The Imitation to Innovation Transition:

Exploratory Research in the Chinese Wind Turbine Manufacturing Industry

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Executive Summary

China's rapid emergence as an economic superpower is unparalleled. While in the west we focus overwhelmingly on innovation, here it is imitation that has played the starring role. This thesis is focused on exploring the processes underlying this rapid growth, and answering the deceptively simple question, "What role does imitation play in firms learning and capabilities development?"

Existing literature offers clues in the form of partial theories and countless empirical examples, but very little footing from which to answer this basic question. Instead, theorizing must be undertaken on the basis of original empirical research, specifically theory building through case studies, with existing literature providing the theoretical lens, and the fragmented insights of past empirical findings as clues. This process of interactive theory building through the analysis of the Chinese wind turbine industry is the core endeavor of this thesis.

The design and manufacture of large-scale wind turbines is a highly competitive, technologically advanced global industry historically dominated by a consolidated group of European and American firms. Emerging in the 1990s as a site of low-cost manufacturing, China quickly moved from imitative production into R&D and innovation based competitiveness. In the past 5 years, Chinese firms have emerged among the largest producers of wind turbines globally, and are now beginning to directly compete with European and American firms on the global market. Within China, more then 80 firms pursue the manufacture of wind turbines, with widely varying degrees of success, and underlying capabilities.

In evolutionary economics, imitation and innovation viewed as interlinked and equally crucial. While innovation is the source of novelty, it is through imitation that this novelty is diffused through the economic system. While existing research largely focuses on the static classification of firm capabilities, and the development of the national economy, we focus on the learning process within the firm, and looking to the innovation systems approach, embed this understanding of the firm within a broader network of actors.

Learning is understood as iterative, path dependent and firm specific. Three modes of learning – learning by doing, using, and searching – are identified, and form the basis for further analysis. Alongside these modes of learning, 10 stylized facts are extracted from existing literature, and serve as the theoretical foundation for our understanding of firm scale learning processes. Learning is seen as a conscious investment, and a cumulative activity occurring at multiple scales within the firm far beyond the scope of conventional R&D. As learning proceeds, and capabilities develop, they are not seen as replacing each other, but instead supplement each other, producing parallel multiple approaches. At both the national and international scales, learning is interactive and supported by a complex network of actors including suppliers of input and capital goods, competitors, customers, consultants, technology suppliers and governments.

To address our multi-faceted research question, we break it into three sub-questions. Because of the exploratory nature of this work, these questions are developed sequentially, building on completed work as research progresses. The first two are a closely linked pair: "What approaches to imitation do firms pursue?" and "What forms of learning relate to these strategies?" To address these, we combine existing literature with interview with industry sources and identify key shifts in imitation approaches common to multiple firms. Simultaneously, processes of learning and capabilities creation are discussed. Building on these interviews, we relate approaches to imitation and modes of learning, finding that firm strategies and existing capabilities limit the approaches to imitation that can be pursued, and that these approaches to imitation in turn define opportunities for learning.

While this provides a useful vocabulary of approaches, and defines the relationship of these approaches to modes of learning, it sets aside the unique paths that individual firms follow, and the firms-specific and path-dependent co-evolution of learning and capabilities. This firm level diversity is a core focus of this research, and is explored through case studies of firm histories

guided by our third research question: "How are these strategies assembled into firm-specific histories in which capabilities develop cumulatively and imitation builds innovation capabilities?"

To explore this question, three firms – Goldwind, Dong Fang, and XEMC/Darwind - are selected from among those discussed by industry sources in earlier interviews. Using the vocabulary established through our theory building process, the histories of these firms are examined through publications and discussions with industry sources. Based on this, the approaches to imitation, modes of learning, and capabilities development evident in the development of these firms are characterized, and their relationships examined. Several important observations about the firm level process of learning by imitating emerge from this, and become the basis for further discussion.

The first of these observations is the success of the trial and error based approach to improvement. Through the unique customer expectations and relationships developed in the Chinese market, Chinese firms are able to deliver relatively untested products to customers, and by providing active support for these products, to maintain and improve them, rapidly generating feedback, and sharing the risk of innovation. With this unique arrangement, trial and error within the Chinese market proves far more successful than it would within western markets.

The second observation is more general, and related to the essential role of feedback loops in the trial and error process, and in the development of search routines. While feedback allows for trial and error to proceed, in order to be useful this feedback must be appropriate in terms of complexity, scope, and time-scale. With this in mind, we propose that search routines develop as a way to bridge gaps between required and available feedback. As simple problems are resolved, failures – and the feedback they provide - become less common, and the information they provide becomes more complex and difficult to interpret. As such search routines evolve as a way to allow for continuous improvement to occur without direct feedback, and as a means to translate the available mismatched feedback into useful information at multiple scales.

By vastly increasing the number of effective prototypes, Chinese firms have delayed the need to develop these routines. Nonetheless, as these firms become more experienced, and failures decrease, feedback will diminish, limiting trial and error based improvement. Simultaneously, as these firms enter international markets, trial and error will no longer benefit from market support, and these firms will likely need to transition towards a more proactive, search-based approach to improvement.

Our final observation is that firms pursue multiple approaches to imitation, and therefore multiple modes of learning, simultaneously. While this is somewhat paradoxical given homogenizing pressures within firms, it appears that within the firms studied this is made possible as a side effect of the severe, top down management style, and as a product of the mediating effects of geographic distance within multi-locational firms. Combined, these factors establish multiple selection environments for internal routines, and therefore allow simultaneous approaches to imitation, and learning in multiple modes, building a broad range of capabilities much more quickly than would occur through sequential learning. Taken in comparison to the small geographic scale, and tight control and integration characteristic of Korean and Japanese firms, this begins to explain how the development of these firms is so different from - and so much faster than – these previous examples.

While these observations are intriguing, they are the outcome - not the starting point - of this research, and therefore remain relatively unexplored. Nonetheless, they offer the possibility of unique insights into this crucial process, and serve as a starting point for future research. With this in mind, we encourage future research on this topic and case, recommending that this build on these observations, and focus on exploring the complex role of government and geography within the process of firm-scale capabilities development through imitation.

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At moment, China is primary school students. Licensing is kindergarten. Joint Design is primary school. Maybe in High School we can develop the existing material technology. In the future, in university, Chinese manufacturers will have new innovations. But today, they don't, because they don't have enough experience.

- Pengfei Shi,
Vice President of the Chinese Wind Energy Association (CWEA)

1) Introduction

The rapid rise of China is unique and thrilling, with some calling this China's century. (Fishman, 2004) While the scale and speed of China's rise may be unprecedented, the processes underlying this development share much with previous cases in SE Asia and elsewhere, namely a focus on foreign technology coupled with domestic capabilities building through production and incremental improvement. While in the west we focus overwhelmingly on innovation as the driver of economic development and firm competitiveness, here it is imitation that often plays the starring role.

Imitation plays a critical role in evolutionary theories of economic development, from Schumpeter, through Nelson and Winters, and into current incarnations of evolutionary theory at the core of innovation systems literature. Within this approach, imitation and innovation are interlinked and equally crucial. While innovation is the source of novelty, it is through imitation that this novelty is diffused through the economic system. Despite this, research has historically given surprisingly little attention to the topic.

When research has addressed imitation specifically, it has done so in two very different ways. Within western economies, where competition is seen as occurring between firms, imitation is seen as an important factor in explaining competitiveness, and profitability. Conversely, historical work on newly industrializing economies adopts the nation as the unit of analysis, and studies the role of imitation and learning in the long-term development of national capabilities. (Carlsson, 1991)

Each perspective brings strengths, but also significant blind spots. While firm scale analysis helps us to understand competitiveness, its comparative, cross-sectional focus tends to limit the attention given to the longitudinal process of capabilities building within the firm. National scale studies in countries such as Korea and Taiwan, on the other hand, focus on precisely this process, but lack the detail to understand the relationships between diverse firms within the economy that innovation systems theory understands as so fundamental, opting instead to assume heterogeneity of firms, and a parallel between firm and national scale development. While this literature may give us insights into competition in developed economies, or development in small, tightly controlled nations, it offers very little when it comes to the case of China.

While countless industries are undergoing phenomenal growth within the Chinese economy, we choose to focus on only one: wind turbine manufacturing. The design and manufacture of large-scale wind turbines is a highly competitive, technologically advanced global industry historically dominated by a consolidated group of European and American firms. Emerging in the 1990s as a site of low-cost manufacturing, China has quickly moved from imitative production into R&D and innovation based competitiveness. (Liu, 2006) In the past 5 years, Chinese firms have emerged among the largest producers of wind turbines globally, and are now beginning to directly compete with European and American firms on the global market.

There are several advantages to this industry as the focus of research, both practical and theoretical. It is a relatively open industry, with an international focus, and the subject of great interest recently. From a practical perspective, these factors all contribute to mitigate the difficulties of empirical research in China. Similarly, this industry has been the subject of significant previous research, specifically in the fields of innovation systems and firm learning, within developed economies, and therefore a relatively strong understanding of its requirements and particularities already exists. In more theoretical terms, this industry presents a fascinating mix of firms ranging from large government-owned conglomerates to specialized, publically listed innovators. These firms are spread widely across China, and involved to various degrees in regional, national, and global technology and business networks, and policy regimes. It is precisely this tremendous diversity, founded at the firm level, which existing understandings of imitation within newly industrializing economies are incapable of addressing.

In addressing this, evolutionary economics gives us an approach to understanding economic change through time, with routines as the unit of analysis, and firm heterogeneity as a core tenet. Building on this, innovation systems theory argues that innovation and learning are inherently interactive, and the system scale context of firm behavior is therefore critical to understanding these processes. The physical and relational geography that mediates communications betweens actors becomes crucial, and countless actors, from start-ups to government regulators, become an integral part of processes traditionally viewed as contained within the firm.

With this theoretical perspective in place, many of the weaknesses of existing literature are addressed, and we are left with a deceptively simple question: "What role does imitation play in firms learning and capabilities development?" While this question, framed in this way, may be concise, the path towards an answer is much less so. Existing literature offers clues in the form of partial theories and countless empirical examples, but very little footing from which to answer this basic question. Instead, theorizing must be undertaken on the basis of original empirical research, specifically theory building through case studies, with existing literature providing the theoretical lens, and the fragmented insights of past empirical findings as clues. This process of interactive theory building through the analysis of the Chinese wind turbine industry is the core endeavor of this thesis.

As the basis for this investigation, we first discuss the specifics of the wind turbine manufacturing industry, and the situation in China, followed by an overview of theoretical and empirical literature on imitation. Building on this, we break the central question into sub-questions, and because of the exploratory nature of this work, these questions are developed sequentially, building on completed work as research progresses.

The first two of these questions are a closely linked pair: "What approaches to imitation do firms pursue?" and "What forms of learning relate to these strategies?" To address these, we draw extensively on existing literature on firm learning within the innovation systems approach. Through discussions with industry sources considering a wide range of firms, we identify key shifts in imitation approach common to multiple firms. Simultaneously, processes of learning and capabilities creation are discussed, linking these approaches to specific types of learning within the firm. In addition to these specific linkages, we find that firm strategies and existing capabilities limit the approaches to imitation that can be pursued, and that these approaches to imitation in turn define opportunities for learning.

While this provides a useful vocabulary of approaches, and defines the relationship of these approaches to modes of learning, it necessarily sets aside the unique paths that individual firms follow, and the firms-specific and path-dependent co-evolution of learning and capabilities. This firm level diversity of strategic trajectory is a core focus of this research, and is further explored through case studies of firm histories guided by our third research question: "How are these strategies assembled into firm-specific histories in which capabilities develop cumulatively and imitation builds innovation capabilities?" To explore this, three firms are selected from among those discussed by industry sources in earlier interviews. Using the vocabulary established earlier in the research, the histories of these firms are examined through publications and discussions with industry sources. Based on this, the approaches to imitation, modes of learning, and capabilities development evident in the development of the firm are characterized, and their relationships examined. Several important observations about the firm level process of learning by imitating emerge from this, and become the basis for further discussion.

Perhaps the most interesting such observation is that firms pursue multiple approaches to imitation, and therefore multiple modes of learning, simultaneously. This is somewhat paradoxical given homogenizing pressures within firms. In the cases discussed, it appears that within the firm, heterogeneity is allowed by the limited physical and relational proximity of different division. This occurs either through careful management, or as a side effect of the severe, top down management style that limits internal communications, combined with the mediating effects of geographic distance. This establishes multiple selection environments for internal routines, and therefore allows simultaneous approaches to imitation, and learning in multiple modes. Simultaneous learning builds capabilities a broad range of capabilities much more quickly then sequential learning. Taken in comparison to the small geographic scale, and tight control and integration characteristic of Korean and Japanese firms, this begins to explain how the development of these firms is so different from - and so much faster than - previous examples.

While such observations are intriguing, they are the outcome - not the starting point - of this research, and therefore remain relatively unexplored. Nonetheless, they offer the possibility of unique insights into this crucial process, and serve as a starting point for future research. As such, we conclude with a discussion of the research agenda that stems from our findings in the hope of inciting future research within what we believe to be a promising approach.

2) China and the Wind Turbine Manufacturing Industry

While the main aim of this project is theory building, we see our case study industry, and the specifics of its structure, operation, and development as central to this endeavor. As such, we provide a basic overview of the wind turbine itself, the structure of the industry built around it, and the development of the manufacturing industry in China before moving on to theoretical literature in later chapters.

From their roots as cloth-sailed windmills, wind turbines have become high tech assemblages of customized components. With the largest models producing 7.5MW (Knight, 2010), and having rotor blades twice the length of the wings of a Boeing 747, the design of modern wind turbines requires extensive knowledge of electronics, mechanics, hydraulics, advanced materials and aerodynamics. Despite their staggering size, designs are not based on dramatic new inventions or recent scientific discoveries, but embody the steady accretion of inputs from many actors. (Garud and Karnoe, 2003)

The use of wind for the production of power dates back millennia, with the first electricity producing turbines emerging in the late 19th century. With the 1973 oil crisis wind power was transformed into a potentially viable source of large-scale power generation. Following extensive government support in both Europe and the US, large prototypes were developed, and the modern, horizontal access, three-blade design emerged. With the crisis past, however, this technology fell by the wayside, largely unused until the mid-1990s. At this point, interest in renewable power generation increased dramatically, and with revived government support, the industry entered a period of dramatic growth visible in Figure 1, below. Between 1996 and 2009, global installed capacity increased by a factor of 25.

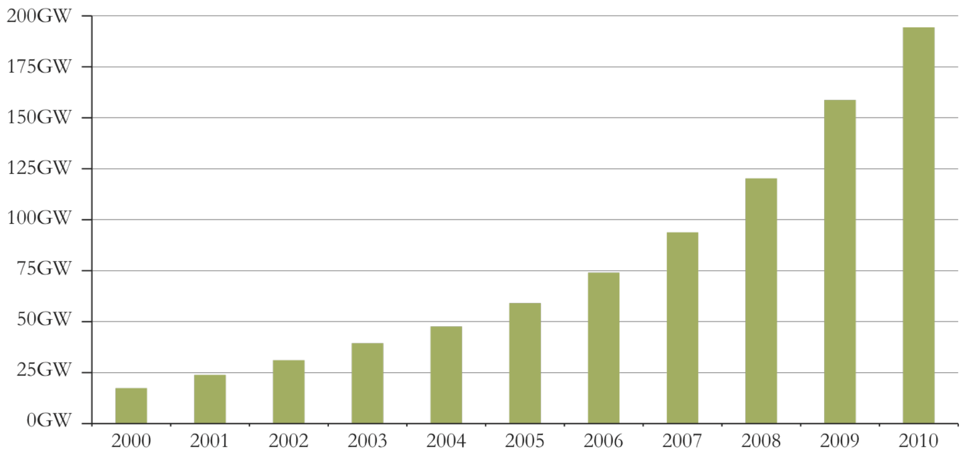

Figure 1: Global Installed Capacity (Global Wind Energy Council)

2.1) Industry Actors and Structure

Given the systemic nature of the turbine itself, and the system in which it operates, an understanding of the key actors in the industry is critical to understanding the requirements placed upon the manufacturers. Four primary actors are directly involved in the design, manufacture and use of turbines:

> **Wind turbine manufacturers** design, test, manufacture, and assist with the operation and maintenance of wind turbines.
>
> **Wind power consulting companies** offer services including turbine design and certification, technical Due Diligence, wind resource mapping, assessment, and forecasting, and turbine performance testing.

Wind farm developers develop and sometimes own and operate wind farms. This involves purchasing or leasing land, quantifying the wind resources, and securing transmission, power sales, turbine supply, construction, and financing agreements. Upon completion of the project, it often resold to a managing owner such as a utility company.

Wind power managing owners are responsible for the operation, maintenance and administration of the completed wind farms. Often much of this responsibility is subcontracted to specialist firms, including subsidiaries of the manufacturers. Wind power managing owners sell the electricity generated to public utilities under project-specific, long-term agreements.

Because of the highly systemic, integrated nature of these products, and the complex network of actors – all of which are "customers" in some sense – interaction between these actors is considered critical for the successful development of wind turbines. (Klagge, Liu et al., 2011)

2.2) Policy and Opportunity: China's Entry into the Market

With rich wind power resources, and a favorable economic and policy environment, China has emerged at the center of the international wind industry over the past decade. After sustained growth of over 100% annually for the past several years, China became the largest wind energy producer worldwide in 2010. With an installed wind power capacity of 42.29 GW, it now accounts for 21.8% of the global total. In terms of scale and rate, this development is unparalled, according to the Global Wind Energy Council.

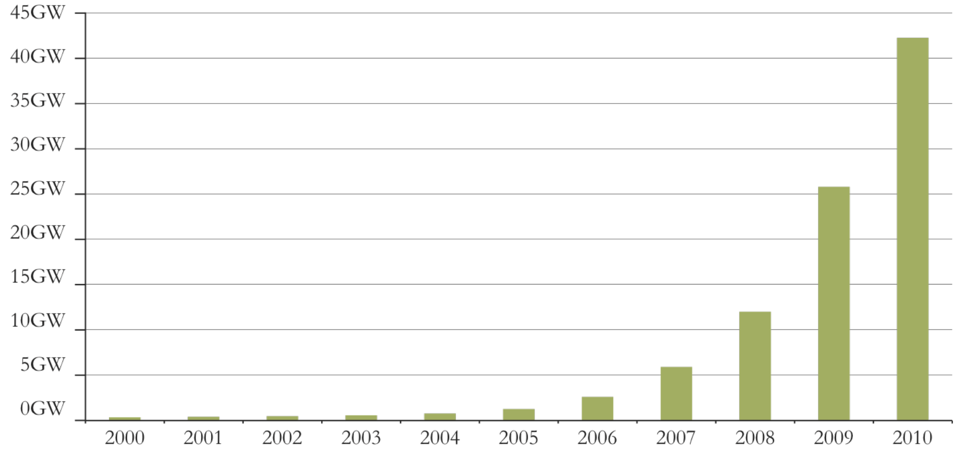

Figure 2: Chinese Market Installed Capacity (Global Wind Energy Council)

National and local government policies have played a crucial role in this development, providing the wind power industry with financial and regulatory support, including investment and R&D subsidies, tax breaks, government run projects and fixed feed-in tariffs which create a guaranteed demand for wind energy. (Klagge, Liu et al., 2011) The government's active involvement the sector began in 2004, with the drafting of the first renewable energy Law. Coming into force in 2006, this law required grid companies to purchase all the electricity produced from renewable sources, and introduced concession projects and competitive bidding as the primary development mechanism. (Lewis, 2007) The wind industry has grown rapidly since this introduction, with the market growth of 60% in the year the law was passed, and four consecutive years of greater than 100% growth (2006-2009). (Global Wind Energy Outlook, 2010)

In 2007, the Chinese government released the 'Medium and Long-term Development Plan for renewable energy in which set market share targets of 10% in 2010 and 15% in 2020, for non-hydro renewable electricity. Additionally, the "Big Five" power producers[1] were required to

[1] China Huaneng, China Datang, China Huadian, China GuoDian and China Power Investment

generate 3% of their electricity from non-hydro renewable energy sources by 2010, and 8% by 2020. (Global Wind Energy Outlook, 2010) With industry sources suggesting figures as high as 150GW for 2020, the rapid growth of this industry, supported by these strong policy measures, will likely continue for the foreseeable future. (Zhang, 2010)

2.3) Transformation of the Chinese Industry

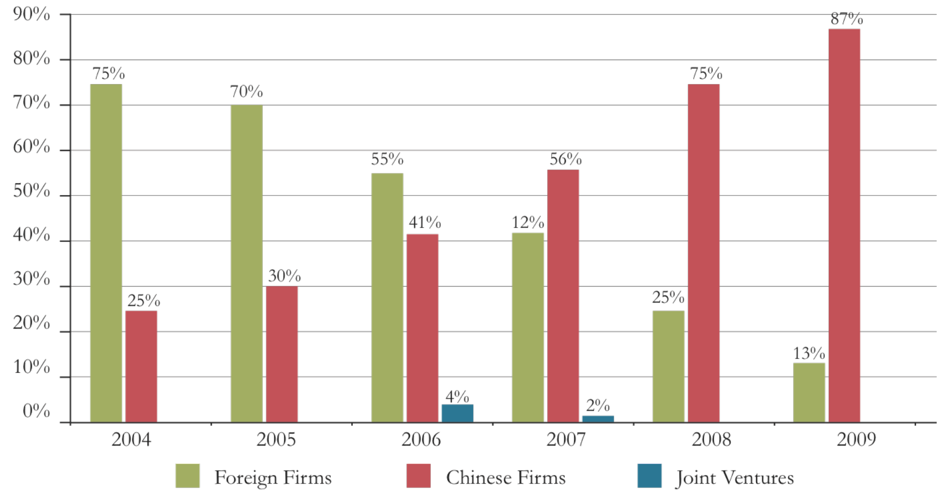

Figure 3: Newly Installed Capacity by Firm Type (China Wind Power Outlook 2010)

While in 1998 Goldwind was the only notable Chinese firm, by the end of 2010 there were more than 80 companies involved in turbine manufacturing. (Global Wind Energy Outlook, 2010) While domestic companies accounted for only 30% of China's cumulative installed turbine market in 2005, they now supply almost 90% of the domestic market and are rapidly developing export strategies. (Li, Shi and Hu, 2010) This dramatic shift towards the domestic production of wind turbines, shown in Figure 3, has been supported by practical factors such as the high cost of transport of turbines, and extensive policy measures such as a 70% domestic content requirement and heavy tariffs on imported turbines.

Manufacturer	Rank	New Installations	Share of Total
Sinovel	1	4386 MW	23.2%
Goldwind	2	3735 MW	19.7%
Dongfang	3	2624 MW	13.9%
United Power	4	1643 MW	8.7%
Mingyang Electric	5	1050 MW	5.5%
Vestas	6	892 MW	4.7%
Shanghai Electric	7	598 MW	3.2%
Gamesa	8	596 MW	3.1%
XEMC Windpower	9	507 MW	2.7%
China Creative Wind Energy	10	486 MW	2.6%

Table 1: Top 10 Manufacturers by 2010 New Installations in the Chinese Market (Chinese Wind Energy Association)

According to the Chinese Wind Energy Association, the manufacturing industry for wind power equipment is now clearly divided into three levels. Three top firms - Goldwind, Sinovel and Dongfang - occupy the highest level, dominating the sector with industry leading capabilities, and earning a place among the world's top ten manufacturers in 2009 (See Table 1, above). Second level firms such as Mingyang, United Power and XEMC, have started to make efforts to with these leading firms, but have not yet reached the same scale. Nonetheless, the have significant experience and capabilities, often with a background in related industries. As turbine size increases and offshore designs become more important, both first and second level firms are developing 5 MW or larger turbines and can be expected to produce competitive and technically mature machines. (Li, Shi and Hu, 2010)

This leaves between 60 and 70 firms with limited capabilities, and little or no installed base of turbines. Unless the export market for increases considerably, or growth in the home market increases more quickly then established firms can supported, there will likely be little room these remaining firms. (Global Wind Energy Outlook, 2010)

As Simon Feng of DNV Beijing explains, “I am in contact with almost 40 companies, and everyone says they have every capability. Some teams just have 10 engineers, but they say they have the capabilities.” With this in mind, he sees the industry as already quite consolidated, and rapidly moving towards having a very limited number of key players, “There are more then 90 firms in total, but among them there is just around half have a prototype. Among those, just half of have an installation record - a cumulative record of more then 2-300MW- around 20. Among these, a lot of the smaller companies, have only 300 or 500MW, and cannot win more projects in the future.” However, to be successful, he argues that a firm needs “deeper capabilities to understand all of the systems”, and that this understanding is limited to between 5 and 10 firms.

To this end, in 2010 policy was introduced that eliminated subsidies and incentives for all but the ten largest manufacturers through product and production capacity requirements. Supported by this regulation, a dramatic consolidation of the industry is expected over the next several years. (Pellman, 2010)

With rapid and unprecedented growth, technological complexity, and the clear role played by foreign firms and technology, the Chinese wind turbine manufacturing industry presents a compelling case for our study of imitation in firm capabilities development and learning. In addition to these theoretical contributions, we hope that by choosing an industry with such political and environmental importance, we are able to make a practical contribution to the development of the industry, and to provide certain insight to those involved in the management of innovation and firm strategy.

3) Imitation and Innovation: Existing Literature

The exploratory nature of this research and case study based approach to theory building demands a wide base of supporting literature. This literature is linked by both theoretical and topical themes, and organized into sections focused on imitation and learning, respectively. We begin the section on imitation with a general discussion of the importance of imitation within evolutionary theory, and from here shift towards a discussion of imitation as a firm strategy within the developed economy, and as a component of national scale development. With a broad background established, existing characterizations of firm-scale imitation strategies are discussed and their applicability explored. Finally, specific literature on imitation as a component of firm-scale learning processes within the context of developing and newly industrialized economies is discussed, and key characteristics of this process established.

While this research focuses on firm scale processes, these processes – especially processes of learning – are interactive and embedded within a broader context. As a basis for understanding this context, and the role it plays within these firm-scale processes, we look to innovation systems literature. A broad overview of this approach is presented, followed by an in-depth discussion of the modes of firm-scale and system-scale learning defined by previous literature within this approach. While this body of literature may at first seem diffuse, it is necessary in order to examine the firm-scale imitation and learning process as embedded within the Chinese context.

3.1) The Importance of Imitation: An Evolutionary Approach

Imitation, and more specifically the nuanced process by which firms learn through imitating, is seen as largely inconsequential in neoclassical economics. The diffusion of technology is instantaneous, and a given technology is available to all firms that will benefit from its adoption without regard for firm specific characteristics or capabilities. Intellectual property protection, licensing, and other such mechanisms are substantial only in so much as they increase the cost of acquiring a technology and therefore shift the utility maximization function.

Evolutionary economics, however, understands technology as an endogenous factor that must be explained in the course of economic analysis. (Nelson and Winter, 1977; Nelson and Winter, 1982) Drawing on the work of Schumpeter, technological change is viewed as a key force driving economic growth. With this acknowledgement comes the acceptance of the fundamental uncertainty of technological development and therefore the inability of firms to understand all potential technological options and their costs. More generally, behavior is not seen as optimal, but maximizing within the constraints of bounded rationality and imperfect information.

In order to explain economic processes without these bounding assumptions, the evolutionary metaphor is adopted from biology and variation and selection processes are taken as fundamental mechanisms shaping change. (Nelson and Winter, 1977) The actions of firms, no longer limited to a simple optimization equation, are shaped by past experience and expectations about the future. Firm-specific search heuristics develop which allow firms to explore and choose options despite uncertainty, creating variation in the process. While such heuristics are specific to the firm, they are embedded within broader frames of reference such as technological paradigms. (Dosi, 1982; Dosi, Freeman and Nelson, 1988) Within a given paradigm, technological development is cumulative, establishing a technological trajectory that further reinforces existing search heuristics. This trajectory establishes technological guideposts (Sahal, 1985) and brings about the development of a dominant design that establishes the basis for future innovation (Abernathy and Utterback, 1978).

These firm scales processes of innovation and variation creation, however, are far from assured in their success. Continuing the evolutionary metaphor, the notion of a 'selection environment' – much more broadly defined than a market – is introduced as the mechanism by which more promising variations are built upon, and less promising ones left behind. This selection environment includes all factors which potentially influence this process, including norms, beliefs, expectations, regulations, policies, taxes, subsidies, and, of course, the market and the needs of customers.

Within this general approach, Nelson and Winters (Nelson and Winter, 1977) propose imitation as the dominant mechanism of technological diffusion, and the only such mechanism by which successful innovation spreads to other firms. While more orthodox work on dynamic competition stresses the expansion of use of an innovation by the innovator, Nelson and Winter build on Schumpeters' strong focus on dynamic competition and creative destruction, proposing that both expansion of use of an innovation by the innovating firm and diffusion of this technology through imitation to competing firms are essential. Furthermore, within their understanding of the time based, evolutionary nature of the economy and the market as a complex selection environment they question the focus of previous studies on imitation as mutually exclusive of innovation, and claim the need to understand innovation and imitation as parallel and interrelated processes which co-occur within a selection environment and technological trajectory, shaping its continued evolution.

3.2) Imitation as a Firm Strategy in Developed Economies

Literature from the fields of business strategy and business economics are aligned with evolutionary approaches in that they adopt the firm as the primary unit of analysis, consider firm heterogeneity, and focus on the competitive advantages of imitation. While imitation is not discussed within the broader context of innovation systems or processes of catching-up in developing countries, this literature provides insights into the operation of the firm, and select articles begin to uncover connections between imitation, learning and capabilities development within the firm.

The classic Teece (1986) article, in particular, provides useful background on the relationship between innovators and imitators, outlining a series of scenarios in which complementary assets, appropriability regimes, and the state of technical development of an innovation define the potential role and successfulness of imitators. Specifically, he argues that while strong appropriability regimes (either institutionalized through IPR law, or constructed through secrecy) grant innovators a monopoly and incentivize innovation, in practice appropriability regimes are almost always weak because secrecy is limited to very specific industries, and patents and other forms of intellectual property protection are difficult to acquire and easy to "invent around". Given this, he argues that the factors which determine the relative success of innovators and imitators are directly related to the lifecycle stage of the product, with the market shifting from price-competition towards design-competition in a reversal of the Abernathy and Utterback's 1978 model. This, he argues, creates opportunities for a transfer of market share between imitators and innovators at multiple stages in the lifecycle, as the capabilities required for success are constantly changing, and firms must adapt.

3.3) Imitation as National Development Strategy

In contrast to literature already discussed, literature on imitation from macro and development economics takes the national economy as the unit of analysis, and focuses on international competitiveness and the catching-up process of nations. Imitation is seen as a critical step in the development process, and intimately related to learning, but the firm-scale imitation to innovation transition is understood as largely linear and automatic, guided by the national scale process.

Among the key focuses of this literature is the process, beginning in the 1960s, whereby countries such as Korea, Taiwan, Singapore, and Hong Kong transformed themselves into technologically advanced, developed economies. In explaining this rapid transformation, and the role of imitation in the development of innovative, world-class firms, a broad "imitation to innovation" framework is proposed by a range of literature. (Segerstrom, 1991; Kim, 1997; Kim and Nelson, 2000) Kim (1980; 1997) argues that the process of innovation in catching up countries is fundamentally different from that of developed countries, but that innovation models such as Utterback and Abernathy (1978) can be useful in understanding this process. Kim (1980) proposes a three-stage model, with developing countries moving from acquisition of foreign technology, to assimilation and eventually improvement. Initially, firms acquire mature, foreign technologies that only require limited local production engineering. In the second phase, process engineering and product design technologies are acquired and applied. Finally, R&D is applied to produce new product lines. The typical sequence of innovation events is therefore 'reversed', with countries moving from mature to early stages of the innovation process. Lee and Lim (2001) expand upon this model, arguing for a range of 'stage skipping' opportunities, and questioning the necessity of sequential transition through this process.

Building on this model, Kim and Lee (1987) and Kim (1997) relate patterns of development to the nature of the production technology pursued. Using Woodward's (1958) differentiation between unit/small batch, large batch/mass production and continuous process technologies, these papers show that product innovation is most important for catching up in unit and small batch production (e.g. large shipbuilding and machinery), while large-batch and mass production (e.g. electronics and cars) dependent on a mix of process innovation and product development. Continuous process technologies (e.g. cement, chemicals, steel) are the most capital and process intensive, but offer little product differentiation, and therefore dependent on production process capabilities and detailed proprietary know-how.

Working from research on the Asian NIEs, Pack (2000) focuses his analysis on the importance of foreign technology in this process, and how it is coupled with local learning. He argues that through extensive spillovers through employees, spinoff firms, local observation, and other such mechanisms, this process presents many unacknowledged opportunities for learning, and that these are critical to the development process of the nation. Additionally, he argues that this importance is maintained even as the nation moves towards innovation because foreign technology plays a role in legitimating and guiding research decisions, and therefore allows for innovation capabilities to develop partially shielded from the uncertainty of frontier innovation. As he succinctly puts it, "Local R&D inevitably has failures, whereas gaining a mastery of technologies that are known to work in other countries has few dead ends" (76).

It is critical to note that because of the relatively small geographic size and strong central control of Korea and other examples, there is an assumption of homogeneity of firms, and simultaneity in firm scale and national scale processes implicit in these models. As such, there is a significant degree of confusion between firm scale and national scale models and mechanisms, and while the discussion takes place with the stated unit of analysis as the nation, authors such as Hobday, Rush and Bessant (2004) , consider these to be firm scale models.

This assumption of firm homogeneity is a core weakness of this approach, and makes specific findings largely inapplicable to the diversity found in China. Nonetheless, the reverse-stages model provides a broad framework for understanding the imitation to innovation transition at the firm scale that can be critically applied. Additionally, insights such as the importance of the type of product technology, the impact of government policy, and the importance of the broader socio-economic environment (Kim, 1997) are likely important, although to an unknown degree.

3.4) Characterizing Strategies of Imitation

Given the tremendous complexity and heterogeneity apparent in intensive, firm scale studies, how then can we begin to characterize the process by which firm capabilities are built, and the firm transitions from imitation to innovation?

Kim and Nelson (2000) propose a distinction between "duplicative imitation" and "creative imitation". Duplicative imitation, they argue "conveys no sustainable competitive advantage to the imitator in a technological sense, but… if legal, is an astute strategy in the early industrialization of low- waged, catching-up countries". Conversely, creative imitation including design copies, creative adaptations, technological leapfrogging, and adaptation to another industry requires significant existing capabilities but also provides "notable learning through substantial investment in R&D activities".

Drawing on developmental psychology and earlier studies on organizational learning, Li and Kozhikode (2008) propose a typology of imitation based on firm strategy and the character of the learning involved: 'blind imitation' vs 'emulation'. This is at first glance similar to the Kim and Nelson's (2000) 'duplicative' and 'creative', but places the emphasis of this division on the strategic intent of the firm, addressing previous arguments that learning is not automatic but instead must be conscious and purposive. (Pack, 2000) Additionally, the focuses on learning inherently moves the typology beyond a static classification of firms, and begins to consider the process by which firms transition between these modes.

Emulation, they say, "involves learning about the properties of, or causal relations between, objects (rather than just about their presence in the environment)" (Want and Harris, 2002), while imitation, involves "recognition and reproduction of the goal of the observed behavior, as well as the specific actions that brought about that goal" (Tomasello, 1990). Original literature on social learning argues that "these two forms of social learning are useful in different circumstances and, in terms of what an observer learns from a model, the two processes may be thought of as complementary.

Want and Harris (2002) argue, "while a 'blind' imitator learns to perform actions for a specific goal, but does not learn the [nuances] involved in those actions, an emulator learns the [nuances] involved, but not the actions or the goal. Intuitively, emulation offers a highly flexible form of knowledge." In social learning, learning by emulation requires greater effort than learning by imitation, but learning by emulation may produce flexibility in terms of the knowledge acquired. Emulation is understood as a slower, more thorough process in which not only the action itself but also its effects must be observed for learning to occur. This flexibility, they argue, is key to allowing firms to develop internal resources to replace the resources being imitated, and in this way transition to into creative imitation and innovation.

Mirroring the analysis of Kim and Nelson (2000), Li and Kozhikode (2008) claim that imitation and emulation serve very different needs, and each is suitable to different firms depending upon their long-term strategies. Firms entering an industry for the long term tend to learn by emulation, while those that wish to accrue maximum short-term profits and exit the industry when it becomes unprofitable choose imitation. Imitation, however, has a role in the early development of firms with a long-term strategy as a means to build baseline competences and "get into the race". Again, the importance of imitation is clear, but imitation and innovation are assumed to be unrelated, and the specific mechanisms by which imitation builds baseline capabilities are not examined.

3.5) Imitation as Firm Strategy in Catching Up Economies

Within the past decade, several articles have emerged which begin to address the prevalent conflation of the firm and national scales through intensive case studies of firms in catching up economies. Focusing on a variety of firms at different stages in the imitation to innovation transition, these studies begin to reveal the complexity and heterogeneity of this process at the firm level.

Working from detailed case studies in three strategic divisions of Samsung, Kim, Shi and Gregory (2004) focus on capabilities creation, and the challenges encountered during the transition process. They propose four stages of the imitation to innovation transition: external learning, internal learning and generation, dependent external performance, and independent external performance. Initially external support such as product and process technology serves as the basis for learning. This, in turn, leads to generating new knowledge directly based on externally sourced knowledge, and generating technology to improve internal capabilities. In addition to these tangible technological developments, the firm must develop intangible capabilities such as organizational learning and new product development processes.

After building sufficient internal capabilities, including product and process technologies and intangible capabilities, the firm is able to transition towards innovation supported by external technology acquisition and support. If such a transition is attempted prematurely, the firm then falls back to being an imitator, while learning from its attempt at innovation. Finally, in the fourth stage the innovation is refined and internalized, leading to increased innovation and global competitiveness.

Five categories of determinants are identified as crucial during this transition process: firm strategy, R&D activities, organizational structure, and manufacturing and new product development processes. Additionally, the insight that these processes and mechanisms of innovation develop prior to achieving innovation-based competitiveness in the global market is strongly supported by the case studies. This suggests that the transition to an innovation-based approach occurs prior to innovation-based competiveness, and that an accumulation of these capabilities, and experience with this approach are the final steps in the transition towards this form of competitiveness.

Hobday, Rush and Bessant (2004) focus on the challenges facing latecomer firms in the transition from catch-up to leadership. Based on in-depth interviews with 25 leading Korean firms, they argue that the that the division between imitation and innovation strategies is a misleading oversimplification, and does not do justice to the main innovation challenges facing Korean firms, especially as they approach leadership. Most major exporters offer a portfolio of products, some of which are technologically advanced and others less advanced, and innovation strategies therefore tend to be executed in relation to the needs of specific products rather than 'the firm' as a whole. Similarly, even leading firms maintain large volumes of production under sub-contracting and licensing agreements. Firms therefore embody a mix of leadership, 'followership' and latecomer strategies mirroring their product portfolio. The imitation-innovation transition does not occur in stages, but through a complex overlapping of simultaneous approaches within the firm.

Similar intensive research is undertaken in the Chinese context by Minagawa, Trott and Hoecht (2007) through interviews with three Chinese manufacturing equipment producers that in the past participated in licit and illicit imitation, and today are relatively large, innovative players in their respective markets. This study offers detailed and nuanced evidence of the relationship between imitation and innovation, and several key insights drawn from it shed light on this process within the specific context of China.

The first case study firm emphasized that both legal distribution and illicit imitation activities where crucial to initial success, and this, in turn, funded the further development of reverse engineering and imitation capabilities, and later general business and capabilities expansion. Notably, the interviewee does not mention a shift away from imitation, but instead the establishment of other forms of product and process development in addition. Another firm emphasized the importance of imitation and reverse engineering individual component in establishing themselves as a fast, cost-effective, and trustworthy supplier. From this position in the market, they were able to effectively build their business and expand into larger complete machines and more advanced research. The final firm emphasized the importance of information sharing through distribution and licensing agreements, and the way in which access to this information allowed for the incremental development of adaptation, learning, and R&D capabilities while limiting risk. Another key point made by this interviewee is that, despite the development of substantial R&D capabilities, the firm still views itself as dedicated to "the *production* of world class and high technology machines" (p463, emphasis added). Product design and engineering are seen as secondary to the establishment of manufacturing processes and facilities. This view that technology is instrumental to manufacturing, and that the focus of the firm is production, is seen in all three cases, and may potentially distinguish the strategy of Chinese firms from western firms that increasingly define themselves as R&D driven.

Explicitly addressing the technology transfer and imitation process at the firm scale, Lall (2000) argues for the fundamental importance of technology in economic development and catching up. However, the process by which this takes place is "strikingly different from textbook depictions of how technology is transferred and used in developing countries." (p16) Instead, he sets out ten features of enterprise-level technology capability development from which future research can proceed. From these ten points, we extract two key ideas that are critical to understanding the process of capabilities development in firms in catching up economies.

Industry and Technology Specificity
Learning depends on existing capabilities and experience, and the nature of the learning is related to the development process of the technology. The learning process and the capabilities necessary for it to occur is therefore highly technology specific. Policies and capabilities useful in one area may be ineffective or counterproductive in another. The specific external agents (firms, consultants, suppliers, institutions, etc.) and the nature and degree of interaction with them is similarly specific. Transferability of experience across technologies and industries is therefore limited.

Capabilities Develop at Diverse Scales and Depths
Capabilities building occurs at all levels within a firm (shop floor, process and product engineering, inventory control, quality management, maintenance, procurement, inventory control, etc.) and formalized R&D is only a very small part of the larger process by which a firm familiarizes itself with a technology. Consequently, the depth of learning for a given technology is flexible, and many activities are possible with only a very basic understanding. Firms can, for example, become quite skilled in the manufacture of licensed technology, and become successful in the market based on this, despite their continued dependence on external capabilities. While this reduces long-term capabilities development, it also decreases the cost, risk, and duration of learning that is demanded by deeper understanding.

While the explicit firm-scale perspective, and focus on learning in Lall's analysis overcomes the conflation of national-and firm scales, and therefore assumptions of homogeneity, certain assumptions of capability building as a linear, additive process remain. Lundvall (2000) argues that this is particularly apparent in relation to the assumption that "know-how" proceed "know-why", noting that "know-why" is generally codified and often shared through knowledge networks, while "know-how" is largely tacit and developed through experience. He argues that both their relative difficulty or importance is highly specific, and they should therefore not be assumed to develop along a common trajectory. This criticism can be taken more broadly, and reinforces the need for future research to set aside such assumptions and provide a framework within which firms can be understood as path-dependent and heterogeneous, and the learning as complex, path dependent, and non-linear.

3.6) The Firm as Embedded Actor within an Innovation System

While this research focuses on firm scale processes, these processes – especially processes of learning – are interactive and embedded within a broader context, as described by Lall (2000). As such, the innovation system approach is adopted as a framework within which to understand the learning process. The focus of this research, however, is not a holistic analysis of the wind turbine innovation system. As such, the system level model serves as a foundation from which firm-level analysis of imitation and learning can be studied intensively.

The general proposal that the innovation process must be understood within a larger system of innovation emerged in the late 1980s and early 1990s in work by Freeman (1987; 1988), Lundvall (1988; 1992) and Nelson (1993; 1994). In line with Nelson and Winter's evolutionary approach, and their concept of the 'selection environment', innovation is seen as influenced by a broad range of actors including companies, government bodies, universities, research institutes, financial markets and institutions and consumers, and other organizations. It is this system of actors, including the relationships between them and institutions influencing them, which forms the innovation system (Carlsson, Jacobsson and Holmén, 2002).

From this broad understanding of the innovation process, numerous particular approaches have emerged. While originally focused on the national unit as the bounds of a given innovation system, these approach has since expanded to include systems defined by regional (Cooke and Uranga, 1997; Braczyk and Cooke, 1998; Cooke, 2001), national (Freeman, 1987; Freeman and

Lundvall, 1988; Lundvall, 1988; Lundvall, 1992), sectoral (Breschi, 1997; Malerba, 2004) and technological (Carlsson, 1991; Jacobsson and Johnson, 2000) boundaries.

The majority of existing research on related to imitation and innovation, especially research focuses on the developing world, has chosen to implicitly or explicitly define the innovation system along national boundaries. The range of historical studies on Asian NIEs previously mentioned have done this in response to the overwhelming importance of national policy in the development process and the strong domestic focus and relative insularity on emerging firms.(Chung, 2003) Similarly Kamp (2002) , adopts a national innovation system approach in her study of the emergence of the wind turbine industry in Denmark and the Netherlands in order to highlight differences in institutional context influencing this development.

For the purposes of focusing on processes of learning within the emerging Chinese wind turbine industry, however, a technological innovation systems approach is advantageous. This is broadly supported by Lall's (2000) argument that interactions occur both within the domestic and international context. Specifically, the wind turbine manufacturing industry is global, and technologically, not nationally, defined. Most major actors are present in all major markets, and R&D, management and manufacturing, are globally dispersed within a single firm. In line with both arguments, the focus of this research is on the imitation-innovation relationship between, what are today, Western/Global and Chinese firms. As such, a globally scoped, technologically defined innovation system is implicit in the aim of this research. To define the innovation system at the purely national scale would make proper analysis impossible. Similarly, the applicability of the technological innovation systems approach to emerging sustainable energy industries has been argued by Jacobsson and Johnson (2000), and successfully demonstrated by Negro (2007) and Suurs (2009).

In adopting such an approach, however, geography comes to play a far larger role within the system. While in the nationally bounded innovation systems of small countries proximity is relatively constant and strong, and the internal geography of this system therefore largely ignored, as the system grows to encompass a large and diverse nation such as China, and the foreign actors involved in a global, technologically defined system, the internal geography – spatial, social, political and institutional - necessarily comes to have a much larger influence. In short, a technologically bounded system is understood as internally heterogeneous, and unlike previous research, the internal structure and organization of the system is critically analyzed.

3.7) Firm Learning as Interactive and Embedded

Within an innovation system approach, the process of firm level capabilities development is understood as an evolutionary learning process, and the ability of a firm to learn is therefore central to its success. In looking at imitation as a means for capabilities development, the characterization of its potential therefore becomes a discussion of its relationship to learning. By examining different approaches to learning, and relating these to different strategies that firms pursue, it becomes possible to close the gap between imitation, learning, and capabilities development.

While an analysis of the innovation system as a whole, especially as undertaken by Lundvall (1992), focuses on system-scale interactive learning, this research instead uses the innovation system as a context for firm scale analysis, and therefore must carefully re-interpret interactive and embedded learning from the perspective of the firm. As such, we adopt the three forms of firm scale learning accepted in current literature: learning by searching, learning by doing and learning by using. (Rosenberg, 1982; Garud, 1997):

Additionally, learning by interacting is often cited as crucial mode of learning within innovations systems literature. Specifically, Lundvall (1988) argues for the importance of close and persistent contact between users and producers during the innovation process, especially where firms are unable to develop the complete set of required knowledge and skills in-house. We, however, see interaction as essential and implicit within all modes of learning, and therefore set aside this category as a distinct mode of learning. Nonetheless, the requirements for learning by interacting developed in existing literature remain essential, and can be viewed as requirements for learning in all modes. Based on an extensive analysis of innovation literature (Andersen and Lundvall, 1988; Lundvall, 1988; Lundvall, 1992; Dodgson, 1996; Grin and Van de Graaf, 1996; Carlsson and Jacobsson, 1997; Cohendet and Llerena, 1997; Van Est, 1997; Williams, Slack and Stewart, 2000; Nooteboom, 2001), Kamp (2002) identifies the following conditions:

1) Proximity in the broad sense, including geographical closeness, cognitive closeness, a common language and culture, national standardization, common codes of conduct, a certain lack of competition and mutual trust between the actors, and congruent frames of meaning regarding the technology.

2) Mutual interest in the learning process.

3) Norms of openness and disclosure, or the presence of an intermediary if information is not transferred easily or if not all relevant actors cooperate spontaneously.

Learning by Doing

The concept 'learning by doing' is introduced in the classic Arrow (1962) article. This mode of learning focuses on the generation of 'know-how': the knowledge and skills necessary to efficiently produce something. This is primarily tacit knowledge that resides in individuals, organizational routines and manufacturing practices (Garud, 1997). For this reason, it is both difficult to transfer, and a potential source of lasting competitive advantage. Arrow argues that the majority of this learning occurs in the course of manufacturing a product, and therefore after design is complete.

Through the recognition and solving of problems, faults and bottlenecks ongoing incremental improvements to production skills accumulate with time (Garud, 1997) . This, in turn, increases production efficiency (Rosenberg, 1982) and supports the development of 'rules of thumb'. (Sahal, 1981) Such improvements often depend on simple trial-and-error experience, although more difficult issues may demand complex, iterative problem solving and therefore include aspects of learning by searching.

Learning by doing is largely a product of production experience, and therefore the combination of volume and time (Kamp, 2002) . However, when looking at processes within the firm, it must be noted that this knowledge is generated within the manufacturing plant, and its diffusion to the firm as a whole is largely dependent on the effectiveness of internal communications, especially the relationship between R&D and manufacturing.

Learning by Using

Rosenberg (1982) introduces the concept of 'learning by using', arguing that learning occurs through observation of the use of the product by customers. While learning in this mode is valuable in all contexts, he argues for its critical importance in relation to products that consist of complex, interdependent components. During use, especially prolonged stress, the interaction of the components cannot be precisely predicted. This interaction can only be assessed after intensive or prolonged use, and the knowledge that this provides can define and improve the optimal performance characteristics of a durable product, and aid in better understanding the role of components and design decisions in determining the useful life of the product.

While prototyping can provide limited learning by using in-house, the primary actors in this mode of learning are the end-users of the technology. As such, effective communications between the user and producer are central to this mode of learning. Kamp (2002) identifies two additional key facilitating conditions:

1) The presence of users. This can become a limiting factor in cases when technologies are developed entirely by R&D departments without user involvement.

2) The existence of a user group of a minimum size and degree of sophistication. The characteristics of the product under consideration determine the minimum size of the demand and its minimum degree of sophistication. (Andersen and Lundvall, 1988)

Learning by Searching

Learning by searching is related to the development of search heuristics, and the active, systematic and organized search for new knowledge that these allow. As such, it includes wide a range of activities related to research and development of products and processes, both in response to technological opportunities and the demands of the market. Learning by searching involves a similarly broad range of actors, from universities and public research institutes to firm R&D departments, and, potentially, customers.

Kamp (2002) identifies key conditions for learning by searching through an extensive analysis of innovation literature (Nelson and Winter, 1977; Hedberg, 1981; Sahal, 1981; Dosi, 1982; Nelson and Winter, 1982; Andersen and Lundvall, 1988; McKelvey, 1997; Frenken, Marengo and Valente, 1999; Frenken, 2001; Carlsson, Jacobsson and Holmén, 2002):

1) The presence of mechanisms guiding the search process, including technological guidepost, appropriate scientific theories, a technological paradigm, and standards and regulations.

2) An environment that is not (too) hostile, supporting the possibility of making mistakes and learning from them.

3) The availability of capital, and some level of knowledge and experience in the field of study, to support the process.

4) Institutions supporting the ownership of novelties and new knowledge.

The broad range of literature discussed provides a basis for understanding the role of imitation in economic theory generally, the process of firm capabilities development and national scale catch-up, and the process and modes of firm learning, embedded within the innovation system model. While each specific body of literature brings unique problems and assumptions, all offer insight into the complex situation being examined. With critical consideration and careful reflection, the individual aspects of this diverse body of knowledge can be assembled into the theoretical foundations of this research. This is precisely the intention of the next chapter.

4) The Foundations of a Useful Framework

The vast majority of existing literature on the firm, including learning, capabilities development, and innovation, is developed within the context of leading economies, and therefore assumes the importance of innovation over imitation. Conversely, existing literature focusing on the role of imitation in catching-up economies does so at the national scale, building strong historical arguments for the importance of imitation in developing innovation capabilities, but offering only national-scale insights into the imitation/innovation transition.

Fundamentally, the firm is the basis for contemporary models of the national economy and system of innovation. Without an understanding of the process by which the firm develops capabilities, we cannot understand the broader development of catching up nations through these models. An understanding of the firm in the context of imitation is therefore the critical first step in bringing together the literature on imitation and innovation, and in creating a holistic understanding of how firms, and firm capabilities, act as the engines of development.

While these two bodies of literature both partially address this issue, their contradictory research methodologies, degree of generalizability, and unit of analysis mean that their relationship is unclear, and they cannot be directly combined or extended. An overarching framework is needed which carefully frames these issues in relation to existing literature and supports future research. Supported by historical examples of the imitation to innovation transition, such a framework allows the critical application of innovation-focused literature on the firm to situations in which imitation is dominant, and to China in particular. Existing literature gives us all the pieces, but placing them in relation to each other, and in relation to the issues, demands further original, exploratory research.

As the basis for such a project, we identify 10 insights from existing literature that are fundamental to understanding the relationship between learning and imitation at the firm scale. Combined with the finding of more broadly scoped literature discussed previously, these key points serve as the theoretical foundations for our empirical investigation of this process as it occurs within the Chinese wind turbine manufacturing industry.

1) Learning must be consciously undertaken to occur. The decision to focus on learning increases risk and uncertainty, and creates additional costs. (Lall, 2000; Pack, 2000; Li and Kozhikode, 2008)

2) Learning is cumulative, and therefore depends on existing capabilities and experience in a firm specific, path dependent way. (Nelson and Winter, 1982; Dosi, Freeman and Nelson, 1988; Lall, 2000)

3) The learning process and necessary capabilities are highly technology specific and dependent on the technological development and life-cycle stage of the industry. (Teece, 1986; Kim and Lee, 1987; Kim, 1997; Lall, 2000; Teece, 2000). Similarly, external agents (firms, consultants, suppliers, institutions, etc.) and the nature and degree of interaction with them technology specific. For this reason, related experience and capabilities often have limited transferability, and at times may prove counterproductive. (Lall, 2000)

4) Formalized R&D is only a small aspect of the learning process, with capabilities building occurs at all levels within a firm, including the shop floor, process and product engineering, inventory control, quality management, maintenance, procurement, inventory control, etc. (Lall, 2000)

5) The depth of learning for a given technology is flexible, and largely a firm-specific, strategic decision. (Lall, 2000). While superficial "blind" imitation reduces long-term capabilities development relative to more in-depth, learning focused forms in imitation, it also decreases the cost, risk, and duration of learning and allows for rapid entry and exit into the market.

(Kim and Nelson, 2000; Li and Kozhikode, 2008)

6) Innovation capabilities are supplemented by, and operate in parallel to, existing imitation capabilities. As such, imitation and innovation are not sequential stages, but different approaches to the fundamental problems of product and technology R&D and production. (Hobday, Rush and Bessant, 2004; Minagawa, Trott and Hoecht, 2007)

7) Learning does not take place in isolation, but rather within an innovation system made up of interlinkages and externalities including suppliers of input and capital goods, competitors, customers, consultants, technology suppliers, and other actors. (Lundvall, 1988; Lundvall, 1992; Nelson, 1993; Lall, 2000) Collective learning occurs at the network scale, and these effects play a key role in increasing the rate of technological learning. (Lall, 2000)

8) The specific external agents (firms, consultants, suppliers, institutions, etc.) and the nature and degree of interaction with and between them is technology dependent. (Carlsson, 1991; Jacobsson and Johnson, 2000) Transferability of experience across technologies and industries is therefore limited. (Lall, 2000)

9) Interactions occur both within the domestic and international context. The development of domestic capabilities and foreign technology transfer is complimentary, given the appropriate conditions. (Lall, 2000)

10) Even as the nation becomes innovative, foreign technology is important in legitimating and guiding research decisions allowing for innovation to develop in a context of reduced risk. (Lall, 2000)

With these key points in mind, we can look more critically at how existing literature has characterized – some might say theorized – the role and process of imitation in capabilities development at the firm scale. In attempting to understand ways in which existing literature could be applied to the situation in China, several key weaknesses become apparent. These weaknesses, in turn, become key requirements for a more useful approach.

Firm heterogeneity is both a basic tenet of an evolutionary approach, and immediately apparent in the case at hand. Existing literature, however, largely fails to account for firm heterogeneity in learning and capabilities development. This, in turn, leads to a conflation of national and firm scale processes, disallowing analysis of the interactions between firms. A framework must therefore allow for firm heterogeneity, and understand the national and firm scales and distinctive, but related.

Stemming from this assumption of heterogeneity is a limited focus on interactions between firms within a developing economy. Instead, it is assumed that knowledge is largely produced in the developed world, and is transferred through imitation to the developing world. In large countries such as China, however, advanced firms within the economy can plausibly serve as equally important sources of knowledge, especially in cases where proximities of various kinds (geographical, cognitive, organizational, social and institutional) limit knowledge flows (Boschma, 2005). As such, learning must be understood as occurring within a complex system of firms and actors, local and global.

While national scale studies strongly link imitation and future innovation, firm scale studies largely fail to establish a holistic framework which links imitation and innovation, or provides an understanding of changes the transition process. A successful framework must therefore establish underlying mechanisms which bridge imitation and innovation, and consider the relationship by which imitation offers opportunities for learning, and builds capabilities that directly support innovation.

Firm scale capabilities development is assumed to proceed in a linear, cumulative way that is common to all firms. While learning itself is sequential, cumulative process, empirical evidence suggests that firms often do not progress through the stages of imitation in a linear way, and often adopt numerous, simultaneous strategies. A useful framework must understand the unique development trajectory of a firm as a path dependent assemblage of strategies and opportunities.

What we describe is a holistic approach to imitation that understands it as related to innovation, and contextualized within a broader system of actors at multiple scales. Evolutionary theory and empirical studies on imitation provide concrete examples and underlying theories related to the functioning and development of the firm, and the role of learning and imitation within this process. Innovations system literature provides us with contextualization, and a means for understanding internal firm activities, inter-firm relationships, and the broader innovation system as interrelated and co-dependent. Finally, literature on modes of learning and necessary conditions allows us to operationalize the diffuse notion of firm learning, and to construct concrete links between modes of learning and strategies of imitation.

These key requirements, drawn from this diverse body of literature, provide the foundation for an approach that is broad and inclusive, but tacit of the nuance that defines intra-firm activities and processes. This combination of breadth and depth is essential, but makes for a difficult research project. With this challenge in mind, we turn to the research design, and the task of constructing a method by which we deconstruct this complex question into a series of interconnected, concrete research problems.

5) Research Design

Drawing on evolutionary economics, and innovation systems literature, capabilities development is understood as iterative and cumulative learning process, and the capabilities of a firm as a product of a specific, path dependent development trajectory. While this complex, co-evolutionary approach is fundamental to a theoretical understanding, it presents significant methodological difficulties. It demands an intensive, longitudinal approach to theory building that deconstructs the history of the firm, examining this history as a series of learning processes that have combined and interacted to produce current capabilities. Such an analysis, however, requires both a typology of strategies of imitation and learning, and a carefully selected series of case studies that offer opportunities for testing and improving the theoretical understanding of these strategies and the ways in which firms pursue them.

To this end, learning is understood as occurring in distinctive modes, and in relation to distinct strategies and approaches. However, these modes and strategies are themselves dependent on existing firm capabilities, and therefore the outcomes of previous learning processes. A fundamental tension exists between the need to build a working model and vocabulary, and the requirement that this be applied in a case-specific and path dependent way. In order to address this issue, we have elected to begin the exploration with a theoretical proposal, and in stages to flesh out and apply this model, testing and revising as we proceed. In this way, we incrementally and iteratively improve and develop the model, incorporating greater detail and nuance as the structure develops.

This process is undertaken in three steps, each guided by a concrete research question. While conceptually sequential, in practice these steps relate to scales of theorizing and were pursued in an organic, iterative fashion, with issues discovered within later, more detailed theorizing forcing a momentary steps backwards to the stage at which that framework is defined in order to reconsider foundational assumptions before proceeding. As an exploratory, theory-building project with limited empirical evidence, our aim is not to prove our model in any sense, but instead to rigorously develop, refine, and apply it, thereby demonstrating potential usefulness and insight in the hopes that it will support future research.

What events and capabilities delimit strategies of imitation?
The first stage of the research focused on examining the history of a wide range of firms and identifying key dimensions which affect imitation strategy and practice, and therefore along which modes of imitation can be delimited. In dividing the complex problem of firm histories and imitation strategies in this way, we establish the vocabulary and boundaries that are necessary as groundwork for intensive research into the individual modes, and their relationships to learning and capabilities development. Such a framework is merely scaffolding, defining the points of difference between modes and strategies, while leaving their specific character unexplored.

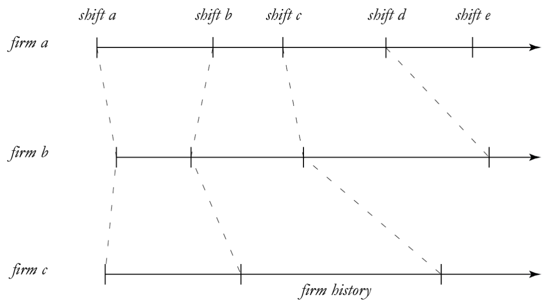

Figure 4: Aligning Shifts in Firm Histories

As a practical consideration, because of the impossibility of directly interviewing the necessary range of firms, industry sources with broad knowledge were utilized as a relatively efficient path to high-level experience, diverse perspectives, and otherwise impossible insider access. Interviews were semi-structured, with outlines prepared to address specific areas of expertise, and to address issues raised in previous interviews. The emerging framework, and the general history of the industry was discussed as background material, and based on this the sources were asked to recommend firms which they saw as relevant to the research, or as examples of unique strategies and approaches to learning by imitating, or clear transition processes between approaches.

Additionally, firms suggested by previous sources were discussed when deemed relevant. For each of these firms, the history was discussed, and key shifts in modes of imitation and the factors involved in these transitions identified.

While empirical evidence, and case-specific examples are the foundation of this research, the influence of specific cases, general observations by sources, and the influence and explanatory power of existing literature is nearly impossible to pull apart at this stage in the research. While some may criticize this approach as unscientific, we acknowledge the need for creativity and the inherent gap between specific examples and theoretical models at this early stage in theory building. For this reason, we choose to accept the framework that emerges as a working model. As a working model, it is not taken as truth, and operated within, but instead treated a guide for further research of increasing precision, and constantly tested and revised throughout this process.

What modes of learning and processes of capabilities development characterize these individual imitation strategies?

With a vocabulary of strategies defined by our working framework, we begin the task of exploring these individual approaches, characterizing their nature and relationship to processes of learning and capability creation. Drawing on the discussions of specific cases in earlier interviews, and additional interviews with engineers, managers, and executives within individual firms, we construct descriptions of these strategies, including opportunities for learning of different types. As this process proceeds, the previously defined boundaries are continually examined and, when necessary, revised. As additional evidence is successfully incorporated into the framework, it gains robustness and nuance, evolving towards a solid theoretical perspective.

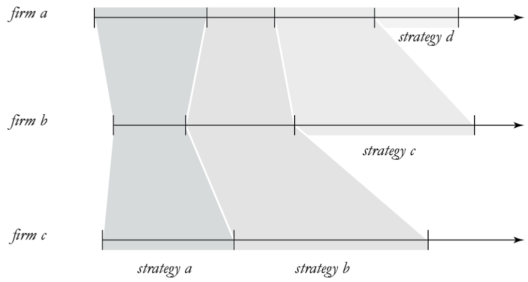

Figure 5: Identifying Strategies of Imitation

A particular difficulty arises in that we expect these strategies to overlap to some degree, and at times to function in parallel. For this reason, we focus considerable attention in these interviews on the changing internal structure of the organization, and the relationship between this and changing strategies of imitation. Similarly, in characterizing these strategies we do not treat the firm as an absolute unit of analysis, but instead consider functional organization units and the concept of routines in order to identify parallel well-defined strategies within organizations.

How are these strategies assembled into firm-specific histories in which capabilities develop cumulatively and imitation builds innovation capabilities?

While the previous stages of the analysis is built upon evolutionary ideas and therefore accounts for firm-heterogeneity at a theoretical level, the resulting framework is necessarily abstracted and generalized, and therefore is unable to fully address the complex, co-evolutionary, and path-dependent way in which strategies, capabilities, and learning develop within a particular firm.

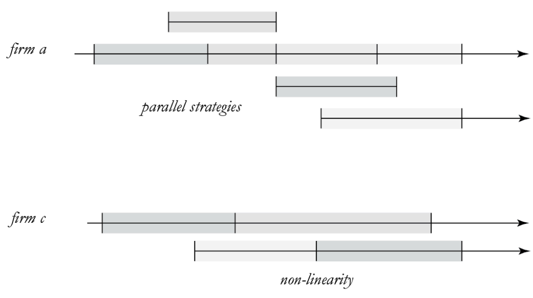

Figure 6: Addressing Firm-Specific Complexity

With this in mind, three case studies were selected as the focus of intensive research which utilized the newly developed framework to trace strategies of imitation undertaken through the history of the firm, and to explore unique routines involved in transitions between these modes and the co-evolutionary process by which learning builds capabilities, which, in turn, establish opportunities for new strategies and further learning. The case studies were selected from firms discussed in earlier interviews, and limited on both practical and theoretical grounds. Of primary importance was the potential explanatory power of the proposed framework, and for this reason firms were selected which pursued complex or unique learning strategies, or have achieved success in the industry that cannot be adequately explained by existing theories. For each case, research was undertaken through a broad range of sources, including industry reports, newspapers articles, and discussions of these unique cases with industry insiders, and employees of the firms when possible.

Firm	HQ	Founded	Domestic Rank	R&D	Factories	Acquisitions
Goldwind	Urumqi, Xinjiang	1998	2	Urumqi, Beijing, DE	8 Domestic 1 Foreign	Vensys, DE
XEMC	Xiangtan, Hunan	1936	7	Xiangtan, NL	3 Domestic	Darwind, NL
Dong Fang	Chengdu, Sichuan	1958	3	Chengdu	2 Domestic	~

Table 2: Key Data on Case Study Firms (China Wind Power Outlook 2010)

Given that these firms could not be selected until the research was at a relatively advanced stage, the accessibility of certain firms was limited by practical choices made earlier in the research such as the location of the interviews, and the connections pursued. In two of the three case studies, it was possible to interview executives, engineers or consultants with direct experience in the firm. In the remaining case, sources within the firm were not available because of the distant location of the firm, and lack of branches in either Beijing or Europe. In this case, additional time was given to written data sources, and a particular emphasis was placed on this firm during interviews with industry insiders.

5.1) A Pragmatic Approach to Research in China

While the size, growth, and diversity of the industry in China is precisely what makes it such an important topic, it presents tremendous difficulties for research. With between 80 and 90 wind turbine manufacturers spread across the country, the first issue is a practical one: where does one go to “find” the wind turbine industry in China? Going into this project, the reason for such a decision was quite clear: I need a plane ticket. Making such a choice, with limited knowledge and experience, however, was quite difficult. In the end, I chose Beijing, and this proved a highly advantageous decision for several reasons. Let me first explain my logic in choosing Beijing and my approach to research in China more generally, and then discuss briefly the implications of these choices, and the realities of research in China.

Several large cities are home to significant numbers of firms, and wind farm locations are generally quite remote. Beijing, however, seemed particularly suitable for several reasons, largely related to its position as the national capital. Foreign embassies serve as initial contacts, and offer opportunities for interviews and networking with other industry players. Major industry associations (CREIA, CWEA, CWEEA) are based in Beijing, and offer similar opportunities. As home to leading universities (Tsinghua, Peking), and research institutes, Beijing is emerging as a center of R&D, with major firms based elsewhere (Goldwind, Vestas) establishing R&D centers in Beijing. Finally, several key firms including Sinovel (China’s largest manufacturer in 2010) and United Power (4th in 2010) are based in Beijing. Additionally, Tianjin - only 30 minutes away by high-speed train - is home to the majority of foreign manufacturing facilities and suppliers in the country (Tianjin is center of international wind power industry, 2009).

With Beijing selected, the next issue is networking within the industry, and gaining access to firms. Firms in China generally, and state owned firms in particular, are notoriously difficult to contact or to arrange interviews with. Interviews with wind power specialists in European embassies and industry associations were therefore initially contacted and interviewed to establish an entry point into the industry. From there, using the snowball method, further interviews were arranged with industry sources such as consultancies and experts, and employees specializing in technology strategy and R&D within major firms. In all, 10 in-depth discussions were undertaken, each of which lasted 1-2 hours, and included discussion of the learning process of firms, the development of the industry, and the identification of key firms for further investigation. Key examples, as they emerged, served as the basis for specific discussion with later interviewees, and eventually the basis for intensive case studies.

While this approach to research is far from ideal in its rigor, and presents concerns as to the generalizability and validity of the data, it is taken as necessary given the timeline for research and the limitations imposed by context. On subjects as simple as the number of firms in Beijing, or the origin of a firm's design technology, limited information is available, and sources are often contradictory. Issues of transparency, insularity, and weak communications within firms all limit this research, but more importantly limit the development of the industry itself. While apparent only to a limited extent initially, these issues run very deep, and even industry insiders lack crucial information such as the location of major wind farms. This obviously impacts the industry itself, and especially issues of communication and learning between firms. As such, it will be discussed in greater depth in that context.

For the time being, suffice it to say that very few people – if anyone at all – has a clear picture of the industry as a whole, or even of the operation of specific firms in which they work. We have made every attempt to gather data thoughtfully and intelligently, to avoid bias, and to validate the data we have. This research is exploratory, and focused on theory building, and for this reason, these limitations were deemed workable. However, the limited fieldwork is admittedly a weakness of this research – and research on China quite generally - and further fieldwork is a tremendous opportunity for future research.

5.1) A Brief Reflection on Research in China

A pragmatic approach and solid argumentation are crucial in defining and reinforcing the validity and scope of this research. However, the aim of this research is also to encourage further research in this area, and specifically in China. With this in mind, we momentarily set aside the defensive argumentation of academic writing, and adopt a more introspective tone to discuss the experience of research in China, hopefully offering encouragement and advice to those considering it.

In reflecting on this, a few points come to mind that are worth mentioning.

Thank You Zhigao Liu

Before heading to China, my academic advisor introduced me to his colleague Zhigao Liu. You'll see me thank Zhigao several times – he asks the right questions, knows the right people, and is a dear friend – but here, the point is simply that someone like Zhigao makes research such as this possible. With a well-known institution to support him, and a strong personal network, he was able to arrange introductions and interviews, and with real-world experience, similar research and language skills, he offered insight into sometimes confusing interviews, and an invaluable perspective on theoretical and practical concerns. Going into this project, I didn't realize all this – I thought I could do it alone – but in retrospect I see that without this kind of support my fieldwork would have been much more difficult, and my outcomes much weaker. If you want to do research in China, find someone there to work with. Without them, an already difficult task will become much more difficult.

Building Connections is Slow

Zhigao and I worked in parallel to arrange interviews. He used his personal network – Guanxi, and yes, it's just as important as everyone says – while I drew on European embassy and industry connections. Both proved fruitful and lead us to very different sources. My approach, however, proved much slower then I initially expected. It takes a day or two to get an email back, then a week to arrange a meeting, then a few days of research to find potential connections, and to ask for introductions. Repeat. Every step is essential, and every interview valuable, but the process is quite simply slow. I was in Beijing for 10 weeks. I emailed contacts before I arrived. And the night before I left, I was at dinner with an invaluable source. From there, I likely would have met many others, but I had to go.

And you can't do any of this ahead of time. It's not about a nicely worded email, or even a phone call. If they don't know you, they simply won't respond. You need to them. You need to talk to them. You need to take them out. It takes time, and it takes being there. If you're persistent, and willing to ask for a few introductions, you can find the right people – just give yourself the time to do it.

English is Workable, but Limiting

I'm going to come right out and say it: I don't speak a word of mandarin. Going into it, I thought the solution was monetary: hire a translator. It turned out I didn't need one. Most everyone spoke English. Of course, on average, that's far from the truth. It's pure selection bias. And this is a bias that undoubtedly affected my results. But that's not the point. The point is that you can do research in China without speaking Chinese. Well, actually, you can do research in Beijing, at the tops of large companies with an international focus. These are generally people that have worked, lived, or studied abroad. They're happy to speak English with you, and they can communicate their thoughts and ideas clearly. Do your research in China. Find a local partner. Hire a translator if necessary. Just don't expect to interview factory workers.

That said, my advice to future researchers is quite simple: China is an amazing place for research, and an amazing place to be. There's a challenges, of course, but there's also tremendous opportunities, and a surprising degree of openness and support. It takes times and persistence. You can never expect perfect data, or matching stories. You have to work for every interview. But what you do get is much more valuable, and the research you produce can be exploratory, even groundbreaking, in the truest sense of the words. It's the frontier.

The following chapters are the result of the research design presented here – a complex, iterative process aimed at developing the vocabulary, theoretical constructs, and concrete examples needed to understand imitation and learning within the firm. With our methodology and pragmatic approach outlined, we turn to the heart of the research. By developing and revising our understanding iteratively at multiple scales, and through testing it both theoretically and empirically, we methodically dissect a complex situation, and progress towards answering our interlinked set of research questions.

6) Key Shifts in Imitation Approach

We begin our research by identifying key dimensions along which shifts in imitation strategy can be defined. The distinct strategies defined by these dimensions, in turn, serve to direct further research into their individual characteristics and relationships to learning. These shifts are developed through a synthesis of existing literature, general discussions with industry insiders, and specific discussions of firm histories with actors within firms. While the dimensions are each separately identified in existing literature, their importance to this context, and their structuring into a framework as we have done is largely based on our fieldwork. As such, while the dimensions themselves are broadly applicable, their relative importance in defining strategies is closely linked to the organization and history of the wind turbine industry, and the nature of the technology upon which it is built.

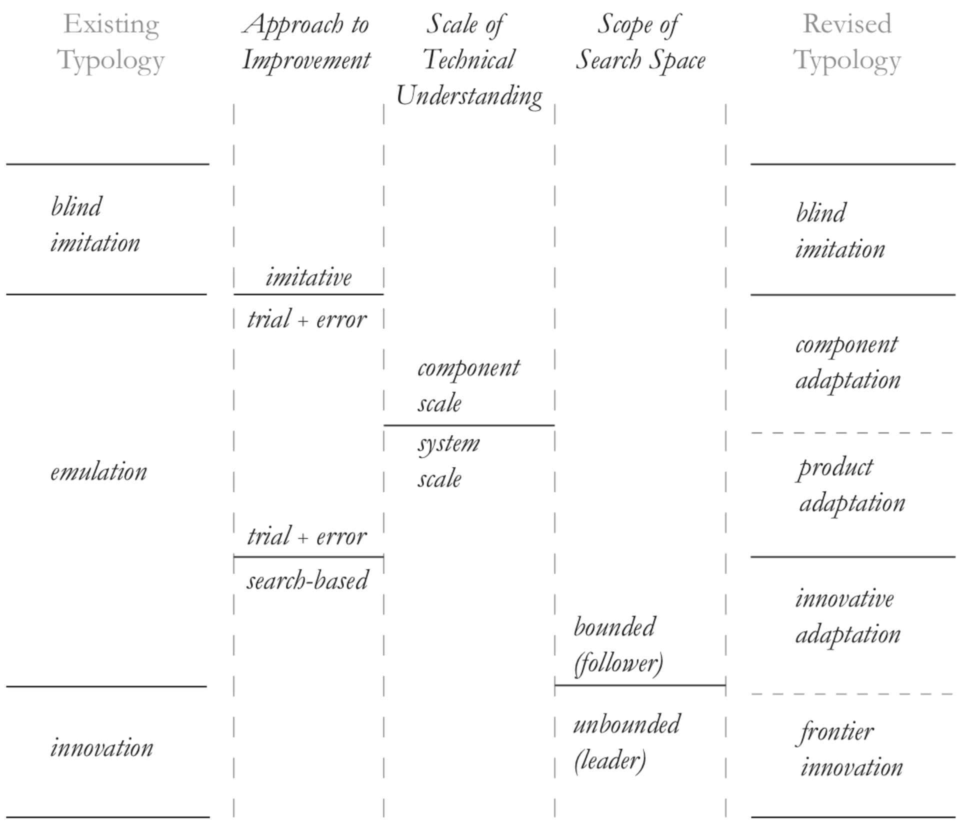

Figure 7: Existing Typology, Proposed Dimensions of Analysis, and Revised Typology

6.1) Approach to Improvement

The first of these dimensions, approach to improvement, is defined by the combination of existing literature on imitation and innovation, and relates to the strategy that the firm uses to address the fundamental uncertainty of innovation as it transitions away from blind imitation. As such, it defines two transitions: from imitative towards trial and error based improvement, and from trial and error based improvement towards search-based improvement. These two distinctions serve to define the primary stages of our typology, and within them further distinctions are made through the two remaining dimensions.

The division between blind imitation and other strategies is quite simple, and well defined in existing literature. Within this approach, the firm sidesteps the risk of innovation completely by giving up the ability to implement changes to the product. Very limited risk exists in the establishment of processes necessary for manufacturing the product, but these are addressed through simple trial and error. More importantly, they are very tightly bounded, with the intent being duplication, not improvement. There is very little risk, but very little flexibility.

The transition from an imitative approach towards a reactive one is defined by an increase in this flexibility, and the strategic decision to invest in not just duplication, but also improvement in a technological or market sense. These improvement, however, are reactive in nature, directly addressing issues raised in the production or operation of the product, and not seeking out potential opportunities in a novel or market leading way. This, in turn, exposes the firm to the uncertainty of both market and technological success, although both are limited. Because, in the broad sense of the technological trajectory, these improvements do not approach the innovation frontier, the search space within which the innovation process must operate is bounded, and improvement process is shielded from the fundamental uncertainty inherent in frontier innovation. Given this limited search space, complex search routines are not required, and options are rapidly implemented and tested, with real world results providing feedback that directs further progress. The trial-and-error based approach to improvement, and the importance of it in defining the imitation strategies of firms within this industry is widely supported by sources, particularly those with experience in R&D management in both western and Chinese firms.

The experience of these sources is especially valuable in defining the next shift along this dimension, from a trial-and-error to a search-based approach. Given the emerging nature of the Chinese industry, and the dominance of imitation based approaches within it, it is important to note the relatively limited number of examples of this transition, and to point out that discussion is very much based on the differences in approach between innovation focused (western) and imitation focused (Chinese) firms – norms, biases, and issues of over-generalization accepted. The cases in which Chinese firms have acquired small, innovative western designs firms provide particular insight into these differences in approach. In adopting this normative notion of innovation, loosely defined by European firms, as the ultimate goal of Chinese firms, and as the only route to frontier innovation, we risk suggesting an assumption of linearity in process and western superiority in innovation that we criticize in previous literature. However, we do this consciously and critically, understanding that is a product of the larger conceptual models within which we operate, and which must eventually come into question.

With these issues in mind, we define the next shift along this dimension as the development of search heuristics guiding R&D, and therefore a search-based approach to improvement. It is critical to note here, however, that this does not imply an unbounded search space, or frontier innovation, and is instead related to a proactive approach towards defining, developing, and testing potential improvements. Within our framework, this shift from a bounded to an unbounded search space occurs separately from the development of search routines, and is discussed as the dimension scope of search space. As such, the transition we discuss here is more closely related to a formalization of the search process, and the development of search heuristics that allow for larger scale, higher risk improvements to be undertaken.

A clear example of this distinction, explained by Frank Strik of XEMC-Darwind and expanded upon here, arises in the approach taken when increasing the size of the blades installed on a wind turbine. Within a trial and error based approach, a firm might see that a wind turbine in a low wind speed environment produces less than the rated power, and address this very directly by increasing the size of the blades, while keeping the other aspects of the design intact. They would purchase larger blades, install them – perhaps even selling this untested product to a customer - and as this modification produced issues and failures within the operating machine, they would address these one by one, in the simplest way possible, introducing countless small changes, and hopefully, eventually creating a reliable machine with greater capacity in low wind situations. A search-based approach to this same issue, however, would propose a range of potential improvements as technical possibilities during the design process, and before concrete needs developed in the field. These potential improvements, rules of thumb, experience, and other elements of search routines would allow the firm to compare designs based on their likely potential for success, while taking into account potential risks, including implications for the operation of the turbine. By proactively establishing technical possibilities, likely market needs, and potential risks, a longer timeline for development is created, and risk is managed internally, insuring that a product delivered to a client is both well integrated, and well tested.

6.2) Scale of Technical Understanding

Within the strategies defined by a trial and error based approach to improvement, we make a further distinction between system-scale and component-scale technical understanding. Weak operational performance and reliability are considered to be among the more pressing issues in this industry, and key sources in both Chinese and western firms cite a lack of system scale understanding of the operation of the turbine and the implications of changes as a key factor in these failures.

Firms initially undertaking improvements of a product pursue this a highly piecemeal fashion, with little understanding of the systemic interactions of the components. As such, changes are implemented, and their systemic and operational effects are only discovered through subsequent failures of the product, with each resolved at the level of the individual component failure, and not at the level of systemic operation.

A system scale understanding demands familiarity with both the individual components, and the complex system of interconnections that underlie operational performance. As these connections are not apparent within the final design documents, this is based on an understanding of the design history and trade-offs that are implicit in the design. As such, the development of this capability is not connected to a fundamental shift in approach, but the slow accumulation of experience with the design and use of the product. Similarly, this transition is gradual, with understanding slowly increasing in scope and integration, first from individual components, towards groups of components and systems, and finally towards the relationships between these systems, and eventually an understanding of the complete product as an integral unit.

Because of the gradual, cumulative nature of this shift, the specific moment of transition and boundaries between these approaches is nearly impossible to operationalize. In discussions with industry sources, however, several key indicators are mentioned in a wide range of cases and begin to act as proxies for this transition. These will be discussed later, within individual case studies. Similarly, it must be mentioned that this distinction is very much built up in conjunction with the shift in modes of learning that it mirrors, and for this reason, it cannot be fully understood until the discussion of the relationships between these approaches and modes of learning that occurs in the next chapter.

6.3) Scope of Search Space

As previously described, within this framework the development of a search-based approach is seen as distinct from the application of this approach to frontier innovation and the emergence of the firm as a global innovator. While the transition from a trial and error based to a search based approach signals the development of search routines, these routines are limited in the uncertainty that they must address, and are guided by technological trajectories developed by frontier innovators at a global scale. In line with this, Lall (2000) argues that even as the nation becomes innovative, foreign technology remains important in legitimating and guiding research decisions, and thereby allowing innovation capabilities to develop in a context of reduced risk.

In light of this, the dimension scope of search space is developed to characterize the transition from innovative followership towards frontier innovation in terms of the bounded or unbounded nature of the search space, and therefore the degree of uncertainty that the innovation process must address. Given the limited number of firms with well-developed search routines in our case study, this is one of the least developed dimensions we propose. Despite this, such a distinction is proven essential both by our later case studies, and the body of existing work on Korea and Japan which struggles to characterize the later stages of the transition process, and the staggered development of innovation capabilities and global leadership.

7) Learning within Strategies of Imitation

With this typology in place, we can begin to characterize these specific approaches, and to discuss their relationships with opportunities for learning in different modes. While, for the sake of clarity, these modes have been presented primarily as a product of identifying shifts in firm histories, it should be noted that the identification of these shifts is based on a discussion of different types of learning, and that these modes are therefore defined by the combination of shifting capabilities and strategic approach previously identified, and the modes of learning which will be discussed.

	learning by doing	*learning by using*	*learning by searching*
blind imitation	experience accumulation without iterative learning	none	none
component scale improvement	rapid learning	limited to "chasing" implications of component changes	none
system scale improvement	learning slowed by longer feedback loop	rapid learning	identification of need for search heuristics
innovative improvement	incorporated into searching	limited to possibilities defined by leading firms	rapid learning
frontier innovation	incorporated into searching	incorporated into searching	limited by fundamental uncertainty of innovation

increasing length of feedback loop →

Figure 8: Relationship between Strategies of Imitation and Modes of Learning

7.1) Blind Imitation

From a theoretical perspective, blind imitation provides opportunities for learning by doing through rapid production ramp up and volume production. By definition, however, this experience cannot be implemented as product changes without a strategic shift towards adaptation. Similarly, learning by using would be supported by the broad base of existing customers and similar products, except that these changes cannot be implemented or tested. Without the possibility to develop, implement, and test improvements, learning as an iterative activity simply cannot occur. On purely theoretical grounds, it can therefore be argued that blind imitation is fundamentally static, encompassing little learning, but, producing experience accumulation and knowledge that can aid the process of learning when a shift towards adaptation occurs.

More importantly, in practice, and within this industry, blind imitation is largely non-existent, with market pressures forcing an almost immediate shift towards adaptation. Cost-cutting, and the lower cost of Chinese wind turbines relative to the international competitors, is a primary source of competitiveness according to Gao Hui, Chief Engineer at Guohua, one of China's big 5 utility firms, and is a key factor in the rapid shift towards adaptation. Given that most major foreign manufacturers are already active in the Chinese market, and have production facilities located there, location and decreased labor costs offer little advantage. As such, the 20% - 30% price advantage of Chinese turbines must be maintained through the use of less expensive components and basic materials, and decreased operating expenses, according to Liang Weiliang, economics affairs officer at the Danish Embassy in Beijing. The market push for cost cutting through local component sourcing is further supported by policies mandating 70% domestic content in government-supported wind power projects. While this requirement was dropped in 2010, according to Simon Feng of DNV, it has become impossible to compete on price without using a very high percentage of domestically produced components. For this reason, every manufacturer operating in China, including international firms, now use greater than the required percentage of domestic components, with certain Gamesa turbines having domestic content as high as 95%.(Bradsher, 2010) In order to meet these requirements initially, international firms invested heavily in training and qualifying Chinese component suppliers, dramatically improving quality and capabilities, and, according to anonymous industry sources, forcing them to adapt to European design and manufacturing standards and practices. (Bradsher, 2010)

Another key pressure cited by both Pengfei Shi of the CWEA and Gao Hui of Guohua, is towards localization and customization of the products to meet the specific requirements of the physical climate. Designs that are licensed from European manufacturers and design agencies are suitable for the European climate and wind regime. China, by contrast, presents a very wide range of climates, from extreme cold of inner Mongolia, through the elevation of Yunnan, to high temperatures of the South. Similarly wind regimes vary greatly, with Mongolia offering relatively high average wind speeds and little variation, while other areas such as the South East have relatively low average wind speeds, but at times very high speeds, especially in the case of typhoons. Each of these sets of conditions demands changes to the design of the turbine

While these factors pressure firms into rapid transition towards adaptation, such a transition is problematic because within this industry almost all firms – and certainly those pursuing blind imitation – acquired their designs through licensing. According to industry sources involved in such deals, however, such contracts are carefully constructed to both lock firms into established suppliers, and to prevent incremental changes and localization in the fear that unforeseen problems will arise, and blame will fall on the design firm. As argued by Teece (1986), appropriability regimes in almost all industries are weak in practice, and China has quite a reputation in relation to intellectual property rights and technology licensing issues. More importantly, sources involved in technology licensing deals argue that firms "simply don't care" about the terms of the contract, and that no legal recourse exists. In this way, changes are both unavoidable and immediate, accompanied by an implicit shift towards an adaptation-based approach.

7.2) Component-Scale Adaptation

In theoretical terms, with the shift towards a trial and error based approach, the product design becomes flexible, allowing for iterative, interactive learning to begin. Undertaking such changes entails a willingness to accept the risk inherent in improvements and product differentiation based competitiveness, as opposed to pure duplication. Experience and knowledge built up during blind imitation can allow a firm to accurately identify simple, well-defined needs of customers and failures in the existing product and process design. In doing this, the risk and uncertainty of innovation is addressed to a small degree, but is still strongly bounded by existing trajectories, strategies, and artifacts.

During component scale adaptation, learning by doing is both rapid and intensive. A simplistic, piecemeal understanding of the product – developed through licensing, reverse engineering, or some combination - allows components to be addressed with relation to their individual functions and requirements. Setting aside complex, long-term and system level issues, components are modified, improved, or replaced with extreme flexibility, and without regard for systemic implications or design-history and the trade-offs it embodies. This, in turn, creates a situation in which feedback, although limited to the component-scale, is rapid and direct. In turn, iterative learning occurs quickly through manufacturing and prototyping, and simple problems are resolved with feedback at the component and/or prototype timescale.

Looking to empirical evidence, this understanding is generally supported, and a key example of the inner-workings of this approach – and its potential pitfalls – is presented in relation to product localization, both in response to the Chinese climate, and through domestic component sourcing. As explained by Rachel Enslow of Azure International, firms have acquired prototypes, blueprints, and sometimes production rights and load calculations, but lack design calculations, design history, and an understanding of the complex set of trade-offs and compromises that are embodied in the design. This lack of comprehensive understanding, combined with operational; experience, and a weak background in related products, has led to many of the issues with reliability and operational performance that overshadow the industry today.

By iteratively implementing component-scale changes, operating the product to failure, and then addressing the points of failure, the system-scale implications of changes are methodically tracked through the design and it's operational performance. If this process were limited to the prototyping stage, it would take years of operation to successfully implement changes in this way. In the Chinese context, however, firms are able to install these prototype-like turbines on customer sites, and through unique expectations, and rapid and effective support, to continue to develop and improve these products in the field. For this reason, the use of the product, and specifically the degree of communication and involvement with the customers becomes crucial. Firms which work closely with customers, and especially those which provide long-term maintenance and repair services have access to a far greater range of opportunities to observe the interaction or components in use, the effect of differing conditions, and minor design changes in operation. Firms that are less involved in these activities have fewer opportunities, and therefore develop this level of understanding at a much slower rate.

While much industry and popular literature has focused on the reliability issues present in the Chinese industry, sources within the industry see these issues as largely offset by the high level of after-sales support provided by Chinese firms. As Gao Hui of Guohua explains, "[Foreign firms] have good turbines, so less failures, but for each failure, because of bad service, it takes a long time to repair. The Chinese [firms] can offer better service, but have more failures. This is the balance we see." Discussing Goldwind, Pengfei Shi of the CWEA cited the experience and rapid feedback this provides as a key feature in the rapid development of firm capabilities, with a similar situation occurring in other firms providing after-sales service.

Looking forwards, Gao Hui points out, "Chinese manufacturers use more engineers staying on site for service, but labor costs are lower, so this isn't a big problem so far", and that "in 3-5 years, Chinese manufacturers can offer the same quality as European counterparts." From the perspective of learning, this practice provides both a much faster iteration cycle – and therefore rate of learning – and an opportunity for the firms to invest in learning supporting a system-scale approach, while at the same time reducing the cost of this learning process for the customers.

The industry's acceptance of relatively untested products has given Chinese firms unprecedented opportunities to rapidly test and improve their products through direct field experience and the rapid feedback in provides. In this way, it is likely that Chinese firms have been able to undertake more complex changes at lower levels of internal capabilities then would otherwise be feasible, while at the same time directly supporting the building of experience in component interactions and operational performance that support a future, system-scale understanding.

However, it should be pointed out that while the rapid feedback allows for quick learning, and a wider ranger of improvements, the response to this feedback is fundamentally limited by the component scale approach, and the need to respond to the individual components in this sequential fashion. While minor technical issues related to quality or component design may become apparent through use, the real value of learning by using is in the demonstration and observation of the interaction of the components in a real world environment. While such problems can still be pursued within a system-scale approach, this process slows dramatically as the problem increases in complexity, and the cost of maintaining and upgrading these provisional designs in the field rises as production and installed base increases. As the product is delivered to customers and learning by using becomes central, immediate issues are quickly sorted out, and failures move beyond the scope of individual components and into the realm of system-scale design. Much as blind imitation produced experience supporting future component-scale adaptation, but does not allow iterative learning, component-scale adaptation both creates, and allows for the identification of, complex system-scale problems, but does not support the effective development, implementation, and testing of system-scale solutions. As such, learning by using is initially quite strong in component-scale adaptation, but as the simple problems are resolved, and more complex ones arise, the piecemeal iterative process and the costs it brings decrease the effectiveness of learning by using within this approach, demanding a conscious investment in the transition towards a system-scale approach.

In relation to learning by searching, a separate set of issues limit learning within this approach. While concrete needs and direct solution allow for improvement of the product, the requirements are quite strictly defined by the component boundaries. Because solutions are limited in scope, and quickly tested through use, the routines and search heuristics central to learning by searching are largely unnecessary. While general experience related to the management of development and operation accrue, learning by searching - defined by iteratively developed and tested search heuristics - does not occur.

7.3) System-Scale Adaptation

A shift towards a component scale understanding is, according to industry sources, critical for addressing issues of reliability and operational performance, and allowing for more complex improvements that span multiple components. However, from a theoretical perspective, it brings potential issues that can affect both the rate of learning, and the effectiveness of the trial and error approach. Within a component-scale approach, the success of a given change can be identified within a single prototype cycle, and judged in isolation from changes made to other components, but as system-scale interactions becomes central, components can no longer be treated independently, and changes must coordinated, with careful consideration of potential interactions between individual improvements, and adequate time to implement and test the unit (including systemic interactions revealed in long term use) in the field. For this reason, the time needed for a given development and testing cycle increases, and the rate at which feedback occurs decreases. As further experience accrues, this process continues, with the emerging systemic understanding introducing ever-greater complexity, and further increasing the length of the trial and error feedback loop.

With the ability to address a broader range of issues, and the newfound focus on systemic interactions, and therefore on operational performance, learning by using becomes central. According to a source with experience in European firms, and now involved in both R&D and field maintenance at a leading Chinese firm, the use of the product, and specifically the degree of communication and involvement with the customers becomes critical to ongoing improvement and learning. For this reason, firms which provide long-term maintenance and repair services have access to a far greater range opportunities to observe the operational performance of their improvements, and therefore for learning by using. Goldwind is an often cited example of the advantage this provides, and the role of maintenance and learning by using within their history is discussed in depth in the case study section.

While learning by using becomes more dominant, learning by doing decreases in importance. The need to understand the implications of component-scale changes within the functioning for the product as a system dramatically increases the complexity of design decisions, increasing the cost and risk associated with an individual change, and therefore limiting the ability to quickly implement and test changes. Similarly, as the feedback loop increases in, the time period that is required before a given improvement can be tested, and it's effectiveness understood increases, increasing risk and limiting the rapid feedback on which component-scale trial and error improvement depends.

This inability to test component-scale changes on an appropriate timeline limits the ability of the firm to feasibly explore all options, and therefore introduces – to a very small extent – the fundamental uncertainty of innovation into the imitation process. While at this point this uncertainty is largely unmanaged, and because it occurs within a reactive, trial and error based approach, it does not allow for learning by searching. However, it serves to signal the need for the development of routines to manage this uncertainty, and for an approach that allows for opportunities and improvements to be pursued despite a lack of direct feedback.

7.4) Innovative Adaptation

As previously mentioned, firms within the Chinese industry are just beginning the shift towards proactive, search based approaches. While firms – to varying degrees – are pursing this transition, no single firm has undeniably completed it. For this reason, at this point our discussion takes on a more speculative nature, with underlying theoretical trends, the approaches of and experiences in acquired design firms providing the basis on which we tentatively extend our understanding.

From a theoretical perspective, we argue that in response to the limited uncertainty generated by the disparate timelines of component-scale improvement and a system-scale approach, a need for proactive, uncertainty managing routines is defined during system-scale adaptation. Within the Chinese wind turbine manufacturing industry, the resulting investment aimed to build these capabilities has manifested as acquisition of outside European firms, with nearly all of the top firms completing such an acquisition. Frank Strik of XEMC-Darwind, sees the expertise of the acquired firm as supporting capabilities building within the firm, and allowing for more fundamental design changes – in short, an incremental step towards a proactive approach. Despite this, he gives the following example of the fundamental differences that remain:

[They] see the competitors is moving in that direction, so they also need to move in that direction, and don't very fundamentally review, "OK, what's the market going to do?", "What can I develop as a company to have a unique position in it?". It's still following behavior. We talked to them about, lets say, an upgrade of our turbine, which has a 115m rotor, which is relatively compact by market standards. They see that most of the competitors have a 126m rotor, so the next product to be developed is this turbine, but with a 126m rotor. And we say, "OK, that's nice, because the competition has chosen for whatever reason this diameter, but what will the market do?" The market is not asking for a rotor diameter, it's asking for a yield, and a cost of energy. [We say,] maybe it's good to consider on a higher level the optimal next step for this turbine. And that's a discussion which is very difficult. So it's [again] taking the next step, the following behavior.

Supported by the emerging search routines – either internally developing, or more often externally acquired, learning by searching slowly takes on a central role. Though initially tightly bounded, and relatively similar to previous improvements in scope, these routines provide the basis for the transition towards a search-based approach to improvement, first incremental and following, and eventually industry leading. This transition was initially founded in the need to address the uncertainty generated in the gap between system scale improvements and component-scale approaches, and for this reason, the incremental innovations characterized as related to learning by doing are the first to be addressed by these search routines. Their focus is not to direct the innovation process as a whole, but only to address the moderate uncertainty generated by the need to make incremental improvements within the context of more fundamental, system-scale changes and limited feedback. In this way, learning by doing transitions away from slow, trial and error based progress, and becomes incorporated into these search processes, and the newfound focus on learning by searching.

Initially, the problems that are addressed in learning by searching are therefore relatively simple, and the time span on which solutions will be tested is much shorter then would occur without the boundaries and direction provided by imitation of basic research outcomes and frontier innovation. Within this well bounded space, developing search routines can move beyond responding to concrete needs discovered through doing and instead begins to proactively search for and investigate potential opportunities for improvement based on their familiarity with the underlying product and process technologies. This introduces significant but well bounded uncertainty, demanding a higher level of risk taking and strategic management, yet maintaining a level of safety that is highly conducive to learning.

System scale improvements, and therefore learning by using, continue much as before, with a trial and error based approach, bounded by imitation of leading firms. The effectiveness of this trial and error approach, however, depends on the position of the firm as "catching up", and as capabilities increase, and the firm moves towards the technological frontier, the search space therefore expands. Mirroring the process that occurred within system-scale adaptation, the rate at which trial and error improvement at the system scale occurs therefore decreases. This is an incremental process, and as it occurs, it supports an ongoing investment in search routines, which, in turn, support further development despite greater uncertainty.

7.5) Frontier Innovation

At an intuitive level, the transition from adaptation (read imitation/following) to frontier innovation (read: technological leadership) seems as thought it should be exceedingly clear. In practice, however, firms operate within industries and networks, and are constantly informed by the decisions of other actors. With this in mind, we see this final transition as a gradual process in which experience allows for research of greater complexity and increasing uncertainty to be pursued. Leadership and followership, then, are viewed primarily as a product of market position, and come to incorporate a far greater range of issues then the development of search capabilities.

With the increasing length of the feedback loop implied by ever more fundamental improvements, the situation which forced the translation of learning by doing into learning by searching, now comes to apply to the process of learning by using. While learning in this mode continues, it does so at an ever-decreasing rate, forcing further development of search routines that can guide these improvements in a proactive way. The obvious end result of this process is a situation in which the feedback loop comes to mirror the development cycle of basic technologies and long-term research, and both learning by doing and learning by using cannot be pursued through trial and error with any degree of success. As such, learning in these modes becomes extremely limited, and learning by searching becomes dominant mode.

As a firm approaches the hypothetical technology frontier, however, the rate at which learning occurs decreases in direct correlation to the increasing complexity and uncertainty entailed in the creation of novelty. Fundamentally, this is a product of the fact that while search routines guide research processes, learning is still dependent on the input of implementation and testing – however small, or seldom – to provide feedback and support. As the complexity, and therefore the timescale, of improvements increases, opportunities for feedback become ever less frequent, uncertainty increases, and – by virtue of its iterative foundations – learning progresses at an ever-slower rate.

7.6) The Limited Role of Firm Interaction in Learning

Previous research on the wind turbine industry (Kamp, 2002; Garud and Karnoe, 2003) has extensively focused on the role of firm interactions, and the roles of research networks, R&D collaboration, public research institutions, and other such actors in industry development. In our case study, however, such interactions are extremely limited, and functionally play almost no role in the product imitation or innovation process. This view is shared both by key industry sources (Etten, 2010; Shi, 2010; Feng, 2011; Meyer, 2011), and recent papers exploring the wind turbine innovation system, including Liu, Britta, et al. (2011). Given the importance of these interactions in previous studies, and their notable lack within our study, a brief discussion of the situation and the reasons leading to it is useful.

The first issue is that, within China, competition between manufacturers is incredibly intense, and firms are largely unwilling to collaborate for fear of aiding their competitors or losing technology (Etten, 2010). While the specifics for this situation are beyond the scope of this paper (and addressed to some extent by Liu, Britta, et al. (2011)), several key issues were mentioned by industry sources. The first of these is the weak institutional framework, specifically IPR protection, and the relatively free flow of employees and technologies between firms (Meyer, 2011). While this situation has improved in recent years, it remains problematic to such an extent that firms often endeavor to split the knowledge necessary to reproduce critical technologies across multiple employees in an attempt to limit their ability to transfer this knowledge to competitors (Strik, 2011).

The second major issue is the lack of a public platform for R&D, and the public institutions and university research programs which would support this (Shi, 2010). Lacking such a platform, R&D is undertaken within the firm, and - in line with the reactive approach dominant in most firms – in direct response to market needs. Related to this lack of public institutions – and increasing the degree of perceived competitiveness - is a lack of regulatory mechanisms and approval processes, and the transparency that they demand. While entities such as ECN in the Netherlands and RISØ in Denmark have proven critical to collaboration, innovation and learning, in the China they are only just being developed (Kamp, 2002; Shi, 2010).

While both research and policy seeks to support the development of these forms of interaction and collaboration, so far they made little concrete contribution to learning process within firms. However, two avenues for learning within firms that have gained far less attention in previous studies are cited by several sources as critical within this industry: relationships with technology source firms – often-European design firms – and component suppliers – both local and international. At the most basic level, wind turbine manufacturers engaged in imitation and licensing act as an intermediary between these firms, translating product designs into component specifications, contracting and organizing component suppliers, and eventually assembling and testing the product. While the importance of these firms to the industry is widely accepted and, in fact, serves as the basis of this thesis, the changes in the nature of their relationship – and therefore the process of learning - as the approach and capabilities of the manufacturers transforms is not well understood.

7.7) Framework as Vocabulary, not Taxonomy

The framework developed here brings together firm strategies, and modes of learning, defining their relationships and interactions. This is a necessary step, allowing us to identify opportunities for learning, and to construct a basic conceptual framework and vocabulary from which more complex, case-specific analysis can proceed. However, this framework – as most are – is essentially static, and the focus of this research is not on static capabilities, but on the process that relates strategies, capabilities, and learning within the specific firm. As such, the framework developed here is not intended to classify firms per se, must instead be thought of as a vocabulary with which to discuss the complex realities of this process within firms.

Before moving onto individual firm histories, it is essential to restate that within firms multiple sets of routines – parallel strategies – are often evident, and that the strategies and modes of learning discussed here relate to sets of routines, and therefore not necessarily firms as a whole. Additionally, it must be noted that these are opportunities for learning, not guarantees that learning will occur. Quite generally, learning demands a conscious decision, careful management, and increased investment and risk-taking. Without this decision to invest in learning, these opportunities go unused, and the realized capabilities of the firm depart from the potential capabilities related to that a particular strategy. Finally, many of the factors discussed as critical to learning in different modes fall outside the boundaries of firm strategy, and often outside the firm itself. The same strategy, and the same opportunities, in different firms, and different circumstances, can produce quite disparate outcomes. As such, even a firm that makes the appropriate internal investments is not guaranteed to succeed in learning, or to build capabilities. It is with this ambiguity in mind that we turn our attention to the case studies in the following section.

8) Case Studies

Up until now, our focus has been on identifying the similarities between cases, and common threads across firm histories. The following chapter inverts this equation, drawing on the similarities and patterns we've established to discuss firms in a highly specific fashion, considering the complex and time-based relationship between strategies, learning, and capabilities, and discussing in depth the implications of industrial development, firm path dependency, and social, political, and institutional context.

We examine the histories of three firms - Goldwind, XEMC/Darwind, and Dong Fang – considering both internal processes, and external factors including industry development and changing regulations and market conditions. With so many factors inherent in the process, our framework becomes a vocabulary of sorts; a useful way of discussing the state of a firm at a given point in time, and the basis from which a firm-specific analysis is built – not a classification system or taxonomy of any sort. With this in mind, much of the detail presented here cannot be abstracted or generalized directly, but nonetheless provides unique insights into this process as it occurs.

8.1) Goldwind

Goldwind (Xinjiang Goldwind Science & Technology Company) was founded in 1998, and ranked fifth globally by Newly Installed Capacity in 2010 (Li, Shi and Hu, 2010). Evolving out of the earliest European supported projects to bring wind power to China in the 1980s and 1990s, it is the oldest major manufacturer, and as a legacy of this is based in Urumqi, Xinjiang, near these original projects. Prior to the firm's 917 million USD IPO on the Hong Kong stock exchange in 2010, it was 55% state owned. (Lewis, 2007; Chim, 2010) At present, it is considered to be one of, if not the, leading Chinese wind turbine manufacturer from a technology capabilities standpoint, and offers a broad range of wind power related services including project development, transportation, maintenance, R&D, and manufacturing both domestically and abroad. (Shi, 2010)

Through interviews with key employees, advisory board members, and individuals involved in acquired firms, this research explores the unique path by which Goldwind has developed market leading capabilities, and the relationship between these capabilities and the development of the industry as a whole. Given the linear, path dependent nature of this process, the case study is presented as a chronological narrative, with key events and strategies affecting learning or differentiating this firm from others within the industry discussed at length.

While the firm was established in 1998, this was preceded by an agreement with Jacobs Energie of Germany to license production rights to a 600KW design. As the first firm willing to license technology to China, Jacobs played a critical role in the early development of the firm, and the strategies that they pursued. While the license included component specifications and support for assembly of turbines, it did not give Goldwind access to the design process, or support for modifications. (Brown, 2002) While the intention of licensing was to allow production, according to a source involved in the deal, the realities of early entry into the industry immediately demanded extensive modification and understanding of the design to a unique extent. In addition to the general pressures for modification previously discussed, several interrelated issues contributed to these pressures at Goldwind.

These issues are all related to the translation (in many senses) of European design documentation into a form which is usable in the Chinese context, both internally, and in specifying components sourced from sub-suppliers. In doing this, the first issue is that the licensed designs where all made in accordance with, and in reference to, European engineering standards. Such standards profoundly affect the design, specifying detailed requirements for common components, measurement techniques and tolerances, and welding and assembly techniques. (Enslow, 2011) In order to begin production of the design, every aspect of the documentation had to be adjusted and modified to fit Chinese engineering standards. This process, however, was made much more difficult by the fact that the documentation was in German and English, and that at the time very few if any Goldwind engineers spoke either of these languages.

Despite these roadblocks, Goldwind forged ahead with the adaptation of the designs, and produced more then 100 of the 600KW turbines. As an engineer from Jacobs involved in the process described it, "Sometimes they did not understand the drawings. Whatever. They looked at it. They copied it, in a certain way, but not 100%. They thought, 'Oh, we don't need this. We don't need this. We'll make this a little bit different.' And they did not understand what was behind that, so they designed in a lot of new failures with these new drawings."

As is common in the industry, there was an immediate strong push towards localization of components, and the extensively modified design, and the component specifications – having been translated, adapted, and modified to fit the now significantly different overall product design – were then given to local component sub-suppliers. At the time, such sub-suppliers had very minimal experience, and limited capabilities. As an engineer involved explained, "When I went into these companies to do quality control, you didn't know where to start. There was no chance. Just be happy that you get the component that looks like the drawing!" Despite this, in 1998 Goldwind turbines contained 33% local content, and by the following year this had increased to 72%. (Lewis, 2007) With the entire supply chain led by the manufacturer, however, this implies that Goldwind took on extensive responsibility in increasing the capabilities of these suppliers and establishing quality control standards and procedures.

Needless to say, the resulting turbine was, according to an original design engineer, "definitely a little bit different, sometimes with very important components." It should be noted that while component localization is an improvement, in the market sense, the vast majority of the changes made were effectively unintentional, simply results of the process by which the licensed design could be produced in the local context. This affected the performance of the turbines, but also meant that in effect, Goldwind never began with a tried-and-tested licensed design, and the opportunity to incrementally introduce and test improvements at the component scale. Instead, they introduced countless changes and over the next several years worked through the complex issues at both the component scale (namely specifications and quality) and the system scale (issues introduced in the translation, adaptation, and localization process, and only discovered in operation).

This process of translation of documentation established a set of routines that Goldwind maintained until the mid 2000's. This is particularly important because, in the view of Rachel Enslow, it is in marked contrast to later entrants in the industry, and nearly every other Chinese firm. As the industry developed rapidly in the 2000s, foreign suppliers and manufacturers entered the market, and the English language skills and familiarity with foreign engineering standards increased rapidly. After working directly with international firms such as GE and Vestas, Chinese component suppliers were both comfortable with foreign documentation, and had adopted routines for quality control. By 2003 it was no longer necessary to translate documentation, and firms handed over component specifications and design documents to suppliers without going to the trouble of examining them. Nonetheless, Goldwind continued with their approach, and, as an engineer involved in the process explained, "both did not understand, in many cases, what was really behind it", but Goldwind "learned more than the others. They had to go deeper. They made failures, and learned out of these failures." Other firms, "just took the drawing, and handed over. They had no idea what was behind all of it." This approach to licensing, and the ongoing investment in learning and deeper understanding of licensed designs that it entailed, is considered a key factor in the success of learning during licensing at Goldwind by several sources, both inside and outside of the firm.

The lack of experience with a tested design that this approach implied was partially mitigated by the decision, inspired by as similar arrangement at Jacobs Energie, to service and maintain turbines in the field, including those made by other manufacturers. Through the subsidiary Tianyuan, created for this purpose, Goldwind was able to rapidly gain operational experience and undertake learning by using. Additionally, by servicing locally installed turbines including Micons and other European built models, they were able to understand their own failures in relation to the operation of a tried and tested design assembled from high quality components. This unique opportunity dramatically contributed to their ability to develop both system and component level capabilities, and to improve their own version of the licensed 600KW design. It should be noted that approach very similar to the learning process described by packaging equipment manufacturers in Minagawa, Trott and Hoecht (2007).

As Goldwind continued to grow, the opportunities for learning by using allowed by the maintenance of other manufacturers designs, emerged as a key strategy for firm learning and differentiated it from other firms. One significant example is gearboxes, one of the most problematic and expensive components. Tianyuan offers gearbox repair, and from this has had the opportunity to repair the gearboxes of competitors machines, giving them unique insights into both problems and solutions which otherwise demands years of prototyping and field experience to discover. As Goldwind undertook extensive vertical integration, and entered the fields of component manufacturing, installation and transportation, and project development, it was able to internalize the feedback produced by such activities, and in doing so to improve its designs at a much deeper level then would otherwise be possible. (Shi, 2010)

With further licensed from German firms REpower and Vensys in the early 2000s, Goldwind expanded into larger turbines, and continued to pursue this unique approach to licensed production and maintenance, rapidly building capability and experience in both component-scale and system-scale-adaptation. With further experience, and likely supported by their extensive experience in turbine operation and gearbox repair, the firm began to focus on permanent magnet direct-drive. This technology eliminates the complex gearbox, oil filter, and high-speed generators, and can result lower failures and increased manufacturing tolerances. However, according to engineers involved in the process, the initial transition towards it demanded extensive investment in learning, and an acceptance of the decreased pace of improvement this investment demanded.

While up until this point Goldwind accomplished extensive learning by doing and learning by using, their approach was focused primarily on component-scale improvement, as evidenced by their piecemeal, component scale approach taken in problem solving. While system-scale adaptation was involved to some degree, it was not the primary approach until the difficult transition brought about by experience gained during the Olympic project. An engineer involved called this project a "disaster", but said that, "they had to change, and they did change. It was a big step." One very concrete piece of evidence that emerged from this transition was the decision that, despite extreme cost pressures, certain essential components could not be sourced to an adequate standard domestically, and European suppliers would be for these components in future projects. This indicates a broader perspective on the operation of the machine, and the standards of individual components that are required for the successful operation of these components within the system during the product life.

This project marks the realization of a system-scale adaption approach, and the development of a well-defined need for search routines and therefore the emergence of opportunities for learning by searching. This extensive investment in innovation capabilities development, took several forms, including, according to sources familiar with company operations, extensive internal changes. Goldwind opened research centers in both Beijing, and abroad in Germany. Simultaneously, there was a strong push to hire foreign employees, and employees with experience in international firms, including GE. Finally, in 2008 they completed the acquisition of the German design and manufacturing firm VENSYS.

This push has resulted in a diverse company, with multiple locations simultaneously pursuing different approaches to innovation and product improvement. With the acquisition of VENSYS, Goldwind gained 1.5MW and 2.5MW direct drive turbines. The VENSYS team, joined by Goldwind engineers, continued to develop and improve these designs. In parallel, a Chinese team based in Urumqi focused on developing a 3MW turbine based on a less advanced drive system.

In the several years since acquisition, the Beijing R&D center has begun to take on incremental improvements of the advanced direct drive designs, including upscaling the 2.5MW turbine to 3MW. With these incremental upgrades shifted to Beijing, the German-based team has transitioned towards longer-term research and major upgrades, including the development of 5MW and 6MW direct drive designs.

The acquisition of VENSYS has also given Goldwind access to the European market. To support this, Goldwind has constructed factories and workshops in Germany to allow for the construction of VENSYS branded turbines. Many of the key components, however, are imported from China and are shared with the Goldwind brand turbines. (Shi, 2010)

Despite the opportunities that the internationalization of the firm has brought, a significant impediment to broad-cased innovation exists in that the firm has a long history of imitation, and because of this the established routines within many departments are aimed at reproduction, rather than design. As one engineer involved said, "Who's actually making the design changes? It's not the original designers anymore, it's the engineers on the ground."

The relationships this previous arrangement created between production and design engineers continues to affect the ability of the firm to resolve problems in a proactive, search routine based way, despite the increasing prevalence of search based routines in the design process. As Goldwind continues these internal changes, it is likely that the shift away from a on-the-ground, reactive based approach to problem solving will spread throughout the company. For the time being, however, Goldwind is, "at the stage to solve problems", while the more innovation driven elements of the company are slowly integrated. (Anonymous-Source, 2011) As this progresses, the longstanding relationship between design and production must adapts to the transition from licensed technology to internal R&D, and the close relationship to engineers that this involves. Until the firm, as a whole, learns to harness the availability of internal, search based R&D, the transition towards innovation-based routines will be only partial.

8.2) XEMC/Darwind

Xiangtan Electric Manufacturing Corporation, Ltd. (XEMC) is a majority state owned firm founded in 1936, and is based in Xiangtan City in Hunan Province. With 70 years of experience in electrical equipment, more than 1000 patents and intellectual property rights, it brings a strong set of related capabilities and experience. XEMC employs more than 10,000 people and manufactures electric machines, heavy trucks, ship propulsion systems, electric locomotives, light rail vehicles, water pumps, defense related products and wind turbines. (Darwind)

In 2006, they began production of a 2MW direct drive turbine originally designed in the Netherlands, and, in 2009, purchased the Dutch design firms Darwind BV and VWEC BV. In 2010, they were ranked 7^{th} in Newly Installed Capacity, although much lower in total install capacity. As a state owned firm, they bring strong connections to the local economy and political party, and are the beneficiary of significant subsidies and research grants, many of which directly support the development of wind turbine manufacturing and technology. (XEMC, 2008; Strik, 2011)

The history of the firm before quite recently is almost impossible to reconstruct beyond official histories. According to these, XEMC entered into the wind energy market in the mid-1990s, with R&D on 300KW and 600KW turbines, eventually installing over 200. Similarly, in the mid 2000s they claim to have independently developed 1.5MW and 2.5MW non-direct drive machines. While the firm has long produced generators for wind turbines, the degree of their involvement and independence of the design in these earlier projects is largely unknown. Pengfei Shi of the CWEA considers XEMC to be a "newcomer to wind, but with experience to produce generators", while engineers involved in development of current designs refer only to experience generated through the development of later, licensed designs.

In the industry more generally, it is common practice is to claim research and development of designs which are based on licensing or technology transfer. (Feng, 2011) While claims reduce industry transparency, they shed light on how the role of technology is conceptualized within large, state-owned firms: These are first and foremost manufacturing firms, and understand R&D to be industrialization and mass production, not basic research and design. A similar perspective is apparent in the manufacturing case studies of Minagawa, Trott and Hoecht (2007)

Despite these claims of earlier entry into the industry, the commonly accepted entry of XEMC into turbine manufacturing occurred in 2006 when the firm undertook a 50-50 Joint Venture with Harakosan of Japan to produce a 2MW direct drive turbine for the Chinese market. In 2007, Harakosan reduced their stake in the venture, and in 2008 sold their remaining shares, completing the transfer of the technology to XEMC. (HARAKOSAN Sells Part of Investment in Hunan Hara XEMC Windpower, 2007; Schwartz, 2009) The design of this turbine traces back to the Dutch firm Zephyros BV, which began developing this design around 2000. In 2002 a prototype was built and installed, and over the next several years testing and certification was complete. When XEMC acquired the 2MW design in 2006, the design had completed testing and certification, and changes made in response to operational experience gained from installed 20 units had been incorporated. (Versteegh, 2004; Strik, 2011)

With a strong supplier base familiar with foreign documentation, and a tried and tested design, XEMC was potentially able to pursue a strategy very close to blind imitation. There was very little of the basic problem solving in either product or process design which occurs both in translation – as in the case of Goldwind – or in licensing and producing a new, untested design. This allowed XEMC to immediately undertake series production, and to gain experience in manufacturing and operation very quickly, delivering more than 150 units over three years. (Darwind; Strik, 2011)

With a tried and tested design to work from, and the pressures for localization and adaptation already discussed, XEMC quickly moved to shift the supply base towards domestic suppliers to reduce costs. They shifted primarily to Chinese suppliers, but did little else. Frank Strik attributes this to the direct way in which they respond to the market, and the unique circumstances of business in China, explaining, "When we walk around [the factory] - especially with the guys who developed the Zephyros turbine - we still see a lot of things which they had on their value engineering list. You see that they are focusing on material, but labor hours and improving assembly speed is not on their agenda."

Instead, XEMC has chosen to focus more on increasing performance, mainly through increasing blade size, and therefore the power output of the turbine. Despite this emphasis on performance, Frank Strik of Darwind-XEMC sees this as reactive behavior, mimicking the moves of competitors, and not trying to address the needs in a fundamental way. He gives the example of the process of component-scale, incremental upgrading XEMC pursued to increase the blade size of the turbine, a relatively easy way to increase capacity:

They went from a 72m rotor to a 90m rotor, and they are now thinking of going to a 110m or 120m rotor diameters. Initially it was mainly upsizing the blades without reengineering [the whole turbine], but if it's a direct drive wind turbine as soon as you go up with your rotor diameter you have to go down with your rotational speed to keep [rotor] tips speeds within acceptable limits. If you do that the generator will start growing in size because its power is rotational speed times torque. So at the moment it really gets expensive and heavy. What you see there is as soon as you do that you have to move further into redesign. So they redesigned the hub to which the blades are fastened to go to a bigger casting, bigger equipment, and bigger pitching mechanisms.

While a more experienced firm would likely address the need for increased power production from a system-scale perspective, XEMC introduced incremental, component scale changes, and then traced the implications of these design changes through the complete product. The complete process took 3-4 years, beginning when the design was first licensed in 2006. By pursuing this process in a cautious way, XEMC was able to develop a turbine with increased power production based on a component-scale understanding, and while avoiding the dramatic operational failures of riskier styles of trial-and-error learning.

This slow, cautious, and incremental approach was noted by several industry sources as unique in the industry. Simon Feng Yuan of the consultancy DNV notes that, "they do not hurry to modify something. The first step is just to go along with the original design. They invest a lot of attention in the technology, the R&D, and they're very respectful of the regulations and the process, but they sacrifice speed, and sacrifice market share." However, he sees this as an effective long-term approach to the market, giving them potential access to the global markets in the future. Frank Strik notes the same approach, and attributes it to their long experience in industrial applications, " 'we'll see what it does' is not in their blood. They've learned their lessons in other industries, building generators. They know they have to do their checks in the process to make sure that when they send something out they know the quality level." This slow and cautious approach has come to characterize XEMC, and continues to underlie their product improvement routines, and technology strategy to this day.

While XEMC established strong production and incremental improvement capabilities, their market share remained limited. Despite upsizing and cost cutting, their 2MW design began to fall behind rapidly developing the market. In 2009, XEMC acquired Darwind BV, a small Dutch turbine design firm made up largely of engineers involved in the development of the earlier 2MW design, and now working on a closely related 5MW offshore design.

As a small, young firm with experienced engineers, and a unique design developed from the ground up as a complete, efficient system, Darwind is, in many ways, the peerfect example of a innovation driven European firm. With years of research complete, and the design finalized, they intended to build a limited number of prototypes, revise the design, and eventually seek production. XEMC, on the other hand, understood "final design" as ready for production, not ready to prototyping, and expected to very quickly be able to bring the 5MW turbine to market.

While Goldwind had almost 10 years experience in wind power, and solid, system scale understanding of the product, and experience with the complete design and development cycle when they acquired VENSYS, XEMC had much more limited experience, approaching product improvement from a component scale perspective. The rapid production timeline and significant quantities of 2MW turbines produced provided experience in doing and using, but only limited learning opportunities because of the tested nature of the design and consequent lack of trial and error problem solving and iterative learning. This reinforced XEMC's core strengths in product industrialization and production, while, according to Frank Strik, Technical VP of XEMC-Darwind, leaving them inexperienced in the earlier stages of turbine design, development, and production.

XEMC purchased the firm with very minor due diligence, and only after the transaction was completed did these differences in expectations become apparent. Frank Strik explains that XEMC was used to working with mature technology, supported by a broad range of high quality suppliers, and with the 5MW, XEMC was forced to adjust the demands of being a leader, seeking out qualified, specialized suppliers, and investing in R&D, prototyping, and testing. As it became apparent the production timeline would need to be sped up significantly, XEMC purchased VWEC BV – a related Dutch firm founded by the head developer of the 2MW turbine they produced, and closely related the Darwind 5MW turbine – in order to bring in greater engineering resources. With the additional resources of XEMC at their disposal, the combined Darwind-VWEC-XEMC pushed ahead with development, and installed two 5MW prototypes in May 2011, with 2.5MW prototypes to be installed several months later.

This development, and the continued collaboration and integration of Darwind-VWEC and XEMC has brought to light countless differences in innovation approach, technology strategy, management style. Frank Strik explains, "They gave us the time to improve, and at some moments they stepped in with a quick change. Where we advised them not to do it in that direction for what we thought were good reasons, in some cases they ignored that. But what we've seen gradually - also on some of their successes where they've made the right choice, but also some of the more complex dossiers - in the end they had to go back to what we'd proposed initially because it was technically not manageable in that time frame to make such a step. And the level of trust has grown." With regard to components, it's similar, with "only one big transfer - the generator - which is their core business, so it's quite logical."

In the future, however, he anticipates greater pressure on cost, and therefore a shift towards domestic suppliers and vertical integration, but believes that, based on their experience with the 2MW design, "they are aware of what they can and cannot do." As an example of this, he notes that they purchase bearings for the 2MW design from a European supplier, although this may be in response to repeated failures more then system-level understanding.

Similarly, once the design is completed, and there is a shift towards incremental upgrading, he sees XEMC's experience as extremely important, and believes that they'll take the lead role. XEMC wants such upgrades completed much more quickly then Darwind would perhaps prefer, and because this they will pursue them using their own resources and approach, with Darwind acting as an oversight team of sorts, warning of potential risks. Such an arrangement is interesting in that it separates the approaches, maintaining the search-based routines of Darwind to develop new products, and the component- scale capabilities of XEMC to support manufacturing and incremental improvements.

The degree to which this separation – similar to the arrangement at Goldwind - is conscious, or simply a product of internal organizational practices, including bureaucracy and strong, top-down hierarchy is difficult to determine. While this separation is at times beneficial, it also erects boundaries to internal communications, and may in fact be a reflection of preexisting internal structures that seek to distribute knowledge across engineers in an attempt to limit the ability of any single engineer to transfer technology to other firms. This issue, and the structuring of firms in this way was mentioned as problematic by several key sources, and is seen by Frank Strik as the key reason that XEMC has been unable to develop a system-scale understanding of the technology.

In the XEMC-Darwind case, the impact of this approach is especially apparent in regards to operational performance and learning by using - a notable weakness of both firms. Frank Strik explains that, although he doesn't understand why, he sees a constant reluctance to share information. He believes that XEMC has learned quite a lot through the operation of their installed 2MW turbines, potentially even improving them in response to field issues, and that information on the performance of these turbines, including operational data, would provide insight into potential weaknesses in the 5MW design. This, in turn, would allow these issues to be addressed at the design phase, and incorporated into initial prototypes, reducing both risk and cost. Instead, XEMC engineers have raised concerns about specific aspects of the 5MW design based on their own operation experience, but remain unwilling to provide basic operational data.

XEMC-Darwind is a rising star in the industry, with cutting edge technology, strong government support, and newfound access to international markets. Despite the strength of their combined experience, however, they are surprisingly lacking in operational experience, and system-scale capabilities founded in learning by using. Related to this, and preventing the development of these capabilities, are the issues of internal communications, and the degree to which knowledge gained through different modes of learning can be combined and utilized. Capabilities in incremental innovation and frontier innovation are both essential, but with active learning and improvement occurring in both approaches simultaneously, we must consider the degree to which they can interact and inform each other, and if they do, the degree to which they can maintain their respective advantages.

8.3) Dong Fang

Dongfang Electrical Machinery Co., Ltd was founded 1958 in Chengdu, Sichuan Province. It is a state owned company focused on manufacturing power-generating equipment including hydroelectric generators and coal, gas and nuclear powered turbines. (DFEM, 2008) Dong Fang entered the wind turbine market in 2004 by licensing a 1.5MW design from RE power of Germany, and by 2008 had shipped over 800 turbines, becoming the 3rd largest manufacturer with 22.3% of installations. (RenewableEnergyWorld.com, 2004; Li, Hu et al., 2007; AMSC, 2010)

As Sebastian Meyer of Azure International explains, "They're not leading on the quality side, or the technology side." but because of their existing position in the market, "They were able to very quickly build up an order book that would be impossible for anyone else." While Dong Fang has so far maintained their position as the 3rd largest Chinese manufacturer, their market share has decreased to 14.8% in 2010, and will likely increase further according the Meyer. (Li, Shi and Hu, 2010)

The previous two case studies have been organized chronologically, tracing the development of routines and capabilities creation through the firm's history. In the case of a Dang Fang, with the resources available to this research, it's not possible to construct such an account. This is a reflection of both the lack of transparency apparent in state owned firms, and Dong Fang's unique approach and strategy, namely a lack of investment in learning which would allow for cumulative capabilities creation. Nonetheless, Dong Fang's success in the market makes it an important actor, and when considered from the standpoint of capabilities and learning, it serves as an example the incredible variety of approaches being pursued, the assumption on which these are based, and the changing demands of the market.

Among the major manufacturers, Dong Fang is perhaps the most traditional. Both Pengfei Shi of the CWEA, and Liang Weiliang, of the Danish Embassy in Beijing, argue that this traditional approach has kept prevented the independence of the wind turbine division, and that, because of this, there is no "big boss" in charge of wind energy within Dong Fang, with negative implications for personnel, decision-making speed, and industry specific knowledge and strategy. More generally, Frank Strik of Darwind describes this lack of leadership within Chinese firms as a key impediment to innovation and risk taking.

This traditional approach is, in part at least, tied to the government oversight of the firm, as Weiliang describes in terms of their locational decisions: "I asked them whether they want to set up an R&D office in Denmark or Europe and they say said 'No, probably never. It will never get approval from the government.'" While the other major firms in the industry have internationalized and developed a presence in key markets, Dong Fang chooses to maintain the core of it's operations in Chengdu, far from the emerging cluster of Beijing. Weiliang notices the affects of this in the difficulties it creates in working for Danish suppliers, and believes that "it really makes it difficult for them to be a part of the global research networks, [and to access] global suppliers."

Dong Fang's unique structure and approach is similarly reflected in their strategies for technology acquisition and R&D. Much like XEMC, their past experience in mature technology and expertise in manufacturing encouraged an extremely fast timeline for prototyping and production ramp up. As Rachel Enslow, an industry consultant, describes it, "Goldwind took 2 years - from prototype to serial production at the 1.5MW level - and Dong Fang took 1…. But Goldwind, prior to that had already had 8 years of experience, and [they] were starting from scratch."

According to an expert involved in an early licensing deal, "They think their technology level is much higher then wind technology. It's peanuts.". This supports their fast production schedule, but also limits their involvement with the technology sources. According to this source, "right with the first turbine, they refused any real communication." While the Chinese viewed the transfer of technology as a simple purchase of blueprints, the licensing firm wanted to guarantee a certain level of quality to protect their brand and design. Even within engineers in China, however, Dong Fang was unwilling to accept feedback, or to improve quality in response to the concerns of engineers.

This approach was further manifested as Dong Fang undertook supply chain localization. While the initial contracts specified the use of certain components from German suppliers, and the licensor worked to reinforce the importance of this, Dong Fang set aside the contract and immediately undertook replacement of these key components. According to Rachel Enslow, "When you actually went and you looked at the factory at what they were doing, they'd changed every component.", including those which " it's not necessarily safe engineering practice to switch." She explains that, "The Chinese look at, for example, a gearbox, and they look at the outside. They look at the basic details of what's given, and they try and back-engineer that… you're basically putting a completely different piece of equipment into that machine then it was originally designed with."

While this approach has specific downsides, including a lack of internal capabilities creation and learning opportunities, and notable issues in reliability and service, it has also allowed Dong Fang to pursue a unique strategy for the acquisition of technology. While other firms have generally shifted towards stronger, more collaborative relationships with partner technology firms, Dong Fang has chosen to pursue what Sebastian Meyers calls a "shotgun approach", collaborating with and licensing from numerous firms simultaneously. While initially they licensed only from one firm, Meyer believes that today they're "clutching at everything they can find.". While one division of the company pursues R&D and Joint Design supported by the international consultancy Garrad Hassan, another division has licensed design from 3 or 4 manufacturers, and is pursuing production more directly.

According to Meyer, this approach reflects the uncertainty of both Dong Fang, and AMSC, a major technology licensor, and is potentially equally problematic for both parties: AMSC is, "not even sure that eventually Dong Fang will produce AMSC licensed turbines, but in the meantime they've got plans, they've spent a lot of engineers time from the AMSC side, and they try to internalize as much as they can from that process, even if they just produce one prototype."

For AMSC, it's possible that this investment of time and resources, and implicit transfer of technology, will prove a failure. Nonetheless, AMSC and other such licensors must accept such risks because there's simply no way to select who is likely to produce the design in the end. This, he argues, means, "there's a kind of selection going on both ways", but, in the end, Dong Fang retains the dominant position, and if "it's got something better up its sleeve elsewhere it will not rollout the AMSC turbine."

This approach is largely dependent maintaning on arms-length relationships with technology suppliers, but also implies that a much more fluid and extensive market for technology exists then would be suggested by the tight-knit relationships and firm acquisitions presented in previous case studies.

Meyer believes that today most necessary technologies can easily be purchased on the open market through design services, technology licenses, and the acquisition of foreign firms. The existence of such a market draws into question a fundamental assumption of this thesis, and the importance of internal capabilities development and learning, specifically those related to technology development. Simon Feng of DNV points out that, "10 years ago I would think it was very important to own the technology. Now, the world is a village. You can buy it."

While the key argument made for purchasing foreign firms is to gain exclusive access to markets and technology, Meyers makes the argument that with almost 100 firms pursuing wind turbine manufacturing but a relatively condensed supply chain – "gearboxes from the same 15 companies, blades from the same 30 companies, generators from the same 15 companies" – there's very little room to differentiate products regardless of the source of the design.

Perhaps even more simply, it should be pointed out that according to Gao Hui, Chief Engineer at one of China's big 5 utility firms, "as customers, actually, we don't care who designs the turbines. We just want to buy the reliable turbines." Pengfei Shi similarly argues that customers, "don't think of WindTec-AMSC or of Garad Hassan. They only see your performance or reliability or your track record.

However, it is important to question the validity of this understanding of the market as the industry becomes more innovative. Simon Feng argues that there is a market for technology, and that ownership is becoming less important, but also that such a market is best suited to, “a mature product, [with] a successful installation record in Europe“. In turn, he argues that the increasing risk involved in licensing more innovative technologies is a greater impediment to this market then issues of modification or profit sharing.

While XEMC and Goldwind have choosen to internalize R&D, and to develop search routines to bound the increasing uncertainty of innovation as it approaches the frontier, Dong Fang instead has attempted to rely on external sources of technology to bound their own incremental R&D. In this sense, it becomes clear that these firms where able to select the appropriate firms to collaborate with and eventually acquire based on their previous history and internal capabilities. Dong Fang, by relying completely on external technology while maintaining ill-suited internal structures and routines, developed very little of these capabilities despite experience in related industries and sizable market share.

At a very basic level, it is clear that while Dong Fang has seen market opportunities, and pursued these effectively, they’ve done so in a short-sighted way, with very minimal investment in learning and capabilities creation. While Goldwind has largely internalized R&D, and XEMC has purchased but not yet integrated Darwind and VWEC, Dong Fang has elected to maintain itself as a traditional, manufacturing based firm which depends on external technology sources and capabilities in related industries for competiveness. In a market shaped by pure price competition and adoption of mature, tested technologies, such a strategy has proven surprisingly effective. However, as the industry approaches the innovation frontier, the fundamental uncertainty of the innovation process is presenting itself as the inability to properly select and pursue viable technology sources – the open-market equivalent of the R&D decision-making process.

9) Discussion and Conclusion

This research project has proven ambitious in both scope and depth. Using a novel methodology, we've examined firm histories and identified strategic transition related to imitation strategy. We've explored the approaches these transitions bound, and defined the potential for learning in different modes within them. Finally, we've used this framework to look inside of firms in a rigorous and nuanced way, and to examine the interconnected processes by which context, routines, and learning coincide to direct firm strategy, and to form capabilities.

The story that has emerged is complex, sometimes to such a degree that maintaining a broad perspective is difficult. With this in mind, this section re-examines the central three research questions that have directed this project, reflecting on them, and answering them to the degree possible. From here, we propose three observations on learning and imitation in China that have, and discuss their implications and potential applicability in a broader context. Finally, we conclude with a discussion of the challenges and opportunities for further research in the hopes of encouraging continued research on this exciting topic.

9.1) Discussion of Research Questions

At its core, this research is concerned with the simple question, "What role does imitation play in firms learning and capabilities development?" This question is, of course, nearly impossible to address in its entirety, and for this reason was deconstructed into three specific questions that guided the theory building process, and the parallel empirical research. In reflecting on these questions, we adopt this same approach, looking at each of these three questions individually and discussing key findings, implications, and the overall effectiveness of this research.

What approaches to imitation do firms pursue?
While previous typologies propose a simplistic blind imitation/emulation/innovation division on primarily theoretical grounds, we develop a typology based on shifts in firm strategy and capabilities observed within firm histories in this industry. By combining existing typologies with this empirical research, we have refine and develop the existing typology of firm strategies related to imitation, and provided the basic categories within which the learning process is explored.

At the center of this revised typology is a redefinition of the "innovation" transition. While in previous literature this transition is often understood as singular and easily defined, we acknowledge that the development of search routines is diverse, multi-scalar, and often unequally distributed within the firm. With this in mind, the initial development of search routines is seen as a key step in the transition towards innovation, but does not itself define the transition of a firm towards an innovative approach. Instead, it is a prerequisite for further development, and a sign of the increasing importance of innovation within the firm. At this early stage, because the search space within which these routines operate is so strictly limited, they are in many ways quite similar to trial-and-error, albeit with certain elements of experience and feedback internalized. As these routines develop, and the search space within which they operate broadens, innovation in the conventional sense becomes central and search based innovation begins to guide the actions of the firm to a greater degree than trial and error bounded through imitation. Understood in this way, innovation does not emerge instantaneously, or without mechanism, but instead slowly in response to specific conditions and demands, supported by a changing approach and internal investments in learning. In short, the transition is unpacked and exposed as a complex process that can be further investigated in future research.

While this perspective on the imitation/innovation transition is likely generalizable to a broad range of catching-up industries, the second major adaptation of the typology – the component scale/system scale division – is industry specific to a much greater degree. Within this industry, engineers and industry insiders consistently recognize the transition it defines as a key demarcation in the development of capabilities and approach. This division, however, is a direct reflection of the structure of the wind turbine manufacturing industry, specifically the strong division between component suppliers and turbine manufacturers, and in other industries, specifically those with greater vertical integration, or those in which a strict component/system division has not emerged, this specific distinction is likely not present, or is unimportant. A similar, capabilities based division within the imitation phase, however, is extremely useful in examining firm capabilities growth, and the possibility of comparable shifts in other industries should be explored in further research.

We believe that, within the limited scope of this industry, our research has successfully developed a typology of strategies of imitation, and defined these strategies in relation to firm capabilities and process. Within this industry, and our research specifically, the framework bring significant clarity to the number and nature of strategies which firms pursue, allowing us to explore and define these strategies in terms of capabilities and learning opportunities. As such, it is a successful and useful working framework, but still far from an abstract typology or system of classification. Similarly, we believe it to be a valuable template from which to work in pursuing similar research in other industries. The improved division of the imitation/innovation transition, in particular, is likely broadly applicable and therefore of particular value.

What forms of learning relate to these strategies?
Adopting the typology developed in answering the previous research question, and building on in-depth interviews and discussions, we examined the opportunities for learning apparent in each approach. The analysis we develop, however, does not directly relate modes of learning to strategies, but instead only delimits the forms of learning that may potentially occur within certain strategies. For this reason, it answers our research question only to a limited extent. Nonetheless it provides a basis from which to consider learning within specific firms, and a foundation from which to analyze our case studies. As such, it is successful in a purely instrumental sense, but leaves much room for further research in terms of defining the likelihood of learning within these modes, and specific factors that influence the emergence of capabilities.

A particularly notable finding of this portion of the research is that blind imitation, while heavily discussed in the literature is, in practice, almost non-existent. Within the Chinese market, and the wind turbine industry specifically, there are numerous reasons for this. Some factors such as localization, price competition, and translation issues or misunderstandings, however, are not limited to this industry or market. With this in mind, it is necessary to reconsider the degree to which blind imitation occurs at all, in any market or industry. If this is the case, and firms must always invest in learning to some degree, then the existing division between imitators and emulators becomes quite useless, and the basic idea that licensed production can be pursued in a purely duplicative fashion must be reconsidered. In the wind turbine industry in China, this certainly appears to be the case, and perhaps the same is true much more broadly.

A key limitation of this research developed is our limited discussion of frontier innovation. While with other strategies, a range of industry examples were available, in the case of this strategy, there are simply no firms that have definitively transitioned to this approach. As such, the discussion undertake is purely theoretical in nature, with very little grounding in empirical research. In this sense, it is much less developed than the other aspects of the research, and is an area in which additional research is absolutely necessary – either in this industry, at a later date, or in another, more mature industry.

How are these strategies assembled into firm-specific histories in which capabilities develop cumulatively and imitation builds innovation capabilities?
Given the focus of this question on firm-specific processes, it is impossible to make a judgment about the degree to which this research has produced an answer in the broad sense. However, for the specific firms examined, this research has provided significant insight into this process. While the generalizability of this research is extremely limited, we believe that it makes a strong argument for absolute firm-specificity and path dependency of these processes. The central role of firm and context specific factors is demonstrated by the case of Goldwind, and the importance of the particular learning processes they developed in response to the seemingly inconsequential lack of English language skills. In our view, much of the success of Goldwind is built on this happenstance investment in learning, and the long-standing routines in constructed.

Without such an intensive analysis – and an awareness of the innovation system and development of the industry – this insight would simply never emerge.

Similarly, the importance of alignments (or misalignments) between the development of firms and development of the industry as a whole plays a surprisingly important role in the success of firms. Here Dong Fang is the ideal example. As a firm with strong related capabilities, they excel in a market focused on cost-competition. However, as the market transitions towards design competition and improved quality standards, these same capabilities become problematic. This is precisely in line with arguments for the life-cycle specificity of related capabilities made by Teece (1986), and the argument by Lall (2000) that as industries develop previously useful capabilities can become counterproductive.

In the end, the theoretical framework constructed existed in order to allow for this case specific analysis of the capabilities creation process within firms. It must be said that while the previous two sections of the research produced this framework, it is fundamentally these case studies that led to the development of more general observations, and an overall perspective on this unique process as it has occurred within firms in the Chinese wind turbine manufacturing industry. With this in mind, we view the case study portion of this research as quite successful – a judgment that we see as supported by the observations and research agenda presented below.

9.2) Observations on Learning and Imitation in China

Throughout this research, certain observations seem to reappear again and again. We've mentioned them briefly, sometimes discussed particulars in depth, but not yet had the opportunity to examine these ideas in a more open fashion, or to discuss their implications. That discussion is precisely the purpose of this chapter. In it, we outline three observations derived from this research, reflecting on their implications and applicability beyond the scope of our specific research.

Customer Risk vs. Innovator Risk: How the Market Supports Trial and Error

In examining this industry, it becomes apparent that trial and error can do much more then we at first assume. We often see trial and error as a failure – a lack of understanding – but the approach seen in China demonstrates the degree to which it can succeed, and the potential advantages that it brings.

In the western context, strong regulatory and legal systems demand a specific mode of R&D and prototyping, and a focus on certification and risk-mitigation. Using the same routines that develop the product, firms establish testing regimes: pushing the product to limits that they define, and in directions where they perceive potential problems. From this, they define an operational envelope, and bring the product to market, limiting operation to this tested domain. The process satisfies standards, and uncovers certain issues, but it's far from real world testing, and provides only limited feedback useful to the innovation process itself.

Chinese firms, in contrast, take a very different approach. Prototyping is relatively limited. Instead, most testing and learning occurs through actual operation, in the real world, and with a real customer. The product sold to customers is far from proven, but customers accept this, seeing a fair deal in "better service, more failures". The risk of innovation, and the process of learning are shared. Instead of a single prototype, these firms effectively have hundreds – hundreds of opportunities for learning and improvement.

From the perspective of learning, these two systems couldn't be more different. In the first, learning stops when the product is certified, and certainly when it is delivered. Any opportunities for learning that emerge after this are, in some sense, *failures* on the part of the manufacturer. The market does not support or allow for such learning, instead rejecting the product as unreliable, as happened to early Chinese turbines sold in the west. In the later approach, however, a degree of failure is assumed, and this risk is shared, and appropriate investments are made to support learning and improvement. Trial and error proceeds indefinitely, and the opportunities for learning are immensely increased. Such an approach, however, is only possible when supported by the right market conditions, cultural norms, and customer relationships.

When literature speaks of the increased risk and investment inherent in learning, it is easy to understand this as a diffuse potential risk – the risk of investing in the wrong technology, for example. In the approach we discuss here, this risk is much more concrete – physical failure and market rejection – but the rewards are also much more tangible. Goldwind is, perhaps, the best example. When they first started, by translating their licensed designs, they introduced countless defects and potential points of failure. But, by offering maintenance and support, and by maintaining the trust of their customers, this potential disaster became the basis for an industry leading understanding of turbine design and operation. Failures are opportunities for learning – the more you have, the faster you learn, potentially.

We call this the frontier mentality – big risks, big rewards, and, honestly, nobody really knows what they're doing anyway. It supports learning, absolutely, but is a product of a much broader approach, a few aspects of which we've come across in the course of this research. Culturally, a focus on relationships, interpersonal trust, and face-saving supports these complex relationships. Economically, a very particular system for the management of risk and working capital allows for firms to take risks that would impossible in another context – building, or buying, hundreds of untested turbines, for example. Finally, the role of the current political system, and specifically the state ownership of firms allow risks to be pooled and time horizons extended in a way that produces incentives beyond the scope of individual firms. Fundamentally, it's simply a different approach, and, from the perspective of learning, it appears to be a highly advantageous one. The factors listed here are just the very beginning of considering this complex problem, a topic that absolutely demands further research in the future.

Turning our attention back to western markets, this raises a very interesting set of questions: How does risk-mitigation culture limit opportunities for learning by trial and error? Does it force firms into proactive, search-based routines, perhaps unnecessarily? To what extent is the success of the western model of innovation coupled to western values and institutions?

The Feedback Loop

Learning is an iterative process. It is about proposing solutions, testing these solutions, and responding to the results. Feedback is essential. For learning to be successful, and improvements to occur, however, this feedback must meet many requirements. In terms of complexity, it must match the understanding of those responding to it – systemic failure cannot be directly translated into component-scale improvements. Similarly, it must match the timeline on which improvements are made, and occur quickly enough that improvements can be tested and revised without falling behind the needs of customers and the pace of competitors – when a bolt fails, you can't wait 3 years to build and test a prototype. Finally, the scope of search space – the degree of uncertainty addressed – must be appropriate to the question at hand, and limited to such a degree that results can be understood within the domain of possible solutions, and in a timely manner. Feedback is fundamental, but often mismatched to the needs of the problem at hand.

In our view, search routines do not emerge from some essential need for innovation – trial and error can be equally innovative, given the right environment – but, instead, develop to bridge gaps and misalignments between problems, solutions, and feedback. As a firm moves from component to system-scale adaptation, the feedback that emerges from learning by using begins mismatch the needs of continued component-scale improvement. As the product improves, and basic weaknesses in components are resolved, failures – which is it say, feedback – become fewer and further between, and when they do occur, responsibility is nearly impossible to translate to the component scale. If, after years of use, a component fails, is this because of an issue with that component, an issue with components connected to it, or the specific operational history of that particular machine? And if you replace that component, and the machine runs for another three years, how do you learn in the meantime?

In this example, as issues become more complex, and a systemic understanding emerges, search routines develop to connect together disparate solutions and tests. In the years leading up to that failure, engineers examine the problem proactively, looking for potential weaknesses in design and components. When the problem occurs, they compare this problem to countless similar problems – perhaps, in the case of Goldwind, even to failures in turbines produced by other manufacturers. In short, they develop search heuristic and innovation-like routines, and these allow them to distill and internalize the feedback necessary for continued improvement at all scales.

Viewing search routines as a product of misalignments in feedback loops helps us to understand why firms develop these routines, but also why imitation becomes so difficult as firms approach the frontier, and how the specific context of China has allowed trial and error to go so far. In the end, it comes down to simple numbers: for a given product, as you improve it, the number of failures decreases, and therefore the rate of learning decreases. More fundamentally, as the scale of understanding of a product increases, so to does the complexity of problems and solutions, and therefore the amount of information necessary to understand potential solutions, and the time needed to test them. The length of the feedback loop inevitably increases. At some point, the rate at which trial and error can generate improvements, and the rate at which the market demands them become severely mismatched. At this point, the firm is forced to make a strategic shift towards imitating *different* technology – a proactive, strategic decision in of itself, as demonstrated by Dong Fang – or to develop routines which allow it to develop improvements without external feedback – innovation.

Chinese firms, both by introducing problems to refined products and by massively increasing the number of prototypes, and therefore the likelihood of a given failure occurring and feedback being produced, have been able to avoid the costly development of search routines much longer then would otherwise be possible. Nonetheless, they inevitably run into the same basic problem: they only learn when they fail, and they're getting very good at what they do.

As Chinese firms shift towards international markets, this whole system is coming under further pressure. Suddenly they must sell products that *will not fail*, and in this way must further limit their own potential for learning through trial and error. These two pressures – one fundamental, the other contextual – are aligning to force Chinese firms to attempt a rapid transition towards search based routines, a process that we see clearly expressed through the sudden acquisition of western design firms. With this in mind, it becomes difficult to see trial and error as a true alternative to western approaches to innovation. Nonetheless, particularly from the perspective of learning and rapid capabilities development, trial and error plays a crucial role, and is likely underestimated in current literature.

Parallel Strategies: Carefully Managed Proximity and Internal Heterogeneity

Throughout this research, there is a fundamental tension between two understandings of learning: cumulative and sequential in theory, and simultaneous, overlapping and complex in reality. Here, we come back to a core tenet of evolutionary economics: the firm is a bundle of routines, not a sealed, hermetic unit, or a black box. The unit of analysis throughout this research has been the routine, in all its flexibility and ambiguity. With this in mind, the question of parallel strategies can be considered as a question of internal heterogeneity of routines, and the degree to which firms support multiple sets of routines, and therefore implicitly, multiple selection environments. If each approach to imitation – which is to say, set of routines – presents distinct opportunities for learning, is it not ideal to pursue multiple approaches simultaneously?

Heterogeneity of routines within firms is a massively complex issue, but, fundamentally, there is a pressure for homogeneity within firms. After all, the firm itself is an emergent property of homogeneous routines – without this, it would be nothing more then a set of individuals. In the case of Chinese firms, however, these pressures seem to be somehow mitigated, allowing the mergence of parallel sets of routines, and therefore learning in multiple modes.

Much like the previous discussion of the "frontier mentality", the particular conditions that allow this to occur are nearly impossible to ascertain. However, two points, in particular, stand out. First, Chinese firms are traditionally quite hierarchically organized, and this limits horizontal information flows dramatically, potentially allowing for diversity by artificially separating different departments and operations. Second, Chinese firms are extremely concerned about corporate espionage and employee poaching, and with this in mind have further restricted already limited horizontal information flows, often going so far as to prevent any one individual from understanding any key technology in it's entirety. On the one hand, this rigid structure and the limitations it places on information flows severely limits the ability of the firm to move past component scale understanding, and to introduce proper communication channels between manufacturing, design, and operational aspects of the firm. On the other hand, this same structure allows different units within the firm to specialize in the approach that proves most suitable to their own goals, and prevents uncertainty at one level from disrupting learning at another level. It allows learning in multiple modes, simultaneously.

Exactly how and why this approach works is the topic for further research, and in addition to the previously mentioned points, is likely related to the size and loose governance of China, particular structures of management and internal communications within the firm, the initial, resource based locational division of production and R&D, and the ability to purchase european design firms to pursue advanced R&D. Nonetheless, it is likely that this specific mix of factors, and the unique balance between heterogeneity and diversity which they allow, is at the core of what differentiates China's firms, and their astronomical rates of growth and capabilities development, from previous examples in SE-Asia and other NIEs.

In some sense, it's very simple: by learning in many modes at once, they build up capabilities far more rapidly than by linearly progressing through these modes. The process is messy, risky, and at times a bit wasteful, but as one China observer explained, "If they get it right 70% of the time, they're happy. And things get done a lot faster." He was talking about building a bridge before knowing the size of the road it supported, but the same could be said for China's firms.

9.3) Development of a Research Agenda

While this research has provided considerable insight into the theoretical issues explored, and a unique perspective on this particular industry and its development, we remain far from establishing concrete answers to these difficult questions. The theoretical framework, detailed case studies, and general observations are pieces of a much larger puzzles, and clues for future researchers, but not answers in of themselves. The organization and guidance of future research, informed by the empirical evidence and theoretical perspective we provide, is our primary contribution to scientific research. The agenda developed here is seen as the ultimate findings of this research, and as the conclusion to this work.

Trial and Error and Feedback Loops

When beginning this research, the fundamental importance of trial and error within the Chinese market was not apparent. This research has done much to argue for its importance, and the need for extensive research on it within the Chinese context, and a reconsideration of its role within general theories of imitation within the firm. The potential implications of such research are tremendous.

While within research, especially research related to innovation management, the importance of trial and error is sometimes underestimated, and often uncomfortable, in other fields its importance is acknowledged to a far greater extent. A particularly strong proponent of this idea, in fact, is Linus Torvalds, the inventor of the operating system Linux. In explaining why he believes open source software is superior to other forms, he draws on evolutionary analogies, and argues to his fellow designers and programmers, "don't EVER make the mistake that you can design something better than what you get from ruthless massively parallel trial-and-error with a feedback cycle. That's giving your intelligence much too much credit." (Torvalds, 2001)

Setting aside the technical focus, one can look to the area of Political Economy, and here discovers that incremental changes and trial and error are considered uniquely important within the Chinese approach to policy making. (McMillan and Naughton, 1992) More recently, the importance of trial and error within the economic development of China has become a topic of interest in popular literature, such as the Financial Times article, "How China boomed by trial and error." (Harford, 2011) With this increased attention, and the broad implications outlined here, trial and error is likely to become an important research topic, with China as a key example.

How then should research in this area proceed? While the topic itself is extremely broad, we see a unique opportunity in the further development and internationalization of the wind turbine manufacturing industry. As mentioned previously, their trial and error based approach is being tested on two fronts: approaching the frontier, and moving into international markets.

Over the next several years, Chinese manufacturers are expected to become internationally competitive in the technological arena, and hence to undertake R&D which is much less bounded by imitation of industry trajectories. Continued research on firms as they approach the frontier will shed light on the effectiveness of trial and error in the face of an increasingly large and complex search space. In some sense, it is a perfect situation for the application of trial and error, and an ideal test of the limits of this approach. Such research must be carried out within individual firms, and focus on the product development process, the development of search routines, and the ability of firms to create improvements through direct feedback while operating at or near the global innovation frontier.

On the other hand, as firms move into international markets, the unique context of China, and the support it provides for trial and error will be left behind. This, in turn, will force an internalization of these feedback routines as search heuristics, and the development of internal feedback mechanisms such as prototyping and simulation. This transformation is a natural experiment of sorts, a perfect opportunity to separate the internal routines of these firms from the context in which they operate, and to understand the importance of the Chinese context in supporting trial and error. Simultaneously, this transition will demand huge internal changes within firms, and the transformation of existing routines. As such, it will present an opportunity to examine the flexibility and adaptability of these firms – the degree to which these firms have learned to learn.

As this happens, there are no guarantees that the result will be a transformation towards a western model of innovation. Up until now, the trial and error based model has proven tremendously successful. Perhaps, in perverse reversal of the licensing relationships of 10 years ago, firms will undertake industry leading, trial and error led innovation in the Chinese market, while delivering only mature, tested products to international markets. Again, in-depth firm-history based research on specific firms appears to be the only way to track this complex transition, and is an exciting opportunity for future research.

Parallel Strategies

Within the context of China, and potentially other developing economies, further investigation of the parallel strategies issue can shed light on differences in rates of firm development and learning. More generally, it provides an opportunity to view the process by which sets of routines are internally bundled and layered to form the complex hierarchy and governance structure we call the firm. In other words, by watching the firm, as is it forms, we can better understand the hidden internal structure guiding the operation of established firms, and the interlinked roles of disparate strategies and approaches within the firm.

In examining the Chinese context specifically, several factors are apparent which are likely related to the development of parallel strategies, and which should be further investigated. The first of these is the influence of firm governance and organization, and the traditionally vertical and hierarchical organization of Chinese firms. This structure, and specifically the limitations of information flows it enforces, likely contributes to the separation and differentiation of parallel units within the firm, and therefore the development of disparate routines. Additionally, fears of industrial espionage are deeply held, and have likely further limited and redirected information flows and the distribution of capabilities within the firm. Within the firm structure and culture, these two factors likely play a very large role in allowing increased heterogeneity, and therefore parallel routines. For this reason, further research into the organization structure of large Chinese firms, the role of this fear-based distribution of knowledge, and the implications of this structure on information flows and internal routine heterogeneity is of tremendous value.

It must also be considered that both China itself, and the wind turbine industry in particular, present unique geographic distribution of resources, and therefore limitations on information exchange. Given the central role of proximity in maintaining internal homogeneity, it is likely that this plays an equally large role in the development of parallel routines, and as such deserves significant research attention.

To state the obvious, China is large, and this differentiates it from many previous examples of industrial catching-up economies in SE-Asia. While many industries do not actively utilize this size, and instead develop around industrial clusters, firms operating in the wind turbine industry tend to have production, management, and R&D broadly distributed across the country, with each located according to its unique needs. Given the large size and high shipping costs of the end product, final assembly is near installation sites – often remote, unpopulated areas. R&D, however, must be located based on access to researchers, universities and key suppliers – generally large cities and centers of academic excellence. The location of management is often more flexible, but in China in particular, management is often closely linked to local government, and the location of the management is therefore also a critical decision. Goldwind, for example, maintains its headquarters in remote Urumqi, largely because of extensive government support, despite R&D and production across the country, and the obvious disadvantages of this location. These industry-specific demands, combined with the size of China, and unique institutional and regulatory context it has created have produced large, complex, and widely spread firms. This produces many questions: How has this unique organization affected the development of routines within these firms? How has it affected the development of the industry on the whole? These basic, geographically focused, questions are likely at the core of understanding firm organization and internal communications within this industry, and hence internal homogeneity and the development of parallel routines.

Moving towards the issue of the state, it is important to note that the government at all levels plays a very active role, and the rules, regulations, and most importantly subsidies and support, varies dramatically across China. With this in mind, geography is essential in understanding not only information flows within the firm, but also the emergence of disparate selection environments. Given the tremendous role of the government within this industry, it is likely that the specific differences in support and regulation experienced in different locations play a critical role in forming the different selection environments that evolutionary economics would understand as essential to creating disparate sets our routines. This, of course, brings us to the topic of the role of the state.

Reading between the Lines: the Role of the State

Everywhere in this research the role of the state is apparent, although only implicitly. Every firm is or was state-owned.. They operate on loans from state banks, and build factories on land given to them by the state. They do R&D supported by government subsidies, and sell their final product to government projects where the power produced is sold to government run power firms at government-mandated prices. Even within the firms, key positions are often political positions, and despite an absolute fear of competitors, high-level executives move between firms, setting aside these fears to meet political needs.

Volumes of work exist on the Chinese government and its role in development. Still, a comprehensive picture of it, abstracted to a degree that is useful for research like ours is effectively impossible to discern. The government is everywhere, involved in everything, but nobody quite knows how, or how much.

That government, however, is not a single, unitary actor, but countless, complex, and overlapping systems of governance, policy, regulation, and authority. It is diffuse, multi-faceted, and profoundly opaque to the outside observer - a problematic and immeasurable variable in every equation. Still, as a central actor in this process, it is an absolutely critical area for further research. In this case, with limited visibility and little expertise, we can do little but point out this critical importance, and suggest that such research will likely be exploratory and theory building. Additionally, we can provide two small suggestions that we believe may be useful in guiding this research. First, we believe that a geographical perspective is critical, as the governance system of china is diffuse, multi-scalar, and locationally bound. Second, we see that the government, as such, is complex and specific to such a degree that research must proceed from specific case studies, and build outwards from there. With no boundaries or definitions of scope, more conventional theorizing is of little use, and we must begin with empirical observations and absolute specifics.

This last point on the need for absolute specificity, and theory building from case-studies, should be taken much more broadly, and is the single most important piece of advice on how research in China can proceed successfully As this entire thesis has argued, and hopefully demonstrated, the situations we are examining are truly unmapped terrain, and specific cases must serve as the grounding for theorizing which, with time, can produce more generalizable findings. In examining these cases, however, we must refrain from apply conventional assumptions and interpretations, even vocabulary.

A Conclusion, of Sorts

The goal of this work has been to explore the unique situation in China, and in doing so to shed light on the complex process by which imitation supports capabilities development. With such a simple question, we've gotten to the heart of many complex and fundamental issues related to innovation, imitation and the theory of the firm. We've answered very few, if any, of these questions, but hopefully have made apparent the tremendous complexity and importance of the topic, and laid the groundwork for future research.

We have made every attempt to take the situation as it is, and through iterative theorizing founded on specific cases, to develop a framework which allows us to examine these cases in an objective and unbiased fashion. This has produced an innovative body of knowledge, but one that is largely detached from existing literature. Nonetheless, the topic we consider is of unarguable practical importance. At the present, our findings offer insight into an important industry and topic, and will likely prove useful to those both involved in, and studying, this specific industry. At the same time, we aim that observations and research agenda produced is thought provoking for a broader range of researchers, raising exciting questions, even if we cannot yet answer them.

In the future, and with much additional work, we believe that research in this mode, and with China and this industry as the working example, can make a very significant contribution to a wide range of fields, including evolutionary economics, innovation economics and management, the theory of the firm, and political and economic geography. The observations presented in last section are immature, but potentially fruitful. They're the outcome of this research, and a starting point for future research. Through all of this, it must be remembered that this is truly exploratory research, and that these are observations and ideas, not formal hypotheses. In that sense, this entire thesis is purely instrumental – a stepping-stone from which researchers can proceed. Read it as such, and take it as inspiration for future research.

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