared finished before it was in order to secure full government subsidies. See Steve Scherer and Stephen Jewkes, ‘China’s fraud-hit Suntech strikes more trouble in Italy’, Reuters, 29 August 2012.

<sup>313</sup> The German bonds were pledged by GSF to Suntech, which in turn guaranteed the CDB loan. When the bonds were shown to be fake, Suntech had to restate its balance sheet to show increased net liabilities. The further result of the legal action was that Suntech’s interest in GSF became unsaleable when it tried to raise funds to make a US\$541m bond repayment due in March 2013. Ibid. Also, S3, 11 December 2012; S8, 24 September 2012; S10, 5 June 2013.

The demise of Suntech was a murky affair. It was not explained why management thought Javier Romero would be able to borrow hundreds of millions of euros of bonds for use as a guarantee with Suntech, or why it took two years to realise the bonds were fake. Separately, Shi Zhengrong was accused of profiting unfairly, and misleading shareholders, over transactions involving Suntech's investments in silicon feedstock and other businesses.<sup>314</sup>

Nonetheless, it is indisputable that Suntech was the leader in China in recognising the need to develop downstream project management capabilities in order to raise margins as solar manufacturing oversupply increased. This was the impulse to dynamic capabilities. The challenges of building project origination and execution capabilities overseas without experience in China, however, proved too much for what was then China's leading photovoltaics firm.

## **5.6. Case study: Canadian Solar**

Canadian Solar was the most successful Chinese photovoltaic firm in working around the constraint of not having a domestic Chinese market in which to hone downstream skills. It launched directly into international project development and, like Envision, with some success. However, Canadian Solar could not make project development as large a share of its business as US rivals, and did not participate in more innovative businesses like residential leasing in foreign markets.

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<sup>314</sup> Angus Grigg, 'Shi flew too close to the sun', *The Australian Financial Review*, 28 March 2013.

A senior Canadian Solar manager described how, in 2001, founder Shawn Qu was working for the solar subsidiary of Automation Tooling Systems (ATS) in Canada. ATS was approached by Volkswagen's China unit with a request for photovoltaic chargers to maintain battery levels in stored Jetta model cars, which experienced higher than normal idle leakage when held for delivery in factory car parks. The Canadian firm was uninterested in the order, however Qu convinced management to back him in setting up a small China manufacturing line with Volkswagen as its anchor customer. Locating its earliest production in Changsu in Jiangsu province, the Chinese name the business took was a homonym of ATS (*a te si* / 阿特斯), although always known as Canadian Solar in English. After US\$3m turnover in 2002, the firm was paid a further US\$4m by Volkswagen in 2003, as well as US\$5m for a home lighting products sold to China's government-subsidised rural off-grid market.<sup>315</sup>

In 2004, Canadian Solar began to export to Germany. In 2005, as exports grew, Qu secured US\$13m venture capital investment in Hong Kong and Japan, allowing Canadian Solar to expand capacity and position itself for a November 2006 Nasdaq IPO, raising US\$116m. The following years were characterised by steady expansion and clear decisions to neither invest in silicon feedstock production, nor enter long-term contracts for silicon supplies in what Qu regarded as a temporary bubble. In 2007-9, Canadian's gross margins were depressed compared with its peers (Table 48) as it paid high spot prices for silicon feedstock. However, when prices fell, the firm prospered. Based on steady expansion and a

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<sup>315</sup> S2, 15 October 2013. ATS provided used solar cell and module production equipment to Canadian Solar and subsequently exchanged this for equity.



narrow focus on cell and module production, by 2010 Canadian Solar was a global Top 10 photovoltaic supplier (Table 45).

The Canadian Solar manager described how, in 2009, as silicon, wafer, cell and module prices fell, Qu set up a solar project development team. In doing so he focused on the only non-Chinese market he knew: Canada. This coincided with the government of Ontario's decision to build utility-scale solar plants. Emphasising the 'Canadian' side of its identity, Canadian Solar won a series of tenders, in some cases assisted by its ability to secure CDB loans.<sup>316</sup> Canadian Solar also started an EPC business in Canada in 2010 and entered a majority-controlled joint venture with Canada's largest existing solar project developer, SkyPower, in April 2012. From Canada, Qu expanded into the US. By 2013, the Canadian Solar interviewee noted, the firm had an 800MW pipeline of north American projects.<sup>317</sup> The approach was considerably more conservative than Suntech's near-simultaneous efforts to build businesses in Japan, the US and Europe – all places in which Shi Zhengrong had never lived.

**Table 53. Canadian Solar cumulative solar plant completions, 2012-2017. MW**

2012	2013	2014	2015	2016	2017E
81	262	628	1,196	2,536	3,586

Source: company reports

Canadian Solar could not, however, build a project development business as fast or as profitably as the leading US firm, First Solar, in the

<sup>316</sup> For example, CDB helped to finance a group of nine solar projects, totalling 76MW, developed by Canadian Solar and sold to Canadian energy company TransCanada in 2012 and 2013.

<sup>317</sup> S2, 15 October 2013.

United States. By 2013, First Solar was constructing more than 1GW of solar plants each year. In March 2015, Canadian Solar bought Sharp's US solar project business, Recurrent Energy, for US\$261m and continued to expand into new markets, including the UK, Japan and Brazil. By the end of 2016, Canadian Solar completed more than 2.5GW of solar plants and had another 2GW in late-stage development.<sup>318</sup>

**Table 54. Canadian Solar and First Solar: project development and other service revenues as a share of total revenues, 2013-2015.**

	2013	2014	2015
First Solar	65%	67%	61%
Canadian Solar	22%	44%	31%

Source: company reports

The challenge for Canadian Solar, as for other manufacturers engaged in project development, was that the market became increasingly crowded. Utility firms with lower costs of capital entered, and margins fell. Canadian Solar's gross margins for EPC and project development reduced from 27.8 per cent in 2013 to 23.2 percent in 2014 and 20.5 percent in 2015. Nonetheless, the firm re-committed to its project development strategy, becoming an owner-operator of some projects and a seller of others. At the end of 2016, Canadian Solar held 1,196MW of solar projects as an independent power producer (IPP), a portfolio it valued at US\$1.6bn.<sup>319</sup> The firm was unique among Chinese photovoltaics companies in its exposure to international project development.

<sup>318</sup> The 2.5GW of completed plants included those undertaken by Recurrent Energy.

<sup>319</sup> The major components of the portfolio were US (808MW), China (198MW), UK (125MW), and Japan (60MW); the Canadian plants had been sold.

From 2016, the Canadian Solar manager stated, the slowly maturing Chinese project development market became of increasing interest. Early experience with Golden Sun projects saw the firm unable to connect some projects to the grid, faced by long subsidy payment delays, and unable to find buyers.<sup>320</sup> In 2016 and early 2017, however, Canadian Solar was able to sell almost 100MW of recently completed China projects to Shenzhen Energy Group, a private buyer. At the end of 2016, China became Canadian Solar's equal biggest project market, along with the US, with 400MW under construction in each country. Half the projects in China were under the NEA's Top Runner programme.

Strikingly, Canadian Solar was the most parsimonious of the big Chinese firms in R&D spending (Table 55, Table 56). (The firm received no Chinese government subsidies to support R&D.) In a sub-sector where differentiation and higher margins were particularly difficult to achieve through manufacturing capabilities, Canadian Solar concentrated strategy on its dynamic capabilities for forward integration into solar farm development in international markets. The firm outperformed all Chinese peers in this respect. However, it could not, in the absence of domestic experience, match international competitors operating in their home markets.

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<sup>320</sup> S2, 15 October 2013.

**Table 55. R&D expenditure of China's four largest mid-stream photovoltaics companies, 2015. US\$m. Rank by 2015 output in () brackets**

Trina (1)	Jinko (2)	Canadian Solar (3)	JA Solar (4)
34.1	22.2	17.1	23

Sources: company reports

**Table 56. R&D expenditure of leading Chinese mid-stream photovoltaics companies as a share of revenues, 2007-2015. %**

	2007	2008	2009	2010	2011	2012	2013	2014	2015
Yingli	0.43	0.76	2.54	1.1	1.94	1.65	2.15	4.44	3.98
Trina	0.93	0.37	0.64	1	2.15	2.04	1.12	0.97	1.12
JA Solar	0.16	0.52	1.19	0.54	0.64	1.29	1.23	1.24	1.10
Jinko	0.01	0.02	0.38	0.68	0.41	1.44	0.93	1.09	0.93
Canadian Solar	0.33	0.26	0.5	0.46	1.04	1	0.71	0.41	0.49

Sources: company reports

## 5.7. Case Study: GCL Poly

GCL Poly became the most successful firm in China's solar industry without any photovoltaics experience. The firm used high-speed project management and construction techniques to rush through silicon feedstock capacity expansions while prices were high, building manufacturing capabilities as it did so. Elevated profit margins paid for the learning process, which was facilitated by IP acquired illegally from MOST's silicon technology upgrading programme. GCL Poly achieved unprecedented scale of production, becoming the world's largest silicon feedstock manufacturer.

GCL was founded by Zhu Gongshan, a native of Yancheng city in Jiangsu province. A senior GCL manager explained that Zhu's father was a People's Liberation Army (PLA) officer and his first job was in county-level government in Yancheng. Zhu later worked for a state firm in

Shanghai that supplied equipment to power stations. When private investment in utilities was permitted in the mid-1990s, Zhu organised an investment group for a small, high-efficiency co-generation plant – producing both electricity and steam for heating – near Suzhou. The project ran out of cash during the Asian financial crisis in 1997-8, until Zhu secured Poly (Hong Kong) Investments, a subsidiary of PLA arms trading company Poly Group, as a partner. Zhu and Poly (Hong Kong) Investments went on to develop 18 power plants. The key, the manager stressed, in a period of power shortages in the early 2000s, was to obtain approvals for and build the (typically 30MW) plants very fast. Working in Jiangsu and Zhejiang provinces, GCL became a master. The business was listed in Hong Kong in 2007; it was named GCL Poly because of the connection to the PLA company.<sup>321</sup>

GCL interviewees told two different stories about Zhu Gongshan's decision to move into the manufacture of silicon feedstock. One was that it was officials from the Jiangsu branch of the state grid who promoted the idea and co-invested in a private capacity, motivated in part by the Jiangsu government's strategic commitment to make the province the centre of the Chinese photovoltaic industry.<sup>322</sup> Another interviewee insisted it was other Jiangsu-based, mid-stream solar entrepreneurs who convinced Zhu to invest in silicon feedstock manufacturing, and that the early co-investors were other IPPs and two

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<sup>321</sup> S13, 10 June 2010. Erroneously, it is widely believed that GCL Poly refers to 'polysilicon'. The 30MW co-generation power plants were built for around Rmb240m each; the electricity required a PPA with the provincial grid; the steam was sold privately to commercial users. The interviewee stated that managers from local grid companies were also brought in as minority investors to expedite the development process.

<sup>322</sup> S13, 10 June 2010. The interviewee said that managers from the Jiangsu grid invested in the silicon project until they were bought out in 2008.

downstream solar firms.<sup>323</sup> Whatever the truth, interviewees concurred that GCL spent much of 2005 researching the silicon manufacturing business and in March 2006 Zhu incorporated Jiangsu Zhongneng as his investment vehicle.

A technical specialist at GCL said that Zhu's approach to the technology learning curve was to build a small, 1,500 tonne per annum production line first (costing around US\$200m), and build it fast. With silicon feedstock prices rising, international suppliers like Germany's Wacker Chemie and Hemlock in the US would add capacity; but it would take two to three years. The key was to get ahead of them. Zhu's project team initially sourced the reactors in which crystalline silicon is grown on rods from MSA, a German firm, by identifying the Munich-based company as the supplier to Wacker.<sup>324</sup> Equipment for the purification of trichlorosilane (TCS), which is pumped into the reactors, was sourced in China. The purification process was well below the quality standard multinationals achieved, but good enough for the contemporary solar industry.<sup>325</sup>

In order to acquire chemical process experience, GCL recruited Gan Jufu, an engineer who had helped set up a new silicon feedstock production line at Leshan Xinguang Silicon in Sichuan province, one of the two state-owned firms supported by MOST in 2004-6. Jiangsu Zhongneng was subsequently sued for intellectual property theft, but not before the

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<sup>323</sup> S14, 16 October 2013. This interviewee said that two provincial IPPs and JA Solar and Solarfun were early equity investors. He said that Zhu also knew the founders of Canadian Solar, Trina, Suntech, and Yingli before entering the silicon business.

<sup>324</sup> S15, 6 August 2010.

<sup>325</sup> S16, 31 July 2010.

firm began to master the production process with the help of Gan, who was alleged in court to have brought 30 megabytes of technical information and blueprints with him. Gan was handed a five-year prison sentence in 2008. Jiangsu Zhongneng and GCL, assiduously defended by the Jiangsu provincial government, faced no sanctions.<sup>326</sup>

Jiangsu Zhongneng manufactured its first multi-crystalline silicon in September 2007 and began commercial production in October, just six months after Xinguang. A technical specialist at the firm said the unit cost was initially three times that of multinational competitors, at around US\$85/kg. However, the spot price of solar silicon feedstock was US\$380/kg.<sup>327</sup> A second 1,500-tonne production line was already half-built.

Compared with other Chinese investors, noted another technical manager at GCL, Zhu Gongshan took an additional technological risk. He was the only investor to use hydrochlorination in the chemical process, an incremental, but significant modification of the 50-year-old Siemens process that was becoming popular with global chemicals companies.<sup>328</sup> Hydrochlorination cut out one energy-intensive, and hence expensive,

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<sup>326</sup> According to Chinese press reports, Gan Jufu was recruited to a shell company, Shanghai Sichuang Energy, not directly to Jiangsu Zhongneng. The most detailed press report was in Sichuan's *Leshan Daily*, 23 March 2008. In 2007 and 2008, there was a series of high level meetings between the Sichuan and Jiangsu provincial governments concerning the case; the meetings were reported in the F-1 filing for a NYSE listing of Jiangsu Zhongneng, submitted to the SEC 18 July 2008, that was abandoned during the global financial crisis. An interviewee at GCL would only say of the case: 'Now we do everything ourselves.' S18, 16 October 2013.

<sup>327</sup> S15, 6 August 2010.

<sup>328</sup> An interviewee closely involved with hydrochlorination at GCL explained that while the modification was relatively new, the hydrochlorination process itself was long established and 'largely not patent protected'. GCL hired specialist personnel from Chinese universities to support its core project team in implementing the hydrochlorination. S17, 16 August 2010.

step in the traditional manufacturing process; it could save as much as US\$7/kg in production cost.<sup>329</sup> The downside was that hydrochlorination had a smaller global base of experience; it required greater pressure, and therefore increased safety risks and monitoring requirements. Zhu Gongshan's team implemented hydrochlorination successfully. With the core, contemporary chemical process mastered – albeit at a high unit cost – in late 2007 Jiangsu Zhongneng began to construct a third, much larger 15,000-tonne per annum line. It underwent test production in December 2008.

A consultant to several Chinese silicon feedstock producers stated that operational experience was the key competitive advantage in terms of manufacturing capabilities. Jiangsu Zhongneng, which was absorbed into the listed GCL business in June 2009, began to build operational experience before its Chinese competitors. The firm also acquired deeper experience because, unlike firms like LDK and Yingli, it did not outsource plant construction (LDK to US EPC contractor Fluor, Yingli to South Korean contractors). GCL used its power station project team to design, procure and construct its production lines, sometimes sourcing imported equipment and sometimes Chinese equipment. It was only in 2009, after GCL conquered the basic production process and brought production costs down to US\$45/kg that it built a substantial team of foreign consultants in order to incrementally improve rather than establish its production.<sup>330</sup>

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<sup>329</sup> S6, 26 September 2013.

<sup>330</sup> S6, 26 September 2013. A GCL executive said that in 2008-9 the firm used headhunters in the US to find key consultants/foreign employees as well as hiring specialist from equipment suppliers. S18, 16 October 2013.



In 2009, GCL hired Russ Hamilton, formerly a senior executive at Norway's Renewable Energy Corporation (REC), as Chief Technical Officer, and around 20 other foreign technical specialists. GCL interviewees described how this team contracted with equipment maker GT Solar in the US for a programme to improve GCL's hydrochlorination performance, and purchased larger reactors for further expansion, as well as the first imported trichlorosilane (TCS) purification equipment used by GCL, from the US firm.<sup>331</sup> The quality of GCL's silicon feedstock output improved and production costs fell below levels achieved by other Chinese firms. A major vote of confidence and support came in December 2009 when China Investment Corp., the country's sovereign wealth fund, bought 20 percent of GCL for US\$710m. By the end of 2010, the firm stated that its cost of production was US\$28/kg, compared with US\$25/kg at cost leaders Wacker and Hemlock. GCL produced 16,000 tonnes of silicon feedstock in 2010, more than half the total output in China.<sup>332</sup>

By mid-2012, GCL increased manufacturing capacity to 65,000 tonnes. As in other manufacturing businesses in China, as GCL added capacity the capital cost of that capacity declined rapidly. Where a silicon feedstock production line required almost US\$100/kg when GCL first invested in 2006, the price was US\$45/kg by 2012.<sup>333</sup> Nonetheless, plummeting silicon prices in 2012 saw GCL post a substantial loss as the firm's capacity to cut production costs failed to keep pace with spot prices in a market awash with overcapacity (Table 57). In 2013-14 GCL

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<sup>331</sup> S16, 31 July 2010; S17, 16 August 2010; S19, 6 August 2010; S20, 27 July 2010.

<sup>332</sup> GCL Poly quarterly reports, Q3, Q4 2010; S17, 16 August 2010.

<sup>333</sup> S6, 26 September 2013.

also failed to scale up low-cost production using a much newer chemical process, fluidised bed reactor (FBR) technology.<sup>334</sup>

GCL entered a period of consolidation, during which costs using the traditional Siemens process, with hydrochlorination, were driven down to US\$12/kg by 2016. In 2016, GCL paid US\$150m to acquire assets of former US manufacturer MEMC, including a new South Korean FBR joint venture with Samsung, as well as related MEMC patents.<sup>335</sup> By the end of 2016, the firm's silicon production capacity was 70,000 tonnes per annum.

**Table 57. Quarterly solar grade silicon feedstock prices, Q1 2011 to Q4 2013. US\$/kg**

Q1 2011	Q2 2011	Q3 2011	Q4 2011	Q1 2012	Q2 2012	Q3 2012	Q4 2012	Q1 2013	Q2 2013	Q3 2013	Q4 2013
70	63	52	37	31	26	22	17	18	17	18	18

Source: Yonts (2013)

### Forward integration

From 2010, GCL began to manufacture silicon wafers and quickly moved to processing almost all its silicon feedstock into wafers. In 2016, wafer output reached 17.3GW, with only 9,950 of 69,000 tonnes of silicon production sold to third parties. From 2014, GCL also moved opportunistically into cell and module production, taking a minority interest in and expanding production at in-default Chaori Solar, renamed

<sup>334</sup> S21, 25 September 2014, and company reports. GCL promised to bring 20,000 tonnes of FBR production on line by the end of 2014 with capital cost of US\$13/kg and production cost around US\$10/kg.

<sup>335</sup> MEMC changed its name to SunEdison in 2013; SunEdison filed for bankruptcy protection in April 2016.

GCL System Integration Technology (GCLSIT). In 2016, GCLSIT had annual module production capacity of 4GW.<sup>336</sup>

A senior manager described how, like downstream photovoltaics manufacturers, GCL responded to falling cell and module prices from 2009 by investing in project development. Prior to the investment in GCLSIT in 2014, GCL's strategy was to work at the extreme ends of the value chain: as a producer of silicon feedstock and wafers, and as a project developer. In 2010, before China had developed a significant domestic market, GCL opened a US project development office in San Francisco and entered a 50:50 joint venture with diversified US developer NRG Energy.<sup>337</sup> However, GCL struggled to build a portfolio of profitable investments, either directly or through the joint venture. In 2012, the firm sold out 140MW of US projects it so far developed. Like most Chinese firms, GCL failed to leap directly into international project development without domestic experience.

From late 2013, GCL refocused on the expanding domestic market. A small, loss-making Hong Kong-listed firm, acquired through a reverse takeover, became the vehicle for mainland project development. GCL New Energy (GCLNE) was 62 percent controlled by GCL Poly. By the first quarter of 2015, GCLNE developed or purchased 772MW of projects in China. By early 2016, this had expanded to 2.7GW, and by late 2016 3.5GW. GCLNE became the second biggest Chinese solar developer. The business was an early winner of Top Runner tenders. Nonetheless, it

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<sup>336</sup> Chaori Solar was the first Chinese company since 1949 to default on a domestic bond, in March 2014. GCLSIT is controlled by private interests of Zhu Gongshan's family, which hold more than 50 percent of the equity; the firm is listed on the Shenzhen stock exchange. GCL Poly annual report 2016.

<sup>337</sup> S13, 10 June 2010. The joint venture was named Sunora Energy Solutions.

remained unclear how successful a business GCLNE was. The firm had not sold projects and so margins were unclear. GCLNE targeted 1-1.5GW of project sales in 2017. Prior to 2017, the firm's financial statements were those of a highly-indebted business with negative or negligible returns (Table 58).

**Table 58. GCL New Energy return on assets and debt-equity ratio, 2014-16. %**

	2014	2015	2016
Return on assets	-1.14	-0.10	0.40
Net debt/equity	0.68	3.35	3.72

Sources: company financial statements

The core GCL business, however, had established itself as both world-scale and comparable to leading multinationals in its profit margins. As noted, GCL was the world's largest silicon feedstock manufacturer from 2012, a position it retained (Table 59). GCL's profit margins bounced around as the firm grew fast, and temporarily collapsed in 2012-13. But overall, GCL's margins were comparable to those of the number two global producer, and the only multinational chemicals firm to publish financial results reflecting the performance of a silicon feedstock business, Germany's Wacker (Table 60).<sup>338</sup>

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<sup>338</sup> OCI is a much more diversified business than Wacker, while Hemlock Semiconductor Group comprises several joint ventures between Dow Chemical Company, Corning Inc. and Shin-Etsu Handotai that do not disclose detailed financial information by product.

**Table 59. Top four global silicon feedstock producers, 2015.**

Company	Country of origin	Output (tonnes)
GCL	China	73,000
Wacker	Germany	51,000
OCI	South Korea	44,000
Hemlock	United States	26,000

Source: IHS Insight

**Table 60. GCL and Wacker gross, operating and net margins, 2008-2015. %**

	2008	2009	2010	2011	2012	2013	2014	2015
GCL gross margin	72.55	30.15	36.87	33.19	7.83	11.91	23.12	26.54
GCL operating margin	70.13	22.95	29.97	28.71	1.53	7.65	18.47	22.1
GCL net margin	3.56	-4.04	21.78	16.76	-15.73	-2.6	5.25	11.14
Wacker gross margin	27.6	22.7	28.4	23.7	17.7	14.8	17.5	21.3
Wacker operating margin	27.64	22.68	28.35	23.68	17.68	14.81	17.49	21.32
Wacker net margin	10.22	-2	10.33	7.18	2.43	0.06	4.22	4.66

Sources: company financial statements.

The risk to GCL was that without stronger dynamic capabilities its strategy was too easy to replicate. This is what appeared to be happening in 2014-16 as a Xi'an-based firm, Longi Green Energy (Longi), challenged GCL. Longi massively scaled up the extrusion process that creates monocrystalline ingots from silicon feedstock (as opposed to the casting process that creates multi-crystalline ingots). This reduced the traditional price differential between mono-crystalline wafers with higher solar conversion rates and multi-crystalline wafers. In 2016, Longi extruded enough mono-crystalline silicon to make 6.4GW of wafers. The firm targeted 12GW of capacity by the end of 2017 and 19GW (on par with GCL's multi-crystalline wafer capacity in 2017) in 2019.<sup>339</sup>

<sup>339</sup> See [https://www.pv-magazine.com/2016/01/29/china-longi-invests-456m-in-3-gw-mono-silicon-fab-in-ningxia\\_100022997/](https://www.pv-magazine.com/2016/01/29/china-longi-invests-456m-in-3-gw-mono-silicon-fab-in-ningxia_100022997/) and <http://celltech.solarenergyevents.com/2017/04/01/longi-is-the-fastest-growing-pv-manufacturer-in-the-industry/>. Longi accounted for an estimated 42 percent of

Like GCL, Longi made opportunistic acquisitions of cell and module manufacturing capacity. The global market share of mono-crystalline modules increased to 29 percent in 2017.<sup>340</sup> Longi's success was based on scale, speed of capacity addition, and cost reduction in manufacturing – the GCL formula. GCL's capacity to defend against Longi, however, will depend on its success in adding capabilities in forward integration and services. Manufacturing capabilities alone provided only fleeting advantage.

## **5.8. Discussion**

With respect to the analytical framework of this thesis, the photovoltaic sub-sector presents a scenario in which the developmental state initially determined not to support the building of manufacturing capabilities. The developmental state denied demand-side support in the form of a subsidised domestic market. However, local governments, a semi-reformed banking system, and a MOST bureaucracy that was not aligned with NDRC objectives, provided considerable supply-side support. In this context, an Open National Innovation System (Fu, 2015a, Fu and Zhang, 2011, Lema and Lema, 2012) allowed private firms, sometimes led by returnee technical specialists, to develop considerable scale in the sub-sector based on export demand.

MOST's role in unblocking the key technological bottleneck to global cost leadership in photovoltaics emphasised the continuing importance

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global mono-crystalline wafer production in 2016. When GCL bought FBR assets from bankrupt SunEdison in 2016, Longi acquired its Malaysian mono wafer cutting operation. Accessed 7 June 2017.

<sup>340</sup> IHS Markit data.

of the developmental state in the acquisition of manufacturing capabilities. The learning of contemporary global silicon feedstock production technology was an archetypal state-led S&T and R&D exercise and essential to the development of a complete chain of manufacturing capabilities. However, whereas implementation of new silicon feedstock production techniques was planned to be implemented via state production units, in practice it was a private firm that achieved competitive leadership.

GCL proved not only ruthless in obtaining state-developed manufacturing IP, but also unbeatable in the economies of speed it brought to bear in scaling up silicon feedstock production. The case study highlighted that economies of speed in capacity construction are a powerful complement to the developmental state's orchestration of manufacturing capabilities. If private firms are better able to deliver those economies, then where speed to the commissioning of production is an important variable they have a clear advantage over state firms.

With the full range of manufacturing capabilities in place through the value chain, the photovoltaics sub-sector experienced similar, large reductions in unit costs that occurred in the thermal and wind sub-sectors. However, despite the developmental state's replication of the same conditions for a transition to competition through entrepreneurial dynamic capabilities that existed in the wind sub-sector – openness to firms of all ownership types, devolution of technology bargaining to the firm level, and an environment regulated by laws not fiat – strategically dominant firms did not quickly emerge. Once the benefits of GCL's

economies of speed in plant construction were exhausted, its efforts at forward integration and the building of high-margin service businesses were no more successful than those of other Chinese firms.

From the perspective of industrial organisation theory, the failure of firms defined by advanced dynamic capabilities to emerge in the photovoltaics sub-sector could be attributed to lower barriers to entry (Porter, 1998 (1980)) versus the wind sub-sector. However, the case studies suggested a different interpretation. In the photovoltaics sub-sector, the transition to a competitive environment defined by dynamic capabilities among mid- and down-stream firms appeared to be delayed by three factors relating to the status of the domestic market.

The first was the absence of a significant domestic solar market prior to the establishment of a feed-in tariff in 2011. Consistent with Linder's (1961) 'home market hypothesis', Chinese firms in the photovoltaics sub-sector struggled to integrate forwards into solar farm development in foreign countries without prior domestic experience. Although Canadian Solar made more progress than other Chinese-led firms, it could not keep pace with domestic north American firms. The second factor was that Chinese industrial planners failed to centralise the approval of utility-scale solar farms in the manner they did with wind farms, allowing local governments to approve project winners for reasons of local protectionism rather than price and quality. The third factor was that the retail market for Distributed Generation solar power in China was too immature to allow the best firms to differentiate themselves by quickly building substantial, high-margin DG businesses in



the manner that occurred in developed countries. Each of these factors meant that firms with superior strategic capabilities were unable to differentiate themselves and dominate the sub-sector.

In the photovoltaics sub-sector, the developmental state has not yet created conditions for a transition to competition in which capabilities beyond manufacturing skills are paramount. However, the situation is changing. The creation of a substantial domestic solar market, moves to centralise control of utility-scale projects, and the gradual development of conditions for a large-scale DG market, mean that dynamic capabilities in adjusting to these opportunities are more likely to define a small number of dominant businesses going forward. At the same time, the experience in the photovoltaics sector indicates that the developmental state should carefully analyse how end-user markets will evolve when framing industrial policy. Domestic markets must reward firms with dynamic vertical scope and the strongest strategic capabilities as part of the transition that produces world-class firms.

## **Chapter 6**

### **Findings, limitations and scope for further research**

An overarching conclusion from the empirics of this thesis is that, in the transition from a first stage of development based on the pursuit of narrow manufacturing capabilities to a second stage requiring incipient dynamic capabilities in China's electricity-generating equipment sector, an advantage for developmental-state capabilities gradually gave way to an advantage for entrepreneurial capabilities within the firm. However, the adjustment was messy and difficult for the state -- as the key setter of institutional arrangements -- to manage.

State policy had to adjust in the electricity-generating equipment sector, decentralising economic power to entrepreneurs who competed not just in terms of narrow manufacturing capabilities that state industrial policy nurtured, but in terms of strategy -- including strategic flexibility, marketing, and services. These were dimensions in which NDRC and NEA planners were unable to dictate reliable choices from the top, down.

As Doner and Ramsay observed in a longitudinal study of Thai industry: 'institutions favourable for one stage of economic growth are less suitable for a subsequent stage'; the authors referred to the transitional challenge of 'growing into trouble' (2004:97).

In China, the policies that produced the earliest learning results in the thermal sub-sector grew into trouble as the absence of entrepreneurial, disruptive, private-sector competition constrained the competitive

challenge to multinationals.<sup>341</sup> Change was difficult in part because history and path dependencies were powerful, in part because changing policy created new problems. In the thermal sub-sector, path dependency and institutional stasis took hold; traditional activity silos were maintained in the value chain and there was no opening to private firms. In the wind and photovoltaics sub-sectors, when private and hybrid firms were allowed to compete, some hybrid, state-private firms found new avenues to abuse state subsidy. In the wind sub-sector, Sinovel combined majority private ownership with an apparent inside track at the NDRC, access to state manufacturing assets, and access to financing channels normally associated with state projects, creating a new imbalance between potential private sector gain and state sector risk. Similar tendencies were apparent in the solar sector at LDK and Yingli.

Nor did the state's moves in the wind and solar sectors to use laws and regulations, rather than *fiat*, to establish the competitive playing field produce a smooth transition to decentralised markets. Part of the difficulty was a partially-reformed financial system where banks did not extend and price credit in a disinterested fashion even if, as Lardy (2014) demonstrated, the aggregate trend was slowly in that direction. In the solar sector, a semi-reformed financial system saw foreign private equity

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<sup>341</sup> At the macro-economic level, the most successful long-run development stories appear to have been ones that involved successful *transitions*, including the transition away from state-led infant-industry policy towards greater reliance on decentralised markets and freer, regulated, competition. At least this is the conclusion of empirical studies of slowdown and economic shocks in the post-Second World War European economy (Blanchard and Wolfers, 2000, Van Ark et al., 2008, Eichengreen, 2008, Krugman, 1994, Hayashi and Prescott, 2002, Aiyar et al., 2013). Too monolithic a stress on state-led learning (Amsden, 1989, Chang, 1994), as noted in Chapter 1, missed half the longitudinal story of successful development.

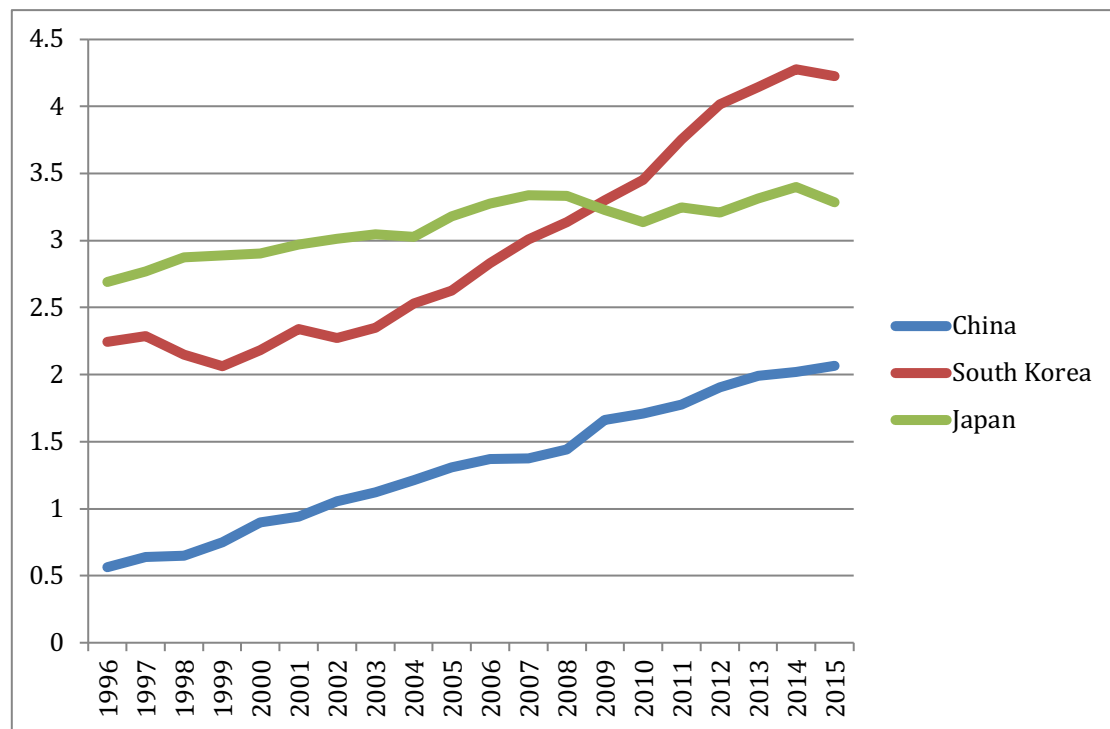
investors step in with bridging finance for offshore IPOs. State commercial banks, taking the IPOs as a signal of firms' commercial viability, then lent recklessly – and outside the NDRC's industrial policy agenda -- to photovoltaics businesses. When the sector faced crisis, central government had little choice but to bail out an industry it had not targeted for support.

Problems of an only partially market-driven financial system were compounded in China by a unique degree of political and fiscal decentralisation. Local governments pursued local industrial policies that conflicted with national industrial policy. In both the wind and solar sectors, the NDRC and the NEA recentralised control over project approvals in order to ensure fair competition and keep the objective of developing large, concentrated, globally competitive firms on track.

The one unchanging requirement for the state during the transition in the state-firm relationship in China's power equipment industry was the need for provision of state-funded R&D support. Indeed, as Amsden and Chu (2003) observed in Taiwan, the state's R&D and S&T support role became more important over time. In China, the budgets of programmes including 863 and 973, mediated by MOST, increased ahead of inflation across the longitudinal research period. Central government provided additional grants to support the opening of nationally-certified laboratories at favoured large firms. There was criticism that the Chinese education system was a drag on innovation (Abrami et al., 2014). However, studies of firm-level R&D revealed that companies continued to make solid technological progress (OECD,

2017). In 2015, China's public and private R&D expenditure as a share of GDP reached 2.1 percent, compared with 4.2 percent in South Korea, 3.3 percent in Japan, and an OECD average of 2.4 percent (Figure 8).<sup>342</sup>

**Figure 8. R&D expenditure (public and private) as a percentage of GDP.  
China, South Korea, Japan, 1996-2015**



Source: UNESCO Institute for Statistics

In sum, the transition from state-led to decentralised capability building was not one that typically involved straightforward trade-offs. Instead it was a matter of complex processes with multiple strands, of failed experiments and tipping points rather than smooth segues, and of powerful path dependencies that challenged government capacity to manage the shift away from state-led development, even when a clear

<sup>342</sup> See <http://www.oecd.org/sti/msti.htm> Accessed 26 June 2017.

commitment to this cause was present.<sup>343</sup> Infant-industry policies worked their magic in China, but they also brought a host of problems when the time came to transition to more entrepreneur-led development.

Despite the noise and confusion, the case studies in this thesis did point to a number of empirical regularities in transitions from developmental state-led to entrepreneurial firm-led economic catch-up. These findings result from addressing the three research questions set out at the start of this dissertation: 1. *What have been the common success strategies of firms transitioning from learning laggards to being globally competitive?* 2. *What have been the most successful developmental state policies that have facilitated this transition?* 3. *How have the most successful firm strategies and most successful developmental state policies evolved over time?*

In particular, five empirical regularities are highlighted in conclusion. The first two lend support to the analytical framework employed in this thesis. The next two highlight transitional themes from the case studies

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<sup>343</sup> The nature of the Chinese government's reform policy under the Xi Jinping administration was a subject of intense controversy at the time of writing, particularly with respect to ownership reform. The reform programme set out by Xi at the 18th Party Congress in November 2012, and refined at the subsequent Central Committee Third Plenum, promised the transformation of state enterprises into state-private enterprises, through investments from three sources: foreign investors, private Chinese firms, and employees. Competition was to be increased in oligopoly sectors including energy, telecommunications, and certain basic materials. Xi further asserted that China's 'managing government' would become a more arm's length 'service government'. However, the implications of these announcements became ambiguous as Xi and premier Li Keqiang subsequently made speeches emphasising the need to strengthen large state enterprises, without referencing ownership reforms. Other pronouncements by senior leaders followed this lead. In June 2017, for instance, Xiao Yaqing, Chairman of the State-owned Assets Supervision and Administration Commission (SASAC), wrote that China must 'firmly oppose' both 'privatisation' and 'de-nationalisation'. See Xiao Yaqing, 'Deepen reform of SOE state assets: make strong and excellent enterprises of a major power' (*Shenhua guoqi guozi gaige: zuoqiang zuo you daguo you qiye*), *Study Times (Xuexi Shibao)*, 16 June 2017. Available in Chinese at: <http://www.studytimes.cn/zydx/GCFT/2017-06-16/9723.htm> Accessed 15 June 2017.

that point to areas for further research. The fifth offers new evidence about a frequently remarked challenge under infant industry policy. Each of the empirical regularities has implications for developmental state policymaking, which are explored.

### **6.1. The nurturing of manufacturing capabilities**

The first set of empirical regularities concerns the acquisition of manufacturing capabilities in the early, developmental state-led period in each industry sub-sector. Three important related points are highlighted as follows:

*The most successful case study firms absorbed requisite technological capabilities for catch-up through a conservative, step-by-step learning approach. Attempts to make technological leaps failed. Firms competed for a long time through manufacturing scale and cost.*

In the thermal sub-sector, step-by-step learning accelerated over three decades from a very slow to a very quick pace, peaking under huge production volumes in 2003-6, when super-critical and USC technology were mastered (Chapter 3:153pp). What was striking was the acceleration in the pace of learning once early learning steps had been completed. However, it was not possible to omit steps. The one learning failure occurred with Shanghai's 1992 Shidongkou super-critical project, after the firm attempted – at the behest of government planners – to make a technological leap into what was then an immature technology.

In the wind sub-sector, Goldwind demonstrated the merits of small, fast learning steps. When subsidies mushroomed, the firm did not rush to make bigger, more complex turbines, despite the pressure from NDRC technology metrics to do so. Goldwind learned steadily. The risk the firm took was with DDPM technology, however the technology was proven, and had undergone commercialisation at firms including Enercon and Vensys. DDPM technology required modification and scaling to larger turbine sizes, challenges that Goldwind was equipped for.

Envision's conclusions about how to develop manufacturing capabilities were strikingly similar to Goldwind's. The firm entered the market with a 1.5MW turbine when competitors were already producing larger ones, and only gradually scaled up production as it mastered lean manufacturing, lean logistics, and system integrator techniques.

In photovoltaics, GCL began with first one, and then a second, small, modified-Siemens-process crystalline silicon feedstock production line. The firm took on manageable technological challenges, but built new capacity extraordinarily fast. GCL was the first company in China to introduce hydrochlorination, however the technology was internationally well-established, and most IP was out of patent protection. Only after building core manufacturing capabilities and scaling up to much larger production lines did GCL hire foreign technicians to take the learning process further forward. Small, quick, incremental learning steps defined GCL's progress.



The leaps in the renewables sector were all failures. Mingyang, in the wind sub-sector, licensed technology for Super Compact Drive turbines for which there was not yet a prototype; this attempt to jump through the technological frontier was a failure. In photovoltaics, China's most technically gifted solar scientist-entrepreneur, Shi Zhengrong, came unstuck making large investments in unproven technologies for built-in photovoltaics (BIPV) and thin-film photovoltaics. GCL attempted to overtake global competition with a leap into FBR technology, albeit after the firm established a strong commercial position with mainstream technology. The leap was a failure, but by this time GCL had sufficient cashflows to persist in trying to commercialise large-scale FBR production; to this end it acquired facilities and IP from MEMC.

Yingli and LDK failed to recognise the need to learn, step-by-step, while making technological progress. The firms engaged foreign project management and EPC contractors to build turnkey silicon feedstock plants. They garnered far less technological understanding of the production process than GCL. Moreover, the foreign-managed turnkey plants were slower to complete than GCL's production lines, and Yingli and LDK were unable to take advantage of the spike in silicon feedstock prices to fund their learning processes. Yingli and LDK never recovered from this setback; when they did begin silicon production, their levels of operational experience and tacit knowledge were far behind GCL. The different firm-level approaches to learning are stylised in Figure 1.

**Figure 9. Manufacturing capabilities: small steps and mature technology, versus leaps with unproven technology and the use of turnkey plants**

Sub-sector	Small, incremental steps with mature technologies	Attempts to leap with uproven technologies and reliance on turnkey plants
<b>Thermal</b>	Shanghai, Harbin, Dongfang Westinghouse sub-critical; Japanese super-critical; Japanese / Siemens USC	Shanghai Shidongkou super-critical with unproven ABB technology*
<b>Wind</b>	Goldwind Repower geared turbines, Goldwind Vensys DDPM Envision geared turbines	Mingyang Aerodyn Super Compact Drive*
<b>Photovoltaics</b>	GCL crystalline silicon feedstock, Siemens process with hydrochlorination	Suntech BIPV and thin-film* GCL Fluidised Bed Reactor (FBR)* Yingli crystalline silicon feedstock, Siemens process ** LDK crystalline silicon feedstock, Siemens process **

\* Unproven, non-commercialised technology

\*\* Turnkey project

The learning experiences at the firm level were reflected in complementary empirical regularities in terms of the most successful developmental state policies that promoted acquisition of manufacturing capabilities. These are summarised as three key points.

*The most successful developmental state policies: focused on conservative, incremental learning steps within the technological frontier; coordinated vertical learning structures at the firm level; and, in the context of low excludability of imported IP, accelerated the diffusion of manufacturing capabilities by ensuring high levels of competition.*

Overall, Chinese industrial policy closely respected the step-by-step nature of technological learning within the firm. Policy planners set out road maps for different electricity-generating equipment sub-sectors, and selected targets within the technological frontier. The technological conservatism of Chinese planners was apparent in the early 1980s with the decision to license mature, established technology in the thermal sub-sector. In the cases of Harbin and Dongfang central government, and in the case of Shanghai local government, worked closely with firms to support vertical learning structures so that the state units acquired a complete range of manufacturing capabilities for turbine-generator sets and boilers. The most closely attentive, and successful, agency of technological development was Shanghai's local developmental state, consistent with Thun's (2006) findings in the automotive sector.

A risk-minimising approach to technology acquisition was still clearer in the renewables sector in the early 2000s with the decision to back the wind sub-sector but not the solar sub-sector. The unit price of wind power was lower; the risk of technological disruption was minimal; and international experience showed that domestic firms enjoyed natural advantages over international competitors.

Within the wind sub-sector, the state studiously facilitated Goldwind's step-by-step learning throughout the value chain. Goldwind learned 'before doing' (Pisano, 1996) for a decade as a state research unit and operator of wind farms when Chinese manufacturing capabilities were low. The provincial branch of MOST then provided grants to allow Goldwind to integrate backwards into turbine assembly and to support component localisation. As manufacturing capabilities increased, the NDRC/NEA were attentive to the need to keep technological standards rising. In 2011, the agencies recentralised wind farm project approvals to prevent local governments from favouring technologically-backward local wind turbine manufacturers.

In the photovoltaics sector, which had not been supported by national industrial policy, MOST stepped in pragmatically to fill out the sub-sector learning chain. MOST organised and funded a programme to import mature technology for silicon feedstock that was essential to reduce the private sector's dependency on imported inputs. Similar to the wind sub-sector, the NDRC/NEA subsequently intervened to keep technical standards steadily rising by introducing the Top Runner programme from 2015.

The one occasion in the thesis empirics where China's planners attempted a technological leap was the Shidongkou super-critical plant in 1992, at a time when the technology was not yet mature. The experience was a chastening one, and the pace of thermal technology acquisition slowed beyond what might have been possible with smaller learning steps. However, in the wake of Shidongkou's failure the

developmental state redoubled its research and testing work, identified Japanese technology that had been proven by 2002, and put the super-critical programme on a sound footing.

In addition to a successful, conservative approach to technology acquisition, the developmental state enforced the non-excludability of imported manufacturing technology in the earliest phase of capability building in the thermal sub-sector. This approach recognised that competition through technological differentiation would not occur for many years and instead focused the big three firms on absorbing Westinghouse IP that was made available to each of them. When technological differentiation did begin to occur in the 2000s, the NDRC and NEA paid close attention to structuring demand for electricity such that it rewarded the most technologically advanced manufacturers. Electricity from super-critical and USC plants was given higher tariffs and priority dispatch (Chapter 3:section 3.4.).

In the middle reaches of capability building, the state remained ambivalent about IP protection. Not only was GCL not meaningfully sanctioned for IP theft in 2006-7, the state endorsed the photovoltaics leader with a major equity investment in 2009. In an environment of still-weak intellectual property (IP) protection, the diffusion of renewables manufacturing capabilities was rapid. The experience was consistent with global IP rights history (Peng et al., 2017), and with experience in other East Asian FDCs (Chapter 1).

The strengthening of China's IP regime was very gradual, and from a low base (Yang, 2003, Chu et al., 2014).<sup>344</sup> Only in the 2010s did the NDRC/NEA become concerned by the persistence of cost-based, rather than technology differentiation-based, competition, which encouraged tightening of the IP regime, and greater enforcement (Huang, 2017, Guo, 2016, Chan and Chao, 2017). In addition, China's 12<sup>th</sup> five-year plan (2011-15) prioritised 'indigenous innovation'. With respect to case study firms, by the end of the research period Goldwind and Envision required IP protection for proprietary technology they developed in DDPM turbines and software respectively, while GCL expended large sums acquiring patents for FBR technology that the firm would wish to protect within China. The case to enforce greater excludability of IP to support the best firms was increasing and the Chinese government reacted in a pragmatic fashion.

## **6.2. Competitive limits of manufacturing capabilities and the transition to competition through dynamic capabilities**

Beyond the first stage of cost-based competition in each of the case study sub-sectors, the competitive dynamic changed because manufacturing capabilities alone provided only limited competitive advantage. For the best firms, aspiring to global competitiveness, there commenced a second stage of competition through dynamic capabilities, associated with forward integration. Second-stage

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<sup>344</sup> Technology exports from China took off from the mid-1990s. The majority were exported to other developing countries, which was one incentive for the state to increase IP protection, including through patents and trademarks. Within China, foreign applicants for invention patents consistently exceeded domestic applicants from the 1980s; however, the gap began to narrow from 1995 (Yang, 2005). As a benchmark of China's strengthening IP regime from the mid-1990s, the Ginarte-Park index of patent rights, measured on a 0-5 scale, increased from 1.33 in 1985 to 4.08 in 2005 (Chu et al., 2013). For an industry-level empirical review of the shift to a stronger IP regime, see Li (2010).

competition was less pronounced in the thermal sub-sector, where the entry of new competitors was prohibited; it was clearly present in the wind sub-sector, and incipient in the photovoltaics sub-sector, where the state placed no limits on market entry. The case studies gave rise to a second related group of empirical regularities that are summarised as follows:

*Manufacturing capabilities alone provided insufficient advantage for sustained competitive leadership. In a second stage of competition, the most successful firms were characterised by dynamic capabilities, which included asset-light systems integration capabilities and product-complementing services. In contrast to the acquisition of manufacturing capabilities, the development of dynamic capabilities rewarded entrepreneurial risk-taking.*

In the thermal sub-sector, the big three firms were protected by the state's prohibition of private sector investment. In these conditions, the firms did not aggressively challenge a traditional sub-division of forward segments of the value chain into design work undertaken by state design institutes and power plant construction work undertaken by state construction firms. This probably explained much of their underperformance, in terms of profit margins, relative to multinational leaders Siemens and GE, which reported large, high-margin servitisation revenues.

Among wind sub-sector case study companies, dynamic capabilities in forward parts of the value chain clearly defined the most successful

firms. Goldwind made bold, entrepreneurial, early strategic moves into asset-light systems integration and wind farm development, contrasting with its steady, cumulative approach to harnessing manufacturing capabilities. With respect to outsourcing strategy, Goldwind's headcount relative to manufacturing output was markedly lower than that of global wind industry leader Vestas. The firm's wind farm development and servitisation strategy was also aggressive. In the low-demand year of 2012, for example, Goldwind lost money on manufacturing but earned overall profits because of its forward integration activities (Chapter 4:Table 8).

Envision made even more aggressive and entrepreneurial strategic bets than Goldwind on forward parts of the value chain. The firm pursued an asset-light systems-integrator model from the outset, integrating pools of design talent in Denmark and the United States with China-based resources. Envision in turn treated manufacturing as a means to the end of value-added software and wind farm management. The company appeared to reap rewards for these risks, although the impact on its bottom line could not be reviewed in audited accounts.

Dynamic, forward-focused capabilities set Goldwind and Envision apart from Mingyang, which remained narrowly focused on manufacturing capabilities. Vain hopes that Aerodyn would deliver a manufacturing technology edge left Mingyang as a perennial low-margin producer (Chapter 5:Table 11).



In the photovoltaics sub-sector, acute competition in middle and downstream manufacturing segments created great pressure for firms to gain competitive advantage through strategic choices. However, opportunities in the domestic market to hone dynamic capabilities were constrained by institutional obstacles and solar market immaturity. Competitive differentiation was possible in more mature foreign solar markets, but firms struggled to integrate forwards overseas without prior domestic experience. Suntech's path-setting strategy to develop proprietary solar projects in Europe ended in failure (Chapter 5:section 5.5). GCL also failed in its bid to launch a solar farm development subsidiary in the US. Canadian Solar, by contrast, succeeded with a strategy, launched only two years later than Suntech, to enter overseas solar farm development. Canadian Solar's success was almost certainly connected to its founder's long experience of living and working in Canada. The firm's forward strategic focus was accompanied by the smallest share of revenues invested in manufacturing R&D of any of the large photovoltaics firms (Chapter 5:Table 17). Canadian Solar did not seek a competitive edge through manufacturing differentiation, but by controlling the channel to end-users for a large part of its manufacturing output.

In the mid-stream of the photovoltaics sub-sector, the most successful firms in recent years all moved to outsource low value-added module assembly. Systems integration across more sections of the value chain may follow, particularly as government measures to centralise control of solar farm development reward China's most capital-efficient firms.

The case studies showed that the developmental state was the agency that created transition conditions for the growth of firms defined by dynamic capabilities. Where the developmental state was most effective, its policies were characterised by the following empirical regularity:

*After the development and diffusion of basic catch-up manufacturing capabilities, the most successful developmental state policies facilitated dynamism in the value chain, including forward integration, outsourcing, and systems integration, in order to support the growth of dynamic capabilities at the firm level.*

In the thermal sub-sector, the Chinese developmental state nurtured manufacturing capabilities to great effect, but failed to facilitate entrepreneurial strategies of servitisation that characterised industry-leading multinationals Siemens and GE. Policymakers maintained a traditional vertical division of labour between manufacturing firms, design institutes and construction companies, leaving the big three manufacturers with insufficient operating space in which to fashion higher-margin businesses. Profit margins consequently trailed far behind those of Siemens and GE.

In the wind sub-sector, by contrast, the state's admission of firms of all ownership types into a new business without legacy vested interests created a marketplace in which forward integration was facilitated and a firm's dynamic capabilities became the source of critical competitive advantage. Goldwind and Envision distinguished themselves with

dynamic capabilities. Both firms pursued aggressive outsourcing, forward integration into wind farm development and servitisation. In turn, policymakers followed the development of the wind sub-sector pragmatically, adjusting regulations and the subsidy system to encourage competition based on lifetime turbine performance, which encouraged further competition in forward parts of the value chain.

In the photovoltaics sub-sector, the NDRC and NEA failed to foresee the forward integration challenges for a technology that the agencies came to support belatedly. As a result, competition through dynamic capabilities was stymied. Local approval of utility solar farms, local subsidies for favoured firms, legal and financing challenges for DG projects, and the under-development of net-metering technology, all constrained forward integration and servitisation. The NDRC and NEA recognised the problems and introduced a range of policies to tackle them. Nonetheless, better research and better planning with respect to the forward segments of the value chain would have seen concentration, and improved margins and cashflows for the best firms, arrive more quickly.

Photovoltaics, like the thermal sub-sector, demonstrated that it was not enough for planning agencies to plan for manufacturing capabilities alone; they needed to consider the entire value chain if infant industry policy was to be optimised and subsidy deployed efficiently. The more successfully the developmental state facilitates vertical dynamism and forward integration at the firm-level once basic production capabilities are in place, the more quickly the best firms achieve improved margins

that support R&D budgets, permitting them to challenge multinational peers through fundamental product innovation.

### **6.3. Firm ownership as a variable in the acquisition of manufacturing versus dynamic capabilities**

The empirics of the thesis revealed a consistent pattern whereby state-owned firms demonstrated no significant weakness relative to private firms in building narrow manufacturing capabilities. Moreover, in the earliest stages of capability building, as was the case in other FDCs (see Chapter 1), state firms offered advantages when the incipient developmental state sought to create vertical learning structures that an undeveloped private sector would not otherwise coordinate.

However, in the transition from competition through manufacturing capabilities to competition by dynamic capabilities, in each sub-sector state ownership became a handicap. Through the 2000s and 2010s, private firms (including ones spawned by the state sector) showed repeatedly that they were faster, more flexible and more resourceful than state units in creating capabilities beyond basic manufacturing competence.

This experience echoed Amsden and Chu's (2003) two-stage heuristic in Taiwan where there was a transition from leadership by state enterprises pursuing import substitution industrialisation (ISI) to leadership by large private sector firms competing through marketing, differentiation and incremental innovation. Similarly, the ownership issue was found by Cusumano (1985) to have been fundamental to the

rise of the asset-light system integrator model in the Japanese automotive industry. The growth of outsourcing reflected the plight of capital-hungry private firms that were less indulged by state industrial policy, and subject to greater competition, compared with firms in sectors like electronics, which remained more vertically-integrated and less capital-efficient. In the case studies in this thesis, systems integration was driven by private firms with less access to state financial system credit than publicly-owned competitors.

It has been claimed by some scholars that, by comparison with the experiences of the former Soviet Union, China illustrated that firm ownership is a less important issue in capability building than most economists propose (Naughton, 2010, Kroeber, 2008, Tian and Estrin, 2008). This thesis suggests that, as China's development progresses, ownership becomes an increasingly significant issue. China's Leninist system facilitated the creation of vertical learning structures through which manufacturing capabilities were delivered. However, as China sought to develop advanced economic capabilities, state ownership became the handicap that orthodox economists argue it almost always is (Megginson and Netter, 2001). This is also the conclusion of a recent study of China's IT industry (Fuller, 2016). The empirical regularity from the case studies in this thesis is summarised as follows:

*In the most successful firms, the development of manufacturing capabilities was less sensitive to state versus private ownership than was the development of dynamic capabilities.*

In the thermal sub-sector, state firms raised Chinese manufacturing capabilities for coal turbine-generators sets from very low levels in the 1970s to close to the global frontier in the 2000s. However, the big three state firms demonstrated little sensitivity to strategic competitive issues. They failed -- unlike private Japanese firms that licensed US and European technology -- to recognise the increasing commercial importance of LGT technology in a timely manner. They accepted the traditional division of labour in forward parts of the value chain, pressing only weakly to develop EPC, maintenance, monitoring and optimisation services. Nor did the firms seek opportunities in overseas markets to develop more forward-integrated business models; they were typically one party in the wholesale export of China's traditional division of activities, working with other state firms that handled design and EPC aspects of foreign projects. When the wind sub-sector took off, the big three failed to compete effectively against private sector entrants, a failure that was frequently attributable to poor service capabilities (Chapter 4:section 4.3). Only Shanghai, in the offshore niche, built a substantial business that endured, and this was based on a Siemens technology license.

With respect to pure wind turbine firms, state-owned, vertically-integrated United Power rose to number two by volume through rapid absorption of manufacturing capabilities. The firm led in developing capabilities for manufacturing large-blade, low wind-speed turbines. However, as the locus of competition moved towards asset-light systems integration, complementary services and wind farm management, United Power's competitive position weakened. There was a similar

trajectory for state-owned Dongfang. This was a clear contrast with Goldwind, which transitioned from state to private ownership, and always-private Envision, which developed far superior dynamic capabilities in forward segments of the value chain.

In silicon feedstock production, privately-held GCL overtook MOST-supported state firms not because it was able to master complex chemical production processes where state firms were not, but because of its capacity to recognise the need for, and deliver, a break-neck pace of capacity construction during a spike in feedstock prices. GCL's greatest advantage was in a narrow, organisational subset of dynamic capabilities, not in manufacturing capabilities.

The firm-level experience in terms of ownership in the case studies was directly reflected in developmental state policies that recognised that, while state ownership was not an impediment to the learning of manufacturing capabilities, it did become an impediment to the development of dynamic capabilities. Hence, effective state policies promoted a transition, summarised as follows:

*The most successful developmental state policies facilitated a transition from state to private ownership at the firm level in order to support the progression from competition based narrowly on manufacturing capabilities to competition based on dynamic capabilities.*

In the thermal sub-sector, the state's failure to deliver private sector competition appeared to contribute to a sub-sector characterised by

limited dynamic capabilities and unable to challenge multinational leaders Siemens and GE. Even the strongest firm, Shanghai, showed only a weak appetite to disrupt the status quo within the sub-sector.

In the wind sub-sector there was the clearest evidence of differential state and private sector firm performance. Unlike Siemens and GE in their home markets, none of the big three thermal firms was able to dominate the new wind turbine market. A new state sector entrant, United Power, acquired manufacturing capabilities quickly. However, no state firm could compete with Goldwind, which transitioned from state unit to private enterprise, and always-private Envision, when the keys to higher margins became asset-light systems integration, forward integration and servitisation. If government policy had restricted the wind sub-sector to state firms, it is unlikely China could have produced companies comparable in profit margin terms with global leaders.

In the photovoltaic sector, the private sector required state industrial policy support for the development of manufacturing capabilities when MOST intervened to fund a silicon feedstock technology programme. That this programme would have been more effective if opened to private as well as state firms was clear when GCL stole some of the MOST-funded IP and quickly outstripped state competitors to become the dominant company in the sub-sector.

The case studies suggested that state ownership was not an obstacle to the development of manufacturing capabilities and that state units were sometimes an efficient means to enter new businesses – including with



the inception of Suntech and Goldwind. However, as businesses developed and the need for flexible, entrepreneurial strategic leadership increased, the case for a transition to private ownership became powerful. This did not guarantee success, as the Suntech case demonstrated, but it did facilitate it, as in the case of Goldwind.

#### **6.4. Centralised versus firm-level technology bargaining as a variable in the acquisition of dynamic capabilities**

The empirics of the thesis showed how, in the early 1980s, centralised bargaining was extremely successful in the thermal sub-sector in minimising technology costs. In the late 1990s and 2000s, China continued to centrally bargain deals in which monopsony purchasing of technology was reported to be a powerful cost-saving tool, whether in the high-speed rail programme (Chen and Haynes, 2016, Lin et al., 2015) or nuclear power (Zhou and Zhang, 2010).

In the wind and photovoltaics sub-sectors, technology bargaining was devolved to the firm level. Consistent with experience in Japan (Gregory, 1985, Lynn, 1982, Peck and Tamura, 1976), China's Ministry of Finance found that in the wind sub-sector firms' technology costs were bid up significantly compared with centralised bargaining (Tan and Seligsohn, 2010a). However, higher cost<sup>345</sup> was offset by the diversity of technological paths pursued by Chinese firms, resulting in technological differentiation and new types of competitive advantage.

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<sup>345</sup> At least for some firms. As noted in the Envision case study, that firm secured manufacturing capabilities at very low cost.

At a theoretical level, the experience was consistent with the distinction between diffusion of mature technology (Eaton and Kortum, 1999, Surry, 1997, Vernon, 1966), in this instance bargained by the developmental state in order to minimise costs, and the innovation or recombination of technology in order to compete through differentiated products and services (Porter, 1998 (1980)). As discussed in the context of endogenous growth theory in chapter 1, in a developing country the latter form of competition requires both the development of requisite technical capabilities and an IP regime that allows for excludability of IP. As this paradigm is created, the empirics of the thesis indicated that a transition to firm-led technology bargaining was important to the growth of firms defined by their dynamic capabilities. The empirical regularity from the case studies can be summarised as:

*Monopsony technology bargaining minimised technology costs.*

*Decentralised technology bargaining increased chances of positive technological differentiation.*

In the thermal sub-sector, central bargaining by the Chinese state secured a technology transfer deal which, by the admission of Westinghouse executives, cost the vendor money. US\$13.8m did not even cover the expense of worker training and management consultancy. The technology itself, accompanied by critical source code, was in effect free, and no royalties were paid on domestic sales of turbine-generator sets. The experience highlighted the benefits to a monopsony FDC purchaser of targeting a commercially weak multinational seller that nonetheless held world-class technology.

However, the case studies also showed that a switch to firm-level bargaining produced benefits that central bargaining could not easily deliver. In the wind sub-sector, Goldwind's acquisition of DDPM technology (Chapter 3:section 4.5) reflected entrepreneurial capabilities that state planners were unlikely to replicate. The firm not only identified a proven but little utilised technology, it also recognised that plummeting prices for rare earth materials meant that the time was ripe for scale DDPM production. Goldwind successively licensed DDPM technology, purchased control of the technology supplier Vensys, and integrated Vensys into its design and development capability-set.

Envision's technology acquisition path (Chapter 3:section 4.7) was still less likely to have been pursued by government planners. The firm's entrepreneurial leaders identified Chinese and foreign production and logistics specialists at wind turbine joint ventures in China and in unrelated but complementary manufacturing sectors overseas, design specialists in Denmark, software specialists in the United States, and blade specialists in the United States; they built a manufacturing and value-added services team from the bottom-up, without any licensing. Central government would not likely have taken such an approach; nor would it have identified Envision's founders, entrepreneurs with no previous experience in wind turbine manufacturing.

In the photovoltaics sector, bargaining for critical silicon feedstock technology was centrally managed by MOST. However, the implementation process, via state firms, was slow, while soaring silicon

feedstock prices recommended speed. It was in this context that a private firm, GCL, appeared to illegally acquire MOST-funded IP as part of its assault on a business sector in which it had no previous experience. It was not only GCL's capacity construction speed that the state planning apparatus could not replicate. The firm was entrepreneurial and flexible in identifying a mix of imported and domestic capital equipment, in taking a strategic risk with and mastering hydrochlorination technology before other Chinese firms, and in recruiting freelance international specialists to further increase its technological edge over domestic rivals.

With respect to appropriate developmental state policy towards technology bargaining, this necessarily depends on the concentration, and hence pricing, of the technology sought. In the high-speed rail and nuclear industries, China negotiated for technology held by only a few multinational firms, making the case for monopsony bargaining stronger. In the wind sub-sector, technology was widely available from typically small design firms. In photovoltaics, mid-stream technology was embedded in manufacturing equipment that could gradually be reverse engineered in China, while silicon feedstock technology was mostly out of patent protection and could also be reverse engineered. Each business had its own technology bargaining characteristics. Nonetheless, as a general rule, the devolution of technology bargaining to the firm level supports the development of dynamic capabilities, an empirical observation from the case studies that can be summarised as:

*The most successful developmental state policies promoted the timely devolution of technology bargaining to the firm level to support the*

*development of dynamic capabilities and the transition to technologically differentiated competition.*

The devolution of technology bargaining in the case studies allowed the most capable firms to differentiate themselves. Goldwind's DDPM technology choice, Envision's disruptive combination of globally-dispersed technology teams with a focus on product-complementary software, and GCL's introduction of hydrochlorination all reflected, and required the growth of, their dynamic capabilities. Envision exploited the opportunity to manage technology acquisition to bring capabilities from a different industry, energy trading, to bear on the wind turbine business, consistent with Jacobides and Winter's (2005) fourth proposition about maturing structures of production and the co-evolution of capabilities and vertical scope.

Devolution of technology bargaining was also linked to the ownership issue. It was private firms that exhibited a stronger record of sourcing technology outside joint ventures and licences. Privately-controlled Goldwind, Envision and GCL led in acquiring technology via foreign takeovers and in hiring foreign technical specialists as consultants or integrating them within their organisations.

### **6.5. Infant industry policies and industrial overcapacity**

Consistent with experience in Japan, South Korea and Taiwan (Peck et al., 1987, Chang, 1994, Johnson, 1982), the empirics of this thesis showed that the signalling effect of infant industry policy, backed by an industry-focused, developmental state-controlled banking system,

encouraged production overcapacity. This was moderated in the thermal sub-sector by the non-admission of new firms, but not in the wind turbine and photovoltaic sub-sectors. In contrast to the common shorthand that industrial policy is about 'picking winners' (Pekkanen, 2003, Little, 1996, Hindley, 1983), it was therefore necessary for the developmental state to identify mechanisms to weed out weaker firms, as noted by Chang (1994). This empirical regularity from the case studies can be summarised as:

*Infant industry policy tends inevitably to overcapacity. Successful developmental state policies involved the culling of weaker firms.*

Despite, or perhaps because of, limited overcapacity in the thermal sub-sector until recent years, the government did nothing to cull the weakest of the three entrants. By the 1990s, a pecking order of success was already apparent among the big three firms, while they remained much smaller in scale than multi-national peers (Nolan, 2001a). Harbin was the weakest of the big three but, despite many rumours to the contrary, the developmental state failed to merge it with one of the two more successful firms and thereby create a duopoly of larger companies able to command higher margins. This contributed, in the thermal sub-sector, to the failure of any firm to challenge for leadership at a global level.

In the wind sub-sector, the competitive landscape was transformed by the admission of hybrid and private firms. There was a large number of entrants, a development amplified by the tendency of local governments

to subsidise and protect local companies of all ownership types. In 2011, the NDRC therefore centralised the provision of all wind farm approvals and temporarily dampened aggregate demand. The result was the culling of large numbers of weaker wind turbine assemblers and component suppliers. This increased market shares and improved margins at the best companies, and paved the way for competition through differentiation and incremental innovation (Chapter 4:210pp). Goldwind, the most capable firm, increased its domestic market share from 18 percent in 2011 to 27 percent in 2016.

In the photovoltaics sub-sector (Chapter 5), a similar pattern played out more fitfully. Local government support for local favourites, an even higher share of solar farm development being locally financed and approved versus the wind sub-sector, and lower mid-stream costs of entry, allowed hundreds of firms to start up. The NEA therefore adjusted the FIT structure to encourage more value-added DG development. This, however, faced a host of legal and financing problems that made the DG market slower to develop than planners desired. More efficaciously, from 2015 the NEA introduced the Top Runner programme that rewarded larger firms able to re-invest in new production machinery and raise solar conversion rates.

A number of indicators suggested that in 2015-17, the NEA's efforts to promote concentration and focus subsidy were yielding results. A group of six large photovoltaics firms – four mid-stream companies and two fully-integrated silicon feedstock producers – stabilised as the market's leaders. Outsourcing of the lowest value-added manufacturing activity --

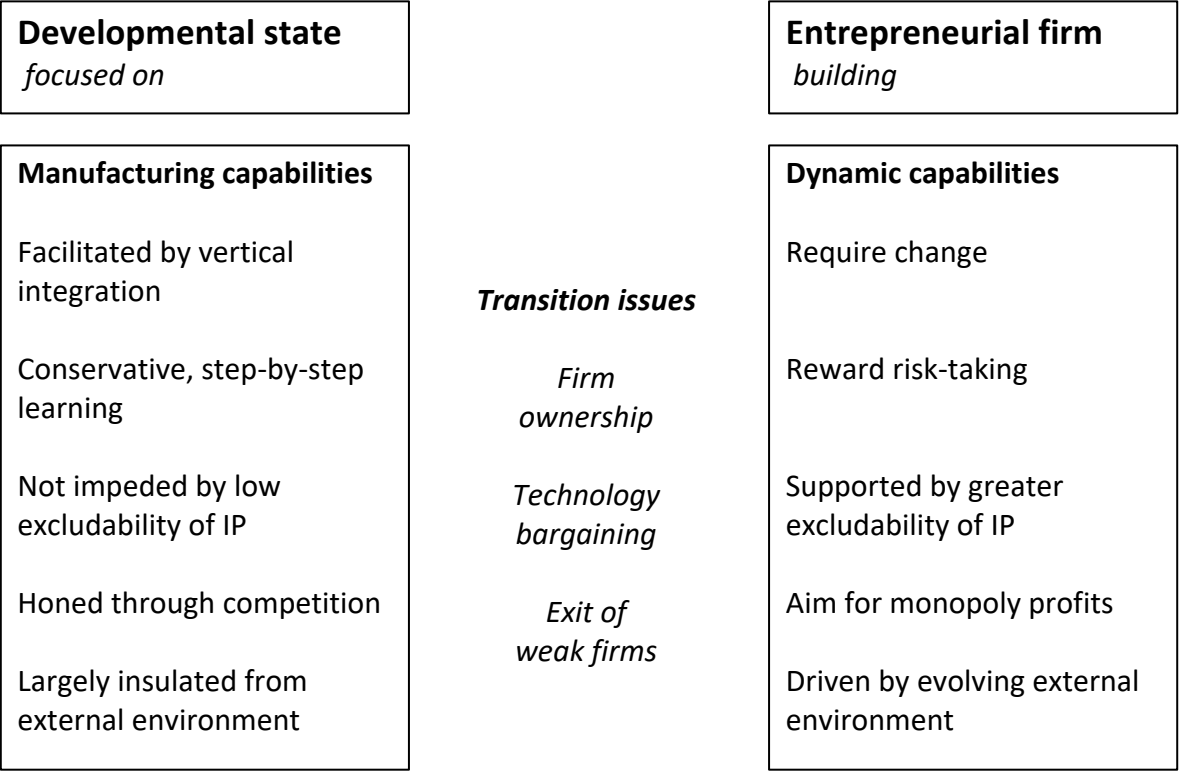
module assembly -- increased rapidly. However, the infrastructural and institutional structure of the photovoltaics sector, particularly with respect to DG, was still, as of 2017, inimical to competition by differentiation in forward parts of the value chain.

In general, the NEA's successes in culling the weakest firms in the electricity-generating equipment industry showed this was easier with private-sector firms. In the thermal sub-sector, locally and nationally state-owned firms represented embedded vested interests that planners failed to face down. Harbin's status as an historic national champion saw it retain its independence despite strong commercial logic for merger.

In terms of the analytical framework of this thesis, the three transition issues that recurred in the case studies as a state-led development process moved towards one driven by entrepreneurial firms are set out in Figure 1. The findings suggest that the study of innovation systems in developing countries should give transitions a central place in whichever heuristic is employed, recognising that the firm-level progression from building manufacturing capabilities to subsequently developing tacit, organisational and strategic capabilities involves a fundamental qualitative shift. As this process occurs, developmental state policy must make substantial adjustments if it is to support the creation of world-class firms. To date, literature on innovation systems in developing economies has tended to treat industrial policy as monolithic when the case studies in this thesis showed that the most effective industrial policy is as dynamic as the high-performing firms it seeks to nurture.



**Figure 10. Developmental state and entrepreneurial firm: transition issues**



**6.6. Limitations and scope for further research**

This thesis attempted to contribute by highlighting ‘developmental state capitalism’ as a simplistic notion. Instead, the thesis showed that the developmental state is not a condition, but a problem solving institution that, if successful, works itself out of a job. The developmental state does so as part of the transition from a *dirigiste* economy in which it focuses firms on learning to a decentralised economy in which atomistic, entrepreneur-led firms, and arm’s-length markets, play the dominant role as profit margins and firm-level R&D investment become the keys to global competitiveness. The state, the entrepreneurial firm and the

arm's length market are always present, but the balance between them changes greatly during the accelerated economic development process that characterises an FDC.

This thesis is subject to a number of clear limitations. The empirical research concerns three sub-sectors of a single industry in China, supported by a survey of complementary secondary empirics in other industries in Japan, South Korea and Taiwan presented in Chapter 1. The findings that were set out in this chapter are not put forward as generalisable to all industries. Instead, it is hoped the findings will be tested in longitudinal studies of other industries in China, and in FDC economies more generally.

The limitations of cross-sectional studies, which have predominated in the economic development literature, were discussed in Chapter 1. This thesis highlights the limitations of longitudinal research. Such research provides context and perspective, identifying change at the state and firm levels over a long period. However, in a single study this can only be done for one industry strand within the overall microeconomy. This shortcoming would be less egregious if more industry histories were written, and it is hoped that in future more longitudinal business research will be undertaken in China, and in FDCs generally.

Broadly, this thesis highlights the need for further research on the role of public versus private ownership in building different industrial capabilities in emerging economies. The clearer that policymakers' understanding is of the issues surrounding firm ownership, the more

likely it is that governments will harness the benefits of state ownership without succumbing to its drawbacks in promoting the development of globally competitive firms. Similarly, there is scope for more empirical studies of transitions in technology bargaining in emerging economies in order to better understand the trade-offs between centralised and decentralised bargaining.

The case study of Envision in the thesis suggests that further research is merited into the phenomenon of 'born global' firms (Cavusgil and Knight, 2009, Knight and Cavusgil, 2004, Zhou et al., 2007) in the middle reaches of development in China. Contrary to the Linder (1961) 'home market' hypothesis that comparative advantage is first developed through domestic demand, Envision entered directly into software development for American clients, as well as the operation of overseas wind farms. Much of the reason for this was the pool of returnee human capital available to Envision. The role of specialist returnee labour was important in the mid-term development of Japan (Gregory, 1985, Morita et al., 1986, Lockwood et al., 1970), South Korea (Urata and Lall, 2003:chapter 6) and Taiwan (Saxenian and Hsu, 2001). However, the tendency has been more pronounced in China, which integrated earlier and more fully into the global economy than Cold War Japan, South Korea and Taiwan. That this may give rise to a particular 'cosmopolitan advantage' for China's development is suggested by recent industry studies of electronics, software and the Internet (Clark, 2016, Fuller, 2016) and warrants further research.

Finally, it is hoped that strategic management scholars – whose work this thesis suggests has much to contribute in developing countries – will conduct more research focused directly on emerging economies. The firm-level focus of strategic management research holds out the potential to redress a traditional bias in studies of FDCs towards state industrial policy, rather than transitions between state policy and entrepreneurial, firm-led development.

## Appendix 1: interviewees

Code	Cumulative Total	Description
Th1	1	Senior manager, Westinghouse China operations
Th2	2	Senior manager, Westinghouse China operations
Th3	3	Technical director, Westinghouse China operations
Th4	4	Technology licensing specialist, Westinghouse US
Th5	5	Senior manager, strategy, Siemens China operations
Th6	6	Senior manager, Siemens China operations
Th7	7	Senior manager, Westinghouse China operations
Th8	8	Senior technology licensing manager, Westinghouse US
Th9	9	Senior manager, Shanghai
Th11	10	Technical director, retired, Shanghai
Th12	11	Senior manager, wind turbines, Shanghai
Th13	12	Senior manager, retired, Shanghai
Th14	13	Senior manager, retired, Shanghai
Th15	14	Wind turbine consultant to Shanghai, Europe-based
Th16	15	Wind turbine consultant to Shanghai, Europe-based
W1	16	Chairman, President or CEO, Chinese wind turbine manufacturer
W2	17	Wind and solar industry consultant and technology supplier, China-based
W3	18	Senior manager, Sinovel
W4	19	Senior technical specialist, Goldwind
W5	20	Senior manager, strategy, Goldwind
W6	21	Senior manager, strategy, Goldwind
W7	22	Senior manager, finance, Goldwind
W8	23	Senior manager, strategy, Mingyang
W9	24	Senior manager, sales, Mingyang
W10	25	Technical specialist, Mingyang
W11	26	Technical director, Envision
W12	27	Senior manager, strategy, Envision
W13	28	Chairman, President or CEO, Chinese wind turbine manufacturer
W14	29	Technical director, software, Envision
W15	30	Senior manager, strategy and technology, Envision
W16	31	Sales (formerly service) manager, Envision
W17	32	Senior manager, strategy and investment, Envision
W18	33	Wind technology specialist, 'Invest in Denmark' investment promotion agency
W19	34	China sales specialist, Romax Tech (Drivetrain), UK-based
W20	35	Senior manager, Romax Tech (Drivetrain), UK-based
W21	36	China focused technical specialist, Garrad Hassan, UK-based
W22	37	Technical specialist, Aerodyn, Germany-based

W23	38	Technical specialist, Mita-Teknik, Denmark-based
W24	39	Technical specialist, Mita-Teknik, Denmark-based
S1	40	Chairman, President or CEO, Chinese photovoltaics manufacturer
S2	41	Senior manager, marketing, Canadian Solar
S3	42	Manager, investor relations, Suntech
S4	43	Manager, sales, Yingli
S6	44	Senior manager and technical specialist, LDK
S7	45	Manager, strategy, Yingli
S8	46	Manager, strategy, Suntech
S9	47	Senior manager and technical specialist, GCL
S10	48	Manager, strategy, Suntech
S11	49	Manager, investor relations, Suntech
S12	50	Journalist, Beijing-based
S13	51	Manager, business development and strategy, GCL
S14	52	Manager, GCL
S15	53	Technical specialist, GCL
S16	54	Technical specialist, GCL
S17	55	Technical specialist, GCL
S18	56	Senior manager, GCL
S19	57	Technical specialist, GCL
S20	58	Technical specialist, GCL
S21	59	Photovoltaics sector financial analyst, Hong Kong-based
S23	60	Technical consultant to case study firms, Holland-based
S24	61	Technical consultant to case study firms, Holland-based
S25	62	Technical consultant to case study firm, UK-based
S26	63	Technical consultant to case study firms, US-based
G1	64	Department director, NDRC
G2	65	Manager, Energy Research Institute (ERI)
G3	66	Professor and NDRC consultant, Tsinghua University
G4	67	Senior manager, ERI
G5	68	Senior manager, China Renewable Energy Industry Association (CREIA)
G6	69	Professor and government consultant, Jiaotong University, Shanghai
G7	70	Senior researcher responsible for China, International Energy Association (IEA)
G8	71	Senior researcher on renewables, World Bank China mission
G9	72	Researcher, Institute of Energy, Environment and Economy, Tsinghua University
G10	73	Researcher, ERI
G11	74	Researcher, CREIA
Other:		
S5		Private equity financier to photovoltaics sector, Singapore-based

S27		Private equity financier to photovoltaics sector, Hong Kong-based
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## **Appendix 2: standardised, semi-structured interview questions**

My research: I am looking at the relationship between firms and the state in conditions of effective industrial policy (such as has been used in Asia in Japan, South Korea, Taiwan, and China).

我的研究方向：关于行业政策的有效性方面，公司/企业和政府的关系（例如亚洲的日本，韩国，台湾和中国）

Here are five important introductory questions that I ask the leaders the companies I look at:

这是我给拜访公司的高层领导设计的 5 个导入性问题：

I.           How do you think about the nature of competition in your industry? Specifically:

你怎么看待你所在行业的竞争特性，具体来看：

What has been the nature of competition in your industry so far? If you have to name the 3 most important dimensions of competition until today, what would you list?

目前为止，你所在行业的竞争特性是怎样的？可以说出目前为止 3 个最重要的竞争点吗？（也就是说竞争的方面，或者优势，客户在对比您公司和其他公司之后为什么选择您公司，比如说销售，价格，技术等等）您觉得是哪些？

If you have to name what you think will be the 3 most important dimensions of competition in the next few years, is there any difference?



如果你需要考虑未来几年 3 个最重要的竞争点，会和目前面临的有所区别吗？

[I do not offer suggested answers to these questions. I want answers that are not influenced by me to begin with. However, I will make suggestions during the meeting.]

（我不会引导您回答，更想听到您本人的想法，但是交流中，我也会提出一些我的建议。）

II. How do you think about the nature of your firm's relationship with the state (in all its different forms, at the national level, the local level, with politicians, with planners like the NDRC, with state financial institutions). Specifically:

您认为贵公司和政府的关系有哪些特点？（各种不同方面的关系，如发改委，金融机构等）具体来看：

In which relationships can you hope to influence government decisions?

在哪种关系领域，您觉得有希望影响到政府决策？

In which relationships do you feel you are only reacting to policy and trying to understand it?

在哪种关系领域，您觉得只能应对政策并且试图理解？

III. How do you think about your firm's strategic choices in the value chain / about strategic choices in terms of vertical integration? Specifically:

您怎么看贵公司在产业价值链上的战略选择/或者说在纵向一体化方面的战略选择，具体来说：

What decided your choices in the past and, with the benefit of hindsight, which decisions were right and which were wrong? What have you learned about the nature of the value chain for your firm?

过去您是根据什么来决策的，如果事后来看，哪些决策是正确的，哪些是错误的，据您的理解，您认为贵公司价值链的特性是什么？

In terms of the future, how do you think about which parts of the value chain you need to control now and how confident are you that you have understood the strategic challenge clearly? Please give a brief description of your firm's value chain.

就未来来看，您觉得目前价值链哪个环节是需要控制的，您觉得您足够清晰地了解了这些战略性的挑战吗？

IV. How do you think about and strategise innovation? And how does the Chinese government and different levels think about and strategise innovation? Specifically:

您如何看待创新并且将创新付诸战略，具体来看，  
How does the way the government thinks about  
and strategises innovation differ from the way you actually see  
innovation happening in practice in your industry?

您觉得政府目前对于创新以及战略实践创新的理解和看法，和公司  
在行业实践中已经进行的创新有哪些不同？

V. What determines the emphasis you place on growing export sales? Specifically:

是什么让您觉得需要重视出口市场销售（海外市场），具体来看，

In the past. 在过去的时候，是什么？

In the future. 在未来，又是什么？

[ends] （结束）

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