FUSING INDIGENOUS KNOWLEDGE AND GLOBAL BEST PRACTICES LEADS A WAY TO GLOBAL COMPETITIVENESS IN EMERGING ECONOMIES: SOURCE OF CHINA'S CONSPICUOUS STRENGTH IN SOLAR AND WIND INDUSTRY

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Summary

In light of a conspicuous strength in China's solar and wind industry in recent years this dissertation analyses an institutional source of its strength. Empirical analysis was conducted focusing on the interaction between indigenous industries ("Domestic") and newly emerging solar and wind industry in absorption of global best practices ("Foreign") thereby fusion between them was demonstrated. Study showed the solar PV industry benefited from the well-established China's semiconductor industry in manufacturing cells and modules more cost-effectively than the global competitors. Similarly, the wind industry has benefited from China's marine and automotive manufacturing industry in forming useful supply chain and thereby enabled cost-effective production with increasing functionality development. Such conspicuous strength was achieved through the joint work of domestic firms' keen focus to learn new technologies and government's catalytic role in fusing the global best practises with domestic know-how. This suggests a new insight for growing economy for its development of global competitive industry. Theoretical implications have been made in elucidating the role of domestic players in technology transfer, importance of supply chain in technology diffusion, importance of scaling and modularity in product design and importance of tacit knowledge in technology transfer.

Keywords: Technology spillover, assimilation, learning, growing economy, competitive advantage, renewable energy.

Chapter I Introduction

1.1 Background

(1) Exploitation of domestic know-how to evolve conspicuous strength.

(2) Early emergence of FD through Fusion of external and internal knowhow through indigenization, innovation and diffusion.

(3) Government catalytic role for indigenization and early functionality development.

1.2 Hypothetical Views

H1 Conspicuous strength can evolve by fusing domestic know-how, absorption, assimilation skill and quest for new market with external knowledge to evolve indigenous product and fulfill the global needs.

H2 A emerging nation can evolve early emergence of functionality development by leveraging the external knowledge (FDI&TT) and domestic know-how to evolve a new production chain to overcome barriers to diffusion.

H3 Government's catalytic role in bringing institutional changes helps in domestic absorption and assimilation capability, and thereby evolve a conspicuous strength to result in indigenization.

Chapter II China's Conspicuous Strength in Solar Manufacturing

Conspicuous strength arises through fusing domestic know-how & foreign explicit knowledge and help further indigenize.

[General summary]
1. An empirical analysis taking the China's domestic solar PV industry.
2. Patentmetrics and indepth case analysis was conducted of both domestic and foreign players.

[New findings]
1. Indigenous FD evolved through fusing the domestic know-how.
2. The assimilation factor of domestic solar cell and module industry is 0.24.
3. Patent technology class can be a useful source to compute the assimilation.
4. MNCs and joint ventures' know-how helps in learning global best practices.

[Further works]
1. Similar investigation has to be performed on China's wind energy adoption and production.

Chapter III China's Conspicuous Strength in Wind Turbine Manufacturing

New Functionality Development through leveraging external and further indigenization and innovation to enhance the product features.

[General summary]
1. An empirical analysis, patentmetrics and indepth case analysis of China's domestic wind turbine manufacturing industry.

[New findings]
1. Early emergence of FD through joint work between industry's intensive effort to learn global best practices.
2. New supply chain evolved through relevant know-how from relevant industries.
3. 2. The assimilation factor of domestic gearbox manufacture industry is 0.29.
4. Emerging economies can utilize its internal demand (energy crisis) as new markets to support the indigenization.

[Further works]
1. Analyze government catalyst role in decarbonization.

Chapter IV China Goverment's Catalytic role in developing Solar and Wind Industry.

Government's can play a catalytic role for the attainment of decarbonization society for nation's sustainability through right policy mechanisms to induce the fusion of external and internal strengths to support the nation's needs.

[General summary]
1. An empirical analysis of domestic manufacturing sector's spillover benefits from local and foreign direct investment in China.
2. In depth case analysis of government role in developing domestic firms through spin-offs.

[New findings]
1. Firms from spin-offs arise from academia through government's catalytic role and support assimilation capacity of external knowledge and transform into useful domestic supply chain.
2. The government R&D investment enhances technology stock and thereby results in increased absorption and assimilation capacity.
3. The increase in domestic technology stock arises from the assimilation of spillover from foreign direct investment and regional know-how.

[Further works]
1. Generalize as a framework for emerging nations.

Chapter V Conclusion

List of Technology Management Publications

[1] N. Srikanth, C. Watanabe, Fusing East and West leads a way to global competitiveness in fusing economy: Sources of China's conspicuous strength in Solar industry, Journal of Technology Management for Growing Economy, Vol. 3 No. 2 October 2012, pp. 7-53.

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[4] N. Srikanth, Co-creation of Offshore Renewable Energy Industry in Emerging Nations, ASEAN Engineering Journal, Accepted for publication, 2013.

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Chapter 1

Introduction

1.0 Background

Technologies like renewable energy face barriers towards adoption in a region due to lack of production chain as well as domestic market. However in the case of China, firstly the increase in renewable energy adoption of up to ~5% of its total energy consumption within a decade during 2000 to 2010, surprises the world community in terms of how the barrier to technology adoption has been minimal even when compared to developed nations. Secondly their lack of imports of the foreign renewable energy products shows that their local production from domestic firms have met their regional needs. Thirdly, their exports of renewable energy products such as solar panels and batteries to global renewable energy market exhibit their Industry's maturity to meet necessary quality and reliability and match their global competitors. Thus it convinces that their industrial ecosystem is capable to generate technology, skilled labor and value chain along with flexibility and scale at world standard to meet the growing domestic and global demand at the fastest pace.

Additionally, to China's own economic growth, a competitive, reliable, environmentally clean and sustainable energy sector was essential to support its modern economic system. This was mainly due to their challenge to dependence on fossil fuels. Consequently China vowed to adopt 15% renewable energy by 2020. Fig. 1.1. shows the present adoption trend of renewables into their energy stream which is in tune to their goal. This has been possible through their coevolution of their domestic industrial evolution of renewable firms and domestic market that are capable to produce and utilize indigenous products such as solar and wind energy for their regional needs.

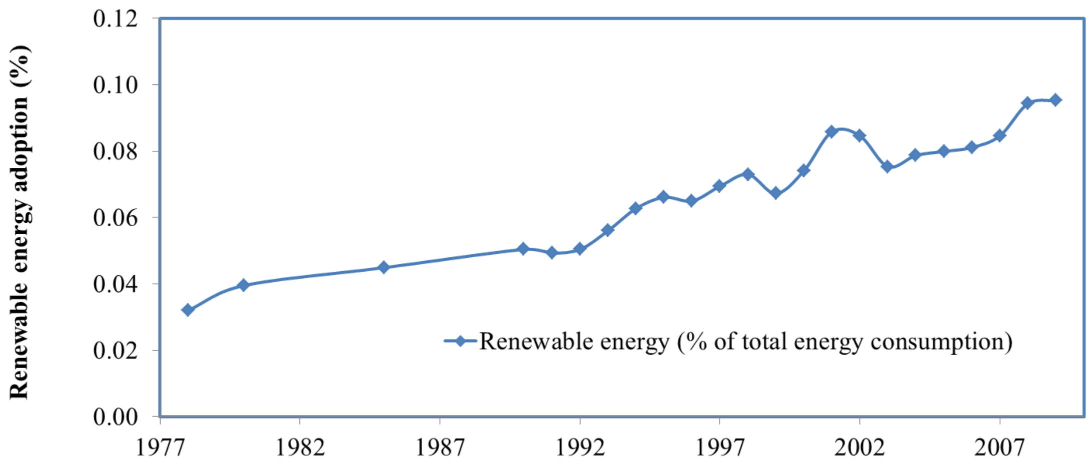


Figure 1.1 Renewable energy adoption in China (*1979-2009*).

1.1 Existing Literature

1.2 China's energy transformation and institutional sources of strength

1.2.1 Terms and Definitions

Production chain is the steps that need to be taken in order to transform raw materials into goods which can then be used by consumers. For instance, a primary product might be pure silicon, and the chain of production will turn this into useful components for a solar farm to deliver electrical power. At each step of the production chain, value is added to the product so it can be sold at a greater price when it becomes the final product.

Technological paradigm is a strong prescription within a specific direction of technical change. Kuhn defined *paradigm shift* as the change in the fundamental assumptions in a paradigm which can be seen as a scientific community's 'school of thought' Kuhn defines the scientific community as ‘the producers and validators of scientific knowledge’ (Kuhn 1962, p. 178). Joseph Schumpeter explicitly put such as paradigm shift as a process of industrial transformation that accompanies radical innovation which he termed creative destruction since he strongly believed that innovation sustains long term prosperity, even as it destroys the established companies.

Technological trajectory: Pattern of “normal” problem solving activity on the ground of a technological paradigm. Strategic implications of a firm includes various ranges (follower/leader, product/process innovation) influenced by technological characteristics, cumulative nature of competencies and increasing barriers to entry, influence on the internal organization differentiation of the management of technologies within a specific trajectories yet within a new trajectory. Consequences are: (a) exclusion effects of paradigms (b) Learning and path dependencies (c) Complementarities within trajectories (d) Convergence of private investments (e) Institutional effects (public investments and procurements).

Competitive advantage: Traditionally size, possession of assets, proximity of sources of energy were seen as competitive advantage. However in recent decades the capacity to mobilize knowledge and technological skills, experience to create new products, processes and services are seen as the key competitive advantage. Innovation contributes to competitive advantage and there are few types of innovations viz., (a) Radical innovation denotes change of the core concept and the components (b) Architectural innovation denotes reinforcement of basic concept and change the organization of the components (c) Incremental innovation denotes innovations of components and reinforcement of existing concepts and unchanged linkages (d) Modular innovation denotes changes of components and unchanged linkages (Shilling 2013).

Co-creation: Failure is expected when a product fails to meet the customers' needs. To ensure that customer needs are met and that such market failures are avoided, co-creation is seen as an alternative to benevolence thesis benevolence thesis predicating its success or failure in a local context on the nature of the Co-creation process and the facilitation of a parallel market where the outcomes of the co-creation process can be exchanged. What is technology transfer? Under technology collaboration, firms with right technologies have opportunities to diversify into new industries using their complimentary assets.

Functionality development: Ability to improve performance of production processes, goods and services by means of innovation.

Product Scaling: Increase in geometric size of products to exploit increasing returns to geometric scale whereby the product performance increases one fold higher than the costs. Thereby the product performance per unit cost increases significantly with geometric size for certain products such as wind turbines and solar wafers.

Conversion ability is a firm's ability to translate a given idea into a launched product. As such, a firm is deemed to have high conversion ability if its likelihood of converting a given idea to a launched product is higher than that of other firms. We show that firms vary dramatically in their conversion ability, and address the question: How did the domestic firms improved in their conversion ability?

An industrial cluster is generally defined as a geographic concentration of interconnected firms in a particular firms related through having one or more complimentary technologies of a particular field with links to related institutions that are related to externalities and complementarities of different types and are located near each other (World Bank 2009). The definitions of platforms and ecosystems can be borrowed from platforms-related literature from earlier researchers as follows:

- *Industry platforms* (Gawer (2010)): "are building blocks (they can be products, technologies, or services) that act as a foundation upon which an array of firms (sometimes called a business ecosystem) can develop complementary products, technologies, or services" (p. 2).
- *Industrial ecosystems* (Gawer (2010)): "Building on these platforms, a large number of firms, loosely assembled in what are sometimes called industrial ecosystems, develop complementary technologies, products, or services" (p. 12)

1.2.2 Technology innovation challenges in emerging economies

Literature review shows significant studies have been performed on technological innovation from economics and business fields that has helped develop useful analytical tools to examine technology development and ways of measuring technology inputs over time (Von Hippel 1998, Mowery and Rosenberg 1998).Although above literature reviews the theoretical framework to examine technological innovation within an industry, very few research has been done that addresses technological innovation in the context of China's conspicuous strength development strategies. Especially, there has been limited research in renewable energy technologies of China (Smith et al., 1993, Stafford et al., 2003) and some research conducted on technological innovation in China in other sectors (Katsigris, 1996, Sutmeier, 1997,, Tidrick, 1986). A detailed understanding of how Chinese firms built competence indigenously and utilized foreign technology transfers to innovate in wind and solar energy technology has not been examined, and is one focus of this dissertation. Key studies from public policy and law on technology innovation with particular attention focused on the impact of environmental policies and research and development policies (Margolis and Kammen, 1999).

Devendra Sahal notes that technology innovation is the linchpin of the productivity performance. However he notes that the new technology is mostly unreliable, inefficient and cumbersome and further discusses at large the temporal and spatial aspects of productivity. Leonard notes that self-financed R&D plays greater role than government financed R&D in promoting the growth of productivity in the manufacturing sector (Leonard, 1971). **But today the developments made by China makes us to rethink.** In reality, the success of the R&D depends on the different factors such as R&D investment, product demand, industry growth, and academia's research interests specific to that industry and is causally related (Nelson and winter, 1975, pp. 338-339). The long term evolution of the technology is governed by the accumulated experience which corresponds as the learning curve in the various technical tasks such as manufacturing, which was first observed in aircraft industry. The other aspect of learning can be observed in the form of thumb rules. For example, naval architect's "inch rule" relates to service speed increases as the square root of the ship length. As new experience is gained, old rules are replaced. These constitute the *Learning by doing* hypothesis of technological innovation. This is because technology is not a plug and play; rather it is acquisition of practical experience and governed by process of cumulative change. Learning by doing has two dimensions viz., certain activity and takes places over time. Cumulated output variable is seen as a measure of experience since the design of new techniques is linked to the production. However there is time requirement involved in assimilating the available know-how through imitation or by recruiting people of that skill, e.t.c., especially for an emerging region such as China.

Learning curves are useful tools to investigate "Learning by doing" in technological innovation's relation to cost (Arrow, 1962, Cohen and Levin 1989), and are useful to investigate renewable energy technologies that are in early stages of development (Mackey and Robert, 1998 and Harmon, 2000). For example, Ibenholt (2002) has studied learning curve analysis to compare the learning by using models of wind industries of United Kingdom, Denmark and Germany. However there have been very few studies of China's renewable industry studies that addresses political and policy incentives behind innovation in wind and solar power (such as Peng (2005)).

1.2.3 Barriers to Technology adoption diffusion into an emerging region

There is correlation between market, performance and new products for any given region. In an emerging region, new products should adapt to the environment and gain its market position and further maintain its market share. A large literature has also dealt with the advantages of bringing a product to market fast (Choperena 1996; Griffin 1997; Kessler and Chakrabarti 1996). Greater speed is claimed to lead to the possibility of building brand loyalty, moving down experience curves faster, building channel relationships, and creating switching costs (Schilling and Hill 1998). However they fail to explain why certain technologies and products face barriers towards diffusion into an emerging region. One reason could be that a new technology for an emerging region such as wind turbine or solar PV depends on the domestic know-how and skills availability about the basic technology components' in the host region. These technology components can range from product level (such as controllers modules, generators, fasteners, e.t.c) and the process knowledge (such as manufacturing processes, assembly processes and servicing processes). Countries that lack such knowledge can greatly face poor technology or product adoption and diffusion. Simplistic allowance of foreign products to flood the region without domestic expertise leads to loss in revenue and foreign exchange and loss in job opportunities. Hence the wind turbine industry growth in China has experienced poor adoption before 1990. A quick look of the China industrial scenario in its early 1990s shows the lack of production chain which may have hindered the growth. Similarly policies have been lacking and institutional changes have been taking place which may have helped in easing those barriers through formation of production chain. Literature review shows no significant work has been focused in understanding these barriers to renewable energy technology adoption in emerging region and its relation to production chain. Existing policy studies are also insufficient in their focus on policy support toward renewable technologies adoption in an emerging region, as they mainly focus on demand side alone, such as in infrastructure support, financial support and project uncertainties supports (Guey lee, 1998, Lew and Logan 2001, and Liu et al., 2000).

1.2.4 Technology transfer challenges in emerging economies

In international development literature (Hirschman 1967, Goulet 1989) and literature coming out of development bank and government institutions (Mansfield 1994; IPCC 2000, US OTA 1987), key focus is in addressing the international technology transfer that typically refers to developing countries with bilateral or unilateral agreements. After Kyoto protocol China gained international relevance to receive useful low carbon energy technologies through Clean Development Mechanism (CDM) facilitated technology transfer projects.

Traditional theories of technology transfer have not been expanded to reflect the current context of technology transfer and competence building aspects of China. Earlier studies have investigated foreign investment and trade in China which addresses investment in energy projects and technologies (Blackman and Wu, 1999). Other related studies that have examined technology transferring strategies for China (Martinot 2001, Taylor and Bogach 1998, Wallace and Tsuo 1997, Zhu 1999). Less research has been written on technology transfer in the wind and solar PV industry in China, although problems with technology transfer arrangements have been explained in studies that more generally examine barriers to wind power development in China (Lew et al., 1998, Lew, 2000, Lew and Logan 2001, Zhang et., 2001, Lin et al., 2002 and Liu et al., 2002).

In the case of ICT (Information Communication Technology) innovation, co-creation was observed in emerging region as an alternative to technology transfer model which demonstrated how it could emerge future markets (Rai, 2010). Technology co-creation as a means for technology creation and transfer from matured industries to industries that experience technology gaps and limits. Firms shift towards cost-effective countries in the process of out-sourcing to reduce their costs. But the skills and the learning developed in the job market goes wasted. Secondly resources that have been built up like research institutes, academic faculties, test centers, standardizing institutions goes wasted if they don't become global nor shift to a similar industry.

1.2.5 Technology spillover and assimilation

Positive spillovers are known to arise when the leading edge technologies of foreign MNCs (Multinational Corporation) influence and improve the productivity of locally owned firms (Feinberg and Mujumdar 2001). Negative effects are also studied (Aitken and Harrison 1999) specifically in pulling the demand from the home grown firms. These are in the context that the locally originated firms within a closed economy tend to have weak technological capabilities. Such deficiencies will disable them to appreciate the value of externally generated knowledge and restrict their absorptive capability to intake the knowledge spillovers by foreign spillovers. Thus positive spillovers may primarily occur from “demonstration effect”, “contagion effects”, people movements, and through pro-competitive effects. Also it is seen that locally owned firms are concentrated in the standard technologies where the foreign firms avoid.

Organizations face ill-structured, complex problems that challenge their capabilities. One pervasive example of complex decision-making is that of the adoption of innovative processing technologies. Grinyer and Norburn (1975) found that more profitable firms use more diverse information to evaluate their performance outcomes than do less profitable firms. A comparable process likely takes place when decision makers are confronted with the prospect of understanding new processing technologies. This is especially prone for manufacturing systems that incorporate radically new tacit type technology (Dewar & Dutton, 1986). Hence this may demand for skilled workforce from a related industry to support technology assimilation.

1.2.6 Industrial Agglomeration

In earlier research of Kuchiki and Tsuji (2005, 2008) and Tsuji et al. (2007) the agglomeration process was described as a flowchart process which postulated that MNCs (multinational corporations) as anchor firms, that established production bases first, followed by SMEs (small medium enterprises) which are suppliers or subcontractors and local firms establishing facilities near them. Kuchiki and Tsuji (2008) developed an alternative explanation to Porter’s framework. They argued that it is difficult to frame policies based on Porter’s framework, since it gives only partial snap shot of the relationship between industrial agglomeration and local growth. Their model was able to identify the targets for policy implementation; however, their study did not highlight the mechanisms behind endogenous R&D

and innovation mechanism. Studies of Tsuji and Ueki (2008) and Ueki et al. (2008) showed the local innovation process due to technical cooperation between industry and local university, R&D institute or local business organization in Indonesia, Thailand and Vietnam. However the earlier studies did not elucidate the essence of earlier knowledge spillover and assimilation capacity of the local industrial firms.

Hence this present study, focuses on endogenous innovation process generated by pure local firms' assimilation capability of knowledge spillover from earlier industries and their recombination, assimilation and recreation skills with global know-how, in addition to traditional technology transfers that were initiated by a top-down approach.

1.3 Research Objectives

The current thinking of technology transfer assumes that when a technology is provided to a region it can start producing without further support. However the importance of the host knowledge in such technology transfer is lacking in literature. This has been key to explain why certain nations have been unsuccessful to assimilate the transferred knowledge and produce indigenized product and evolve domestic industries to supply their regional needs. Thus China's industrial agglomeration is at the center of global attention mainly due to its contribution towards economic growth, minimizing poverty and reducing income inequality. There is no doubt that it enjoyed economic growth through increasing flow of foreign direct investment (FDI), foreign technology transfer, returning Chinese diaspora. However the increased demonstration in contributing to new industries growth, surprises the world community. Agglomeration in China was triggered by FDI and MNCs which aimed to establish alternative production bases in other regions to access cheaper materials, unskilled labor and production of raw materials and commodities. However continuation of Industrial agglomeration shows China has upgraded its capabilities to produce complex or precision work that are high value added business activities. To the technology management community, economists and policy makers, what surprises is that the industrial agglomeration has induced new industries with specialized products compared to the original industries. Thus the aim of this research is to understand the roots of these technology sources and their catalytic players which induced such Industrial evolution. Thereby to help deduce useful framework and policy suggestions for other emerging nations to induce useful policies. These policies may focus to activate economic growth and support new job creation and meet their local demands (such as energy, water, etc.) and thus mature from an agrarian society towards an industrial society and further into the stage of knowledge based economies.

This research, firstly, attempts a forthright analysis of coherent model to postulate a hypothesis of the endogenous innovation processes that evidences in new industry evolution. Second, I focus on the effects of adopting technology spillover on the creation of product and process innovation and thereby support new industrial evolution and growth. Thus attempt is to analyze to what extent the proposed hypothesis characterize counterfactual evidence[1] about ongoing China's transformation. Thirdly, this study extracts the highlights to form useful policy recommendation for emerging economies to foster such knowledge spillover and endogenous industrial evolution. To achieve these objectives, econometric models are utilized to relate the agglomeration through knowledge spillover and industrial productivity and its relation to

[1] http://en.wikipedia.org/wiki/Impact_evaluation

industrial policy that foster industrial evolution and agglomeration and also the innovation process.

Innovation activities happen with technology transfer that is initiated by higher decision levels of various institutions such as policy makers and business heads. However what is ignored in literature is that the technology spillovers that arise due to skilled laborers' mobility and socialization between firms are not well discussed, as they act as carriers of technology. Thus technology transfer should be seen as both top-down (such as joint venture or technology licensing) and as a bottom-up process (such as Co-creation process). However few studies related to developed industrial nations, have highlighted the role of local knowledge spillovers, labor mobility, entrepreneurship, etc. (Saxenian (1994) and Porter (1998, 2000). Saxenian (1994) suggested that inter-firm network among small and medium enterprises (SMEs) fosters industrial clusters as well as innovation. However these interfirm networks differ with between developed and emerging region. For example, research findings between Hashimoto (1997) and Arita et al. (2006) shows contrary opinions in terms of horizontal and vertical integration in the value chain. Also several studies have identified main driving forces of developed nations' Silicon Valley type clusters to differ from emerging economic type clusters. Thus this topic of knowledge spillover and assimilation needs further detailed investigation specific to emerging nations and cannot be extrapolated from a developed region's experience towards an emerging region.

1.4 Research Question

The research question of this thesis is: *what are the institutional and market factors, such as government role, global and domestic market needs and industries that promoted regional innovation and industry evolution*. Literature review shows earlier works does not focus on the local innovation system requirements for technology assimilation and exploitation of externalities such as technology spillover and transferred technology to help absorb and reformulate into indigenized products and evolve domestic value chain.

Question1: *What is the local innovation system in a successful emerging region? What are the key factors for forming this system?*

These questions lead to the following: since the growth of private firms and their new product particular to the region's industrial activity is significant such as solar and wind energy related products and services, to what extent the knowledge spillover from related industries support such constructive industrial output.

Chapter 2 provides the basic framework of a bottom up approach for endogenous industry formation through assimilation of its domestic know how and external information under no obvious official knowledge transfer and with no domestic market pull. This exhibited a co-creation model with the domestic firms in the form of an industrial cluster evolving endogenous capability and transitioning from agglomeration stage to local innovation stage. Agglomeration and clustering create dense networks that can facilitate assimilation capability through labor mobility to generate, share and diffuse knowledge, thereby inducing indigenous product and process innovation.

Chapter 3 provides the case study with the basic framework of technology assimilation along with robust external technology transfer along with intrinsic domestic knowhow under the existence of a domestic market. This case shows the condition of transition from agglomeration stage to local innovation stage with much early indigenous products with early functionality development and a robust production chain. Firstly, it attempts to answer by studying the local production system and its assimilation, absorption and transformation capabilities. Secondly, it attempts to show the effect of the presence of a stable internal market. Thus this research attempts to analyze the agglomeration force as a driver of the endogenous R&D and innovation mechanisms to co-create indigenous production chain and domestic market to meet the regional demands.

Question 2: How does government's catalytic role affect industry evolution and promote knowledge assimilation of existing industrial clusters. To what extent does the local government play an important role in the market oriented innovation process which is driven by agglomeration?

This research question has been studied in the context of an emerging nation by Kuchiki and Tsuji (2005, 2008) from the view point of learning linkage between various actors in a region. Chapter 4 studies this by focusing on government's leadership in endogenous innovation and industrial transformation through a catalytic role. This study answers the government's positive role through a catalytic character which promotes in territorial agglomeration of high technology firms and assimilation and recombination capabilities of external knowhow with domestic capabilities. Comparative studies between the two industries of solar PV and wind industry under same regional setting and time period is performed to show that the involvement of the government in the early stage of industry evolution through setting up tech transfer of matured external technologies along with the platform for assimilation by the domestic industrial clusters along with a domestic specialized market results in a sustained production chain. As a result the specialized market has evolved from a typical market place into a platform that enables the market mechanism to work more smoothly within the industrial cluster. This comparison shows these specialized markets can evolve and sustain the production chain in upgrading certain industrial clusters in an emerging national setting. This chapter has policy implication to promote identification and exploitation of skilled labor supply from other related industries as compared to previous research suggestions of industry-academia linkages to achieve accelerated growth of new industrial evolution.

This research finds the internal linkage which shifts from agglomeration to innovation which plays an important role for industrial evolution in developing region. The findings lead to suggestions to enhance the efficiency and role of policies that emphasize setting up platform between industrial clusters and domestic market evolution for sustained R&D innovation, meet regional needs and support coordination of a firm's investment behavior to upgrade existing cluster's capabilities. These complement to the typical policy to construct 'National Innovation System' and highlight the importance of government in the context of clustering policy.

1.5 Structure of the Dissertation

Chapter 1 discussed the adoption of renewable energy in general and how it related to the technology stock that arose in China with government's catalytic role through R&D investments and inducing more private firm's research investment with external attraction of FDI.

Chapter 2 focuses on the inception and growth of solar industry in the soils of China and the various roots of their technology sources. This was through a co-creation model which wisely used various actors to fuse their domestic know-how from preexisting industries such as semiconductor manufacturing along with the external global know-how. The success of such evolution of the new industry was observed as it supported the foreign markets through exports to fetch useful foreign exchange and created regional jobs and capability development.

Chapter 3 examines the diffusion of the wind industry in China and how its large wind turbine industry evolved and explains the co-evolution of the production chain. It will differ to explain how the additional support of initial technology transfer along with creation of domestic market creation helped the growth of wind industry production and adoption in China. The study will also elucidate how the domestic industries assimilated knowledge spillover and external know-how with its internal manufacturing strengths to develop indigenized products.

Chapter 4 aims to study the government's role in technology transfer and its influences in institutional changes. Comparing the two different industries viz., Solar and Wind industry of China, the strengths of the two industries and how the various actors, knowledge workers, firms and government have done unique moves to secure and evolve useful institutional strength are discussed. Finally, based on the study, suitable firm level and policy level recommendations are presented.

Chapter 5 will provide the general conclusions and new findings specific to each industry and theoretical implications specific to technology transfer, open innovation and indigenization along with useful policy recommendations for emerging economies to meet its clean energy goals so as to become a decarbonized self-sustaining economy.

Chapter 2

Source of China’s Conspicuous Strength in Solar Industry

Abstract

In light of a conspicuous strength in China’s solar industry in recent years this paper analyzes an institutional source of its strength. Empirical analysis was conducted focusing on the interaction between indigenous semiconductor industry (“domestic”) and newly emerging solar industry in absorption of global best practices (“foreign”) thereby fusion between them was demonstrated. Success of this fusion can be attributed to a joint work between industry’s intensive effort in learning global best practices for exploring new business and government’s catalytic role for the attainment of decarbonisation society for nation’s sustainability. This suggests a new insight for growing economy for its development of global competitive industry.

Keywords: Fusion, learning, global best practices, growing economy, global competitiveness

2.1 Introduction

2.1.1 China’s conspicuous strength in solar industry

China has demonstrated in the recent years as the world’s largest solar cell producer as shown in Fig. 2.1. In 2001 China produced world’s solar cells and today four of the top 5 solar cell producers are from China and 3 of the five module producers are. Significant growth in the Chinese solar energy Industry has caused the prices of solar panels to drop worldwide[1]. Chinese manufacturers’ lower prices are being interpreted and complained to the

[1] Financial Times – China’s Rush Into Renewables: The Way The World Turns (28 November 2011): http://www.ft.com/intl/cms/s/0/0502a28a-15c9-11e1-a691-00144feabdc0.html#axzz1nmZeqJQF.

extent of dumping into USA[2] (Melanie Hart (2011)) and in Europe[3] (Reuters (2012)). It is also interesting to note that China with rich solar energy[4] of 5000 mega joules per square meter on at least two-third of its region that spread to a vast land of 9.6 million square kilometre but yet represents a meagre internal PV market. Table 2. 1 and 2 lists the annual and cumulative installations of solar PV installations in different countries which clearly show the West leads significantly than China. The reason being, the highly anticipated national feed in tariff (FIT) was dropped indefinitely until 2011 as PV generation cost was deemed too high during 2006. After spiking in 2006, prices of crystalline silicon PV cells and modules fell by 70 percent through 2011. Only since 2010 that their installed capacity has seen a recognizable growth moving from off-grid stand alone systems to grid-connected applications such as building integrated PV systems and large scale PV power stations. But what interest the research circle is to understand that even with poor internal demand, how did China acquire its knowledge to reach the world's largest production capability[5] and thus what other reasons drive such conspicuous growth. The reality has been that China has effectively used its internal know-how with external knowledge to increase production and thus a key role in reducing the cost.

Table 2.1 Worldwide annual installation of solar PV installations from (*2000 - 2010*)

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
China	0	11	15	10	9	4	12	20	45	228	520	2,200
USA	23	31	46	65	92	117	149	212	349	539	983	2,234
EU	53	94	142	201	708	1,002	987	1,972	5,297	5,803	13,397	21,939
Apac[a]	114	136	186	225	276	296	322	283	563	766	1,618	2,653
ROW[b]	88	56	80	77	29	10	105	42	76	80	284	508
Total	278	328	469	578	1,114	1,429	1,575	2,529	6,330	7,416	16,802	29,534

[a] Asean and pacific countries.
[b] Rest of the world
Source: European Photovoltaic Industry Association (2012).

[2] http://cleantechnica.com/2012/02/12/dumping-solar-study-sheds-light-on-solar-pv-trade-flows-us-China-manufacturing/
[3] Reuters (2012), China's solar companies warn of trade war with EU, http://www.reuters.com/article/2012/07/26/us-China-solar-eu-idUSBRE86P14220120726
[4] Solar and Renewable Energy Sources, China Solar Energy, 2010-02, 38, available at http://www. Chinaygny.cn/
[5] Kevin Bullis, The Chinese Solar Machine, January/February 2012, http://www.technologyreview.com/energy/39356/

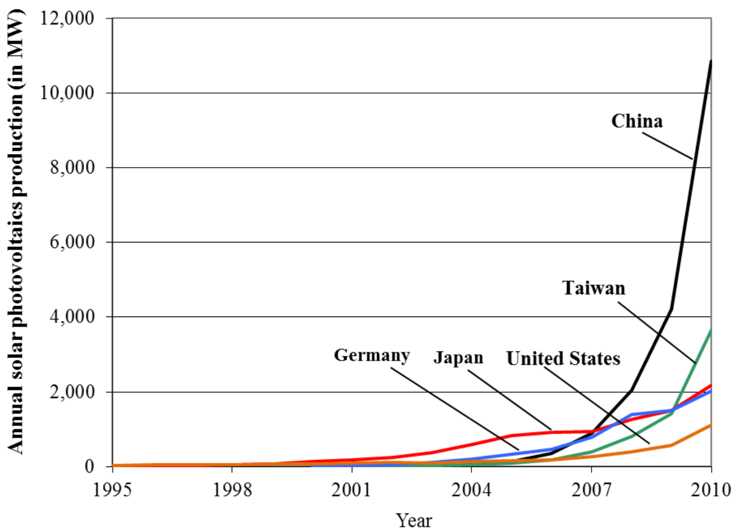


Figure 2.1. Annual photovoltaic production in different countries (*2000 - 2010*).
Source: Earth Policy Institute (2012).

At world level, Solar cell and Solar Module Industry achieved rapid development in 2010, in terms of Global Capacity production growth rate close to 100%, while the Installation statistics shows that the Global Total Installation is about 15.6GW, far more than 6.43GW in 2009. This was achievable due to China contributing to the Global Solar Module output of 43% share in 2010.

Table 2.2 Worldwide cumulative installation of solar PV (*2000 - 2010*)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
China	19	30	45	55	64	68	80	100	145	373	893	3,003
USA	146	177	222	287	379	496	645	856	1,205	1,744	2,820	5,053
EU	154	248	389	590	1,297	2,299	3,285	5,257	10,554	16,357	20,777	51,716
Apac[a]	355	491	677	902	1,178	1,475	1,797	2,080	2,643	3,409	5,116	7,760
ROW[b]	751	807	887	964	993	1,003	1,108	1,150	1,226	1,306	1,200	1,717
Total	1,425	1,753	2,220	2,798	3,911	5,341	6,915	9,443	15,773	23,189	30,806	69,249

[a] Asean and pacific countries.
[b] Rest of the world
Source: European Photovoltaic Industry Association (2012).

2.1.2 Solar cell technologies and value chain

Photovoltaic technology helps convert the solar energy into electrical energy (Chetan (2009)), and China is dominant with the first generation crystalline silicon (C-Si) technology followed by the second popular thin film solar cell (TF-Si) technology which countries such as USA is dominant in terms of cost-competitiveness (Yang Mu et al. (2010)). Fig. 2.2 describes the various steps of the production chain in China.

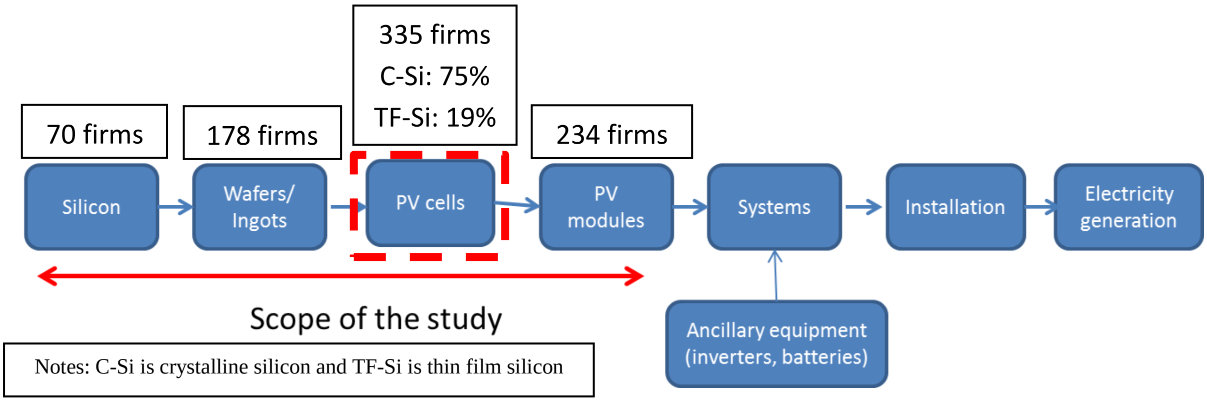


Figure 2.2. Solar PV production chain with indicative number of firms in China *(2011)*.

The solar cell indicated in dotted line in Fig. 2.2, has few important steps in the manufacturing process that can be depicted as shown in below figure 2.3 and is mostly similar to the semiconductor manufacturing process which is illustrated in Fig. 2.3 (Chetan (2009)).

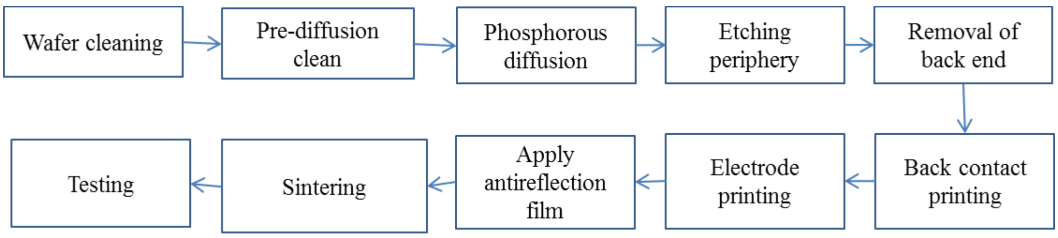


Figure 2.3. PV solar cell manufacturing process steps.

2.1.3 China solar manufacturing industry

China's foot print in the value chain exhibits an asymmetry in the industrial chain, where it exhibits poor competence in the front end and in the back end of the solar value chain (Yang et al. (2010)). China imported 95 % of its PV raw materials due to lack of advanced technologies to produce crystalline silicon and in the final market of finished solar panels it depends on the foreign markets. Thus both export and import exists in the solar supply chain of China. As pointed out in previous paragraphs, China initially focused its production to the installation needs of USA and Europe.

China today manufactures 18% of global silicon material while it produces 47% and 54% of the global production capacity in the cells and module business. This may arise if it is financed by foreign governments which extended subsidies to China's overseas markets. However this study suspects that there are additional underlying reasons for such results.

Production of high purity polycrystalline silicon has been a bottleneck in the Chinese solar PV industrial chain (Yang et al. (2011)). This being the feedstock of further production steps, it affects the overall production capacity. Since 2009, China's silicon production is seeing serious investments and hence a surge in production, however quality and pollution still persist. As per 2009, still China experienced a shortage of 62.5% raw materials for ingot production, which were covered by imports.

The increase in silicon production resulted in wafer manufacturing growth at an annual increase of 100% between 2004 and 2008. One core technology to such process is wafer slicing (or cutting) which aims to cut a long round bar into thin slices of sheets. One way to produce low cost is through making thinner wafer and thereby producers more wafers from a silicon feedstock. For example a reduction of 0.32 mm to 0.18 mm was achieved by

China domestic solar PV cell manufacturing firm that enhanced production. Such know-how comes from the nearby IC manufacturing industry where the art of slicing wafers is being pursued (Arnaud et al. (2011)). Similarly the art of converting monocrystalline silicon to polycrystalline silicon indicates that China's ingot is getting technologically matured.

The next step is the solar cell manufacturing where China leads to be almost half of the world's producer and has sustained its positions since 2003. For example, as per 2008 the top 10 domestic cell producers accounted for 75% of the national production. Table 2. 3 and 4 lists leading firms and their capacity and country of origin. The leading cell producing firm being Suntech which accounts to 20% of the national production. As we discuss about the first generation solar technology (viz., crystalline silicon), China still lags significantly in second generation solar technology (viz., thin film solar cells) compared to USA and Germany.

Further in the production, the solar cells are converted into solar modules, where China has shown clear domination in its know-how to incorporate clusters of PV cells into a unit namely module encapsulation. In 2009, China's share in the world's module was around 59%. This was possible due to its strength in equipment manufacturing that enhanced from the IC manufacturing industry, due to its relatively lowest technological threshold and demands for unskilled labour and low labour costs, thereby was being handled by small medium sized business, and hence good business growth in the whole PV industry.

According to CASolar[6], the solar panel prices from China have been decreasing significantly[7] as shown in Fig. 2.4. Similar price reduction is seen at solar cell and module components which form a part of the solar panel system. Accordingly the top ten firms of the

[6] *www.**casolar**co.com*

[7] The PV cell price 'c' (Yuan/ Watt) and the cumulative production 'Q' (MW) in the log-log chart was found to be $Q=64.1*C^{-0.21}$ and thus a learning rate of 0.14 (Zhang et al. (2012)).

global solar cell manufacturers shows that seven out of the ten top positions have been taken up by China domestic solar manufacturers (as per 2011). Similarly in solar module manufacturing among the top ten positions in terms of production capacity (in MW) eight indigenous Chinese firms have overtaken their global counterparts.

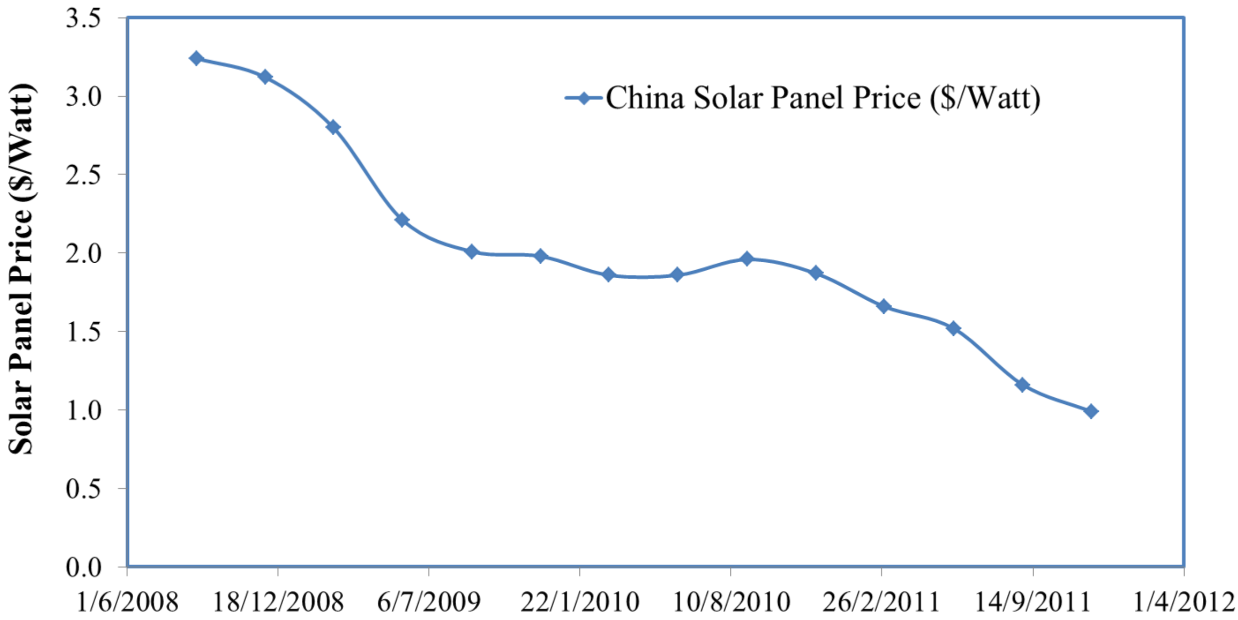


Figure 2.4. Declining trend in China solar panel prices[a]
[a] US$/Watt at current prices (*2008Q2- 2012Q2*).
Source: CASolar[6] (2012).

Table 2.3 Top 10 global solar cell manufacturers in China (*2011*)

Firm	Capacity (MW)	Country
Suntech	2400	China
JA Solar	2100	China
Trina	1900	China
Yingli	1700	China
Motech Solar	1500	Taiwan
Gintech	1500	Taiwan
Canadian Solar	1300	China
Neo Solar Power	1300	Taiwan
Hanwha Solar One	1100	China
Jinko Solar	1100	China

Source: Energytrend (2011) [8].

[8] www.energytrend.com

Table 2.4 Top 10 global solar module manufacturers in China (*2011*)

Firm	Capacity (MW)	Country
Suntech	2400	China
LDK	2500	China
Canadian Solar	2000	China
Trina	1900	China
Yingli	1700	China
Hanwha Solar One	1500	China
Solarworld	1400	Germany
Jinko	1100	China
Suneeg	1000	China
Sunpower	1000	USA

Source: Energytrend (2011)[8].

Table 2.5 give a critical analysis of the asymmetry in the value chain of China's PV manufacturing where the both ends have been relatively weak where at one end it imports its raw material and purely depends on exports. This draws clear attention to understand the roots behind the conspicuous strength in cell and module manufacturing.

Table 2.5 China's manufacturing competitive advantage in Solar PV production chain

Industrial chain	Silicon	Ingot/ Wafer	Cells	Modules	PV arrays
Features[a]	High energy consumption; Poisonous emissions	Decrease in the thickness of silicon wafers is an effective way to reduce cost of PV cells	Large scale production is most important	Fierce competition Labour-intensive	Comprehensive use of combined technologies is required.
Capital[a]	High investment and long payback	Medium investment	Medium investment	Low Investment & short payback	Low Investment & short payback
Technology barrier	High	Medium	Medium	Low	Low
No. of firms[c]	70	178	335	234	700
Manufacturing in China[a]	Weak	Medium	Strong	Strong	Strong

Sources:
[a] China Solar PV Industry Report, 2008-2009 All China Marketing Research, ACMR, p. 1.
[b] Yang, M., Yu, H., Solar photovoltaic Industry in China, China's Industrial Development in the 21st century, p. 195.
[c] No. of firms computed from ENF website (as of 2011).

2.1.4 China solar manufacturing competitiveness

The five principle reasons for the price reduction in silicon cell and module is generally seen from declining silicon prices, competition from thin film products, government incentives, increasing economies of scale and efficiency, and oversupply. Apart from these factors, yet China shows evidence of lower manufacturers' price compared to their global competitors and hence China's domestic solar PV manufacturers have a cost advantage.

The top tier Chinese cell and module manufacturers have shown a cost advantage of 18 and 30 percent compared to the USA counterparts (Gordon et al. (2012)[9]). According to GTM research analyst Shyam Mehta[10], the cost reduction exhibited by China manufacturers than the USA manufactures is 25 to 30 percent in 2012 and Rob Wanless, Director of Business development, Solon Corporation, mentions China manufacturers' solar panel price is US$1 per watt, while USA manufactures' for similar technical specifications is US$1.20 to US$1.30 per watt. From the view of China manufacturers, China has a cost advantage of US$0.20 per watt on modules and US$0.10 per watt (Gordon Brinser et al. (2012)).

According to Alan Goodrich (Solar PV expert at NREL) comparing the case of manufacturing the solar cells from China such as Suntech and further shipping to USA through sea route and land route to reach the solar farm in arizona, verus purely manufacturing still exhibits a 5 percent advantage (Goodrich et al. (2011)). This success they attribute to purely foreign direct investment in terms of capital investment and knowledge transfer into China. Secondly Gordon Brinser et al. (2012) claims the vertical integration and placing the plants, such as keeping the cell manufacturing in China and placing the module

[9] Gordon Brinser, President of SolarWorld Industries America, www.solarworld-usa.com
[10] Shyam Mehta, Senior Analyst at GTM Research, www.greentechmedia.com/research/

manufacturing (which purely involves assembly) closer to the end user (such as solar farm) turns out to be at best cost advantage. For example, Suntech adopts the above methods to have a cost advantage for its 300 MW solar farm in Arizona. However these two studies fails to tell why the China's advantage arises in the cell and module manufacturing in the China's domestic firm such as Suntech versus that of the US based manufacturer like Solarworld, hence the present research investigates the additional advantages in this research.

Section 2.2 puts forth the hypothesis and constructs an analytical framework and demonstrates through empirical and qualitative analysis about technology spillover from domestic semiconductor firms and global solar firms to the domestic solar firms of China. Section 2.3 provides interpretation of the results and presents micro evidences of technology spillover at industry level using patent data and supplements with the case of Suntech solar PV manufacturer's evolution and developments. Section 2.4 briefly summarises the key findings of the analysis and presents policy implications.

2.2 Hypothesis

Prompted by the foregoing observations, the following hypotheses are postulated:

Conspicuous strength emanates from the institutional sources that arose the China's solar industry in recent years. Interaction between indigenous semiconductor industry ("East") and newly emerging solar industry in absorption of global best practices ("West") thereby fusion between them were the reasons for conspicuous strength.

The fusion can be achieved through joint work between industry's intensive effort in learning global best practices for exploring new business and government's catalytic role for the attainment of decarbonisation society for nation's sustainability.

2.3 Literature review

Firms are constantly experiences cash flow due to unexpected downturn which puts pressure on supply chain management in terms of inventories, lead times, operational efficiency, e.t.c. This demands high execution efficiency and distilled formulae for a firm to follow in troubled times so as to catch up at faster pace with technology compared to competitors and to change and dynamically optimize the supply chain (Buckley et al., 2006). However this needs large R&D investment and one way is to exploit the spillovers effectively as a replacement to a firms 'own R&D investment and hence taken for research in this work.

Positive spillovers are known to arise when the leading edge technologies of foreign MNCs influence and improve the productivity of locally owned firms (Feinberg and Mujumdar, 2001). Negative effects are also studied (Aitken and Harrison 1999) specifically in pulling the demand from the home grown firms. These are in the context that the locally original firms within a closed economy tend to have weak technological capabilities. Such deficiencies will disable them to appreciate the value of externally generated knowledge and restrict their absorptive capability to intake the knowledge spillovers by foreign spillovers. Thus positive spillovers may primarily occur from "demonstration effect", "contagion effects", people movements, and through pro-competitive effects. Also it is seen that locally owned firms are concentrated in the standard technologies where the foreign firms avoid.

FDI is another source of knowledge where it is treated as a bundle exported as non-negotiable packages that can reap the full benefit of their comparative advantages in technology and management systems. FDI is the process whereby residents of one country (the source country) acquire ownership assets for the purpose of controlling the production, distribution and other activities of a firm in another country (the host country) (Deepti, 2011). In the interest of space the literature review is not repeated from other chapters. Based on the literature not much research has been done regarding “how FDI induced spillover helps beyond the first generation industry”. Hence in the present study, research focus is to show how China’s FDI in a first industry influences a further new industry, such as Semiconductor industry has supported the next wave of industries such as Solar PV industry and LED industry, Sensor industry, e.t.c., that has newly evolved and established in China. Next, not much literature talks about assimilation of emerging region like China, from publically available open source information and global knowledge and practices such as patents and design standards of the global MNCs.

Industrial clusters have received attention by economic geographers since the obvious characteristic of industrial cluster is in the spatial characteristics of industrialization. The clustering of industrial activity has been studied in terms of regional development. The notion of clusters has two dimensions:

- Consists of actors with a focus in innovation process.
- They help understand the dynamics of innovation in modern economics.

From a competitive analysis in a global economy, Michael porter argued that clusters are conceptual and real entities (Porter 1998). Porter argued that even under market globalization, clusters play a significant role in enhancing firms and the economies’ competitiveness. He emphasized the geographical proximity as a driver and colocation induce physical encounters and informal flows of information helped diminish the meaning of distance that resulted in the agglomeration of industries and firms in specific regions. In his first set of paper, Porter defined clusters as Geographic concentrations of interconnected companies from a supply side such as, specialized suppliers, service providers, firms in related industries and associated institutions (for example universities, standard agencies and trade associations) that both compete and cooperate (Porter 1998,p. 197). While in the recent communication Porter (2003) argues that export oriented cluster drives regional prosperity due to their higher wages and more international linkages than those serving local market. These studies explain the importance of innovation as an important driver of national and regional competitiveness.

In the early models of endogenous economic growth, it was identified knowledge spillovers supported sustainable growth (e.g. Lucas, 1988, Romer 1986, 1990a). Some identified such spillovers were in the form of imitation of innovation and thus not endogenous. However through this research it is shown there are other genuine sources for exploitation such as knowledge spillover from other industries. Published literature mentioned above does not cover the challenges of an emerging region, such as the sources of knowledge for a new industry evolution to cater a domestic need or a foreign market and hence forms the core part of this research.

Economists' interest in the developing region does not cover how industrial clusters play a role in new industry evolution. For example, how China became well known in specific areas of manufacturing of solar energy products even without internal market demand and no external technology collaboration. Hence the dynamic process of new industrial evolution in an emerging region is taken for detailed investigation and forms a part of the main research theme of this study.

2.4 Analytical Framework

2.4.1 Analytical model

Based on the discussion in the preceding section numerical analysis was conducted by utilizing two models, as follows:

(i) Evidence of spillover effects from external knowledge stock of relevant industries

It is generally demonstrated that the production prices of the solar cell depends on the actual production and the internal resources of a firm (Labor and capital). In addition, the process innovation that arises from the indigenous efforts along with a capability to assimilate the external knowledge stock enhances the overall production and thereby the production price of the solar cell.

$$P_r = F(Y, L, K, T, T_s) \quad (2.1)$$

where P_r : solar cell production prices,

Y : actual production of solar cells,

L: number of employees in the solar cell firms,

K: capital stock in solar cell firms,

T: gross technology stock (by terms of TFP) of solar cell firms, and

T_s: technology stock relevant to solar cell production.

Taylor expansion to the secondary term leads to the following analytical model:

$$lnP_r = A + \alpha_1.lnY + \beta_1.lnT + \gamma_1.lnT_s + \delta.lnL + \varepsilon.lnK + \alpha_2.lnY.lnT + \alpha_3.lnY.lnL + \alpha_4.lnY.lnK + \beta_2.lnT.lnT_s + \beta_3.lnT.lnL + \beta_4.lnT.lnK + \gamma_2.lnT_s.lnL + \gamma_4.lnT_s.lnK + \delta_1.lnL.lnK \quad (2.2)$$

where A: coefficient, α_i , β_i, γ_i and ε_i (i = 1 to 4) coefficient corresponding to the respective explanatory variables.

The evidence of the spillover can be further confirmed by checking the magnitude of the derivative $(\partial lnP_r/\partial T_s)$ as depicted by equation (2.3). When the magnitude is negative it demonstrates that the external technology stock T_s relevant to solar cell production provides spillover effects on China solar cell firms' for enhanced production to achieve cost effective prices.

$$\partial lnP_r/\partial lnT_s = \gamma_1 + \beta_2. lnT + \gamma_2. lnL + \gamma_4. lnK \quad (2.3)$$

(ii) Evidence of spillover effects from global solar MNC's knowledge stock.

Solar cells production can be depicted by the following function:

$$Y = F(L, K, T_i, T_g) \quad (2.4)$$

where T_i: Technology stock of solar cell firms by terms of patents, and

T_g: Technology stock of global solar MNC firms by terms of patents.

Gross technology stock can be expressed in terms of T_i and assimilated spillover technology $z.T_g$ (Watanabe et al. (2000)) as follows:

$$T = T_i + z.T_g \quad (2.5)$$

where z: assimilation capacity.

Thus equation (2.4) can be depicted by the following Cobb-Douglas type function:

$$Y = A. L^{\alpha}. K^{\beta}\left(T_i + zT_g\right)^{\gamma} \quad (2.6)$$

where A: scale factor and, α , β and γ: elasticities corresponding to the respective explanatory variables.

Taking logarithm of equation (2.6), following linear function can be obtained:

$$lnY = lnA + \alpha. lnL + \beta. lnK + \gamma. \ln T_i\left(1 + z. T_g/T_i\right) \quad (2.7)$$

When $1 >> z.(T_g/T_i)$, Y can be approximated as follows (Watanabe et al. (2000)):

$$lnY = lnA + \alpha. lnL + \beta. lnK + \gamma. lnT_i + \gamma. z. \left(T_g/T_i\right) \quad (2.8)$$

Assimilation capacity can be identified from equation (2.8) as

$$z = z.\gamma/\gamma \qquad (2.9)$$

2.4.2 Data construction

The data of the dominant domestic solar firms of China involved in solar cell and module manufacturing included details on labour, capital, production, prices, registered year and market share as listed in Appendix A1. The firms' technology sources were investigated either from joint ventures or directly funded from foreign funds. Additional information included in looking into their official web links to access their annual reports and obtain product types, models, capacity and yearly growth. Similarly, data was collected for the top ten global solar firms in terms of market share, labour, capital, production, price and other firm details.

2.5 Results

2.5.1 Empirical findings

Facing a paradigm change from a fossil fuel based society towards a decarbonisation society, China's industrial institutions has evolved a conspicuous strength in solar PV manufacturing by producing useful components in the value chain and initially targeting to export market and further diffusing into its domestic installation. This approach has aided the evolution and growth of China's leading domestic solar PV firms.

Table A1 summarizes the current leading domestic solar firms involved in solar cell and module manufacturing.

The top 74 domestic solar PV cell and module manufacturers form the major share of cell and module manufacturing that amounted to a actual manufacturing capacity of 30325 MW which exceeded world solar panel production in 2011 which amounted to 29534 MW.

(i) Evidence of Technology spillover from Semiconductor industry

Taking the top 74 solar PV cell and module manufacturers production which amounts to a total capacity of 30375 MW in year 2011 which equates closely to the world solar PV installation in 2011 (as per Table 2.1), it shows the accelerated conspicuous Indigenous strength building occurs by the extraneous knowledge spillover from the semiconductor industry. . Hence their knowledge assimilation aspects from the existing semiconductor industry were determined as per equation (2.2):

$$lnP_r = -1.016 + 0.281 lnY - 1.499 lnT - 0.180 lnY.lnT_s - 0.048 lnY.lnK$$

$$(-2.52)^{***} (2.76)^{***} (-2.88)^{**} \quad (-3.57)^{*} \qquad (-3.85)^{*}$$

$$+0.209 LnT.LnL + 0.012 LnT_s.LnL + 0.031 LnL.LnK \qquad adj.\ R^2 = 0.466 \qquad (2.10)$$

$$(2.83)^{***} \qquad (-3.21)^{**} \qquad (3.89)^{*}$$

*, ** and *** indicates significant at the 1%, 3% and 5% level, respectively.

Partial differentiation of P_r with respect to T_s leads to elasticity of spillover technology to production price, as follows:

$$\partial lnP_r / \partial lnT_s = -1.499\ (\partial lnY / \partial lnT_s) - 0.0148 lnT + 0.012 lnL \qquad (2.11)$$

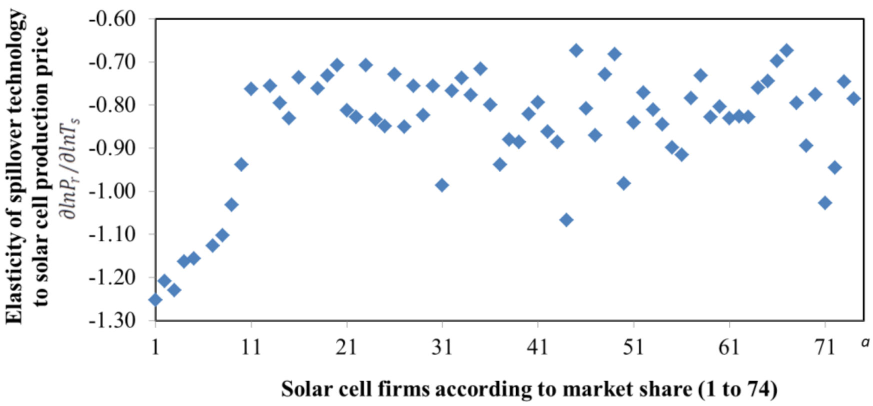


Figure 2.5. Effects of technology spillover from semiconductor industry to China's Indigenous 74 solar cell firms (2011).

[a] Numbers indicate firms examined in accordance to their market share (No. 1 is the largest market share while No.74 is the smallest market share, see Table A1).

Utilizing this relation the sensitivity of price with respect to spilled-over technology stock for the different firms under this study was computed (refer Table A1). Fig. 2.5 demonstrates the elasticity of spillover of different firms (1 to 74) in the order of increasing market share. Results shows that the negative magnitude of the sensitivity which confirms that the knowledge spillage for each firm from semiconductor industries is positive. Comparing the magnitude between the firms, it is obvious that the first ten firms exhibits increased assimilation capability as compared to the rest of the domestic which implies the importance of spillage to achieve decreased price.

(ii) Evidence of Technology spillover from global solar firms.

Taking the top 23 solar PV cell and module manufacturers among the 74 domestic China solar cell and module manufacturers, their manufacturing output amounted to 14340 MW which equates to ~ 50% of China's manufacturing output in 2011. Hence their technology stock build-up is of importance from knowledge assimilation aspects from the global solar firms were investigated as per equation (2.8):

$$lnY = -1.557 + 0.237lnL + 0.023lnK + 0.041lnT_i + 0.010\left(\frac{T_g}{T_i}\right)$$

$$(-17.17)^{*} \quad (2.91)^{*} \qquad (1.02)^{***} \quad (1.48)^{*} \quad (37.62)^{*}$$

$$adj.\mathrm{R}^2 = 0.872 \quad (2.12)$$

* and *** indicates significant at the 1% and 5% level, respectively.

By equation (2.9) assimilation capacity z can be identified as 0.24 of spillover technology from global solar firms.

2.5.2 Qualitative analysis results:

(i) Technology transfer modes to China solar industry

Technology learning and spillover are key to the evolution of new industry. Technology transfer includes all mechanisms by which a domestic firm can acquire useful knowledge from a foreign firm on the critical aspects of the solar value chain's components and system level (Maskus 2004). Based on the technology literature various knowledge transfer modes could exist and were observed within the Chinese solar industry:

(1) Licensing: Codified knowledge and exclusive right to exploit is sold by one party to another, Example Australia PV Science and Engineering Co., helped transfer solar cell manufacturing technology to Jingao Solar co., Ltd., in MAY 2005.[11]

(2) Movement of capital through FDI: Ownership of a productive asset by a foreign entity into the host country. Example, the equipment that is imported is pretty matured for crystalline silicon technology which is a dominant technology when China evolved the solar PV manufacturing industry,

(3) Movement of people through migration, travel and foreign education of students and workers. Example: Suntech CEO was educated in New south wales (NSW) and later when he setup this firm in China he setup collaboration with NSW and has taken up as a visiting professor at NSW,

(4) Diffusion through media and the internet of disembodied knowledge such as access to international patent database, competitor website and international scientific articles,

(5) Integration of benefits into global value chains from foreign technology transferred within the supply chain (Fu, Pietrobelli and Soete 2011), and

[11] http://www.greentechfocus.com/index.php#state=CompanyDetail&id=963

(6) Knowledge spillover from other domestic related industry through labour mobility. It is empirically proven that in China labour mobility during inter-industry results in salary hike and this is an incentive for such knowledge transferor.

(ii) FDI supported knowledge transfer

Among the various modes, FDI supported knowledge transfer can be expected as a dominant factor. It is widely understood that knowledge from technically advanced countries increasingly transcends national boundaries and contributes to the domestic technological development. FDI plays a significant role in the country's economy and China because of skilled labour availability exhibits a good absorbability and productivity. For example FDI increased from 0.9 billion in 1983 to US$ 74.8 billion in 2007 and have been instrumental in developing healthy electronics industries as listed in Table A4. Productivity spillover is observed as one of the benefits of FDI as they become economic externalization. However as pointed out in Table 6, the presence of FDI in all the leading Chinese solar firms is minimal.

Among the world's 15 largest solar cell or module producers in 2010, nine firms operate in China and two had foreign direct investment. Canadian Solar was founded in 2001 and has seven wholly-owned manufacturing subsidiaries across China. JA Solar was founded in 2005 as a joint venture between the Jing Long Industry and Commerce Group Co., Ltd., the Australia PV Science & Engineering Company, and the Australia Solar Development Company. Hanwha SolarOne was initiated by Korean Hanwha Group by acquiring in 2010 the China's Solarfun Power that was originated in 2004. The two companies that were either wholly owned subsidiary of a foreign company or as a joint venture with a foreign company was JA Solar and Canadian Solar. JA Solar was a late entrant to the Chinese PV industry, coming well after home-grown firms like Suntech, Yingli, Trina, and Jiawei Solar China. While Canadian Solar was founded in 2001, there is no indication that its foreign counter part helped to drive enough technology transfer to fuel the growth of China's solar industry. Thus FDI in the traditional sense of technology transfer, and knowledge spillover, has not been a significant factor in the development of China's solar cell and module manufacturing industry and has been a predominantly home-grown industry.

Table 2.6 Technology source of China's top 10 solar PV firms

Chinese Firm	Starting year	FDI-Joint Venture links
Suntech	2001	None
Yingli	1998	None
Jingao	2005	Australia
Solarfun	2004	None
Sunenergy	2004	Australia
Canadian solar	2001	Canada
Ningbo Solar	2003	None
Trina solar	1997	None
Jiangsu Jiaoseng	2004	None

Source: A de la tour et al. Energy Policy 39 (2011), 761-770.

(iii) Technology learning, knowledge spillover from previous industries

The dominance of the China's solar power industry is generally being attributed to: (1) the cheap labour availability of skilled members (2) availability of the matured high end equipment which ensures same silicon based solar panels with high quality as that of the international manufacturers. A closer study shows China builds its factories faster in setting up the necessary supply chain. For example, by 2006, Suntech power of China was manufacturing a million solar panels in an annual year. Today China overall manufactures about 50 million solar panels and over half the world capacity in 2010[12] and thus it has exhibited a doubling the production capacity roughly every year. The aggressive scaling of

[12] http://www.technologyreview.com/energy/39356/

production factories are attributed to the labour availability of other complimentary industries like construction industries. Alongside to its production, it constantly craves for new innovation to enhance its efficiency of the product. Traditionally China set forward to scale their production in standard technology but as supply exceeds demands, to stay afloat globally it has to constantly adopt new innovations to reduce cost and enhance product performance.

To understand the reasons for the availability of skilled labour once needs to look into the possible knowledge spillage. Knowledge is seen as a public good (Nelson, 1959, Balzat et al. 1962). Spillover is a positive externality due to the public nature of knowledge. Spillovers arise if firm A can benefit from firm‘s B R&D activity without sharing the R&D costs of B (Branstetter, 1998). For a new industry to tap existing patents from relevant industries may be a good leverage: "By technological (or R&D) spillovers we mean that a firm can acquire information created by others without paying for that in a market transaction" (Grossman & Helpman, 1991). Many researchers have studied the spillover due to the geographic proximity such as Anselin et al. (2000), Jaffe et al. (1993); while trade related FDI related spillover has been studied by Grossman & Helpman (1991) and Kinoshita (2001).

Assimilation of existing knowledge from relevant know-how along with technology transfer have been key in the Indigenous innovation and thereby the world dominance of the solar PV manufacturing in China. Know-how refers to any methods, techniques, processes, discoveries, inventions, innovations, unpatentable processes, technical information, specifications, recipes, formulae, designs, plans, documentation, drawings, data and other technical information and identified in a tangible form.

Among the various institutions private firms have been the major force in pursing R&D and process innovation to become cost-competitive. This has been favoured by the

National innovation system (NIS) that is composed of the private firms, government agencies, foreign subsidiaries, their supply chain, academia and research institutions and their actors and various linkages (Balzat et al. 2004).

Next absorptive capacity has been addressed on human capital as instrumental in productivity (Griffith et al., 2003 and 2004, Miller et al., 2000). In the case of China, the absorptive capacity through different channels for knowledge spillovers such as R&D, FDI and exports have been through the right calibre labour intake into firms that they have employed such that their interaction effects have resulted in the increased firm production. In such a view, foreign firms have aided as an active player in the NIS through knowledge transfer, knowledge creation and through participation of competition. On average, foreign invested firms (MNEs) have demonstrated the real manufacturing procedure as a predecessor to the domestic firms, such that it was easy for the domestic firms to mimic and practice. For example, the developments of some industries in China such as integrated circuits, automotive have been fuelled by the foreign invested enterprises. The presence of these MNEs helped to fuel development of indigenization in China through technology transfer and rapid diffusion of know-how. The spillover takes place through (a) inter firm mobility of workers and managers (b) industry supply side and customer side relation (c) exports by multinational affiliates (d) utilization of supply chain actors from other relevant industries. Blake et al., 2009, study on 998 Chinese manufacturing firms showed labour transfer between foreign invested firms and local firms affect the productivity of local firms positively when they employ foreign trained workers. Their results confirmed absorptive capacity of local firm is important for spill over to occur and to increase productivity.

Productivity spillover takes place when worker or manager in foreign MNC resigns and joins a domestic firm or starts their own firm specific to that industry. Thereby they exert a positive impact in the industry and the foreign firms in terms of productivity. Fosfuri et al., 2001, showed that the multinational had to increase salary to retain worker after they trained him, else a technology spillover may result to a local firm.

One possible knowledge source can be its own domestic know-how by studying the technology similarities between industries which is one observation that can be made between the new solar industry and existing semiconductor industry in China. Their technology similarity can be observed by closely observing the process plan of the silicon material as shown in below figure 2.6.

China solar manufacturing has been essentially dominant in C-Si technology compared to TF-Si technology. The dominance in the first generation C-Si silicon technology may be due to rich source of raw materials and technology maturity; however one reason that can be postulated is the history of success in China's semiconductor industry even with complex technological nature. Figure 2.6 shows how the semiconductor and solar industries are linked through the silicon value chain.

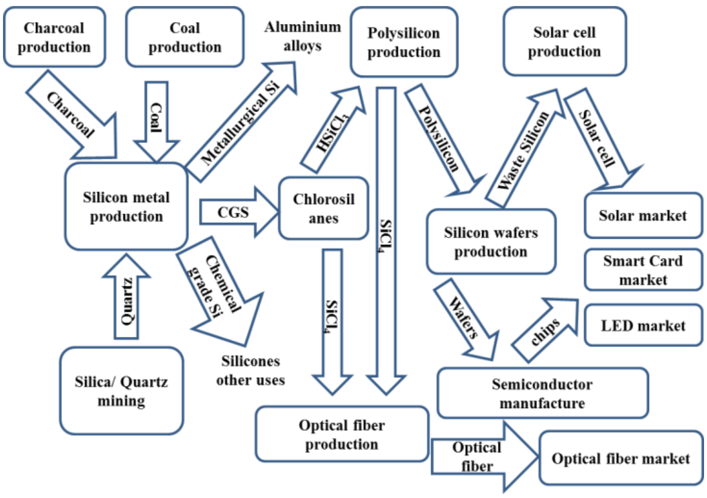


Figure 2.6. The production chain for high-purity silicon and its use in semiconductor, solar cell, smart card, LED and optical fiber manufacturing.

To understand why China chooses to focus on the first generation Solar PV cell and module manufacturing we could investigate its industrial history. China has been successful in the electronic industry in 1990s and has made significant progress as seen in Fig. 2.7. Hence there is significant evidence of its knowledge accumulation in the process technologies that are required for electronics manufacture (Tilman et al., 2008, and Liu X., 2001). Table 2. A4 lists the various electronics industries productivity and capital per capita. The production function of the Chinese electronic industry was studied earlier[13] which shows that the industry has good productivity due to skilled labour. Such healthy presence has exhibited a strong growth in revenue in both semiconductor manufacturing industry and integrated circuit manufacturing industry (which is also called semiconductor packaging industry).

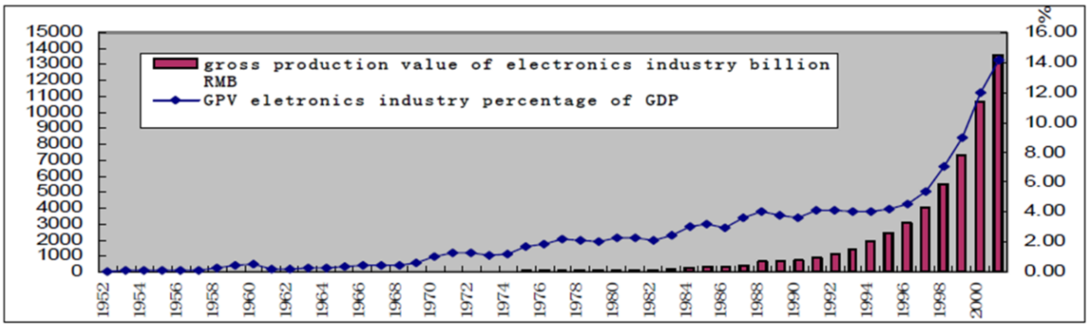


Figure 2.7. China's 50 year electronics industry growth.
Source: Xinxin Kong, National Research Center for Science and Technology for Development (NRCSTD).

Table 2.7 Annual revenue[a] of semiconductor and IC industries in China (*2000-2010*).

Year	Semiconductors	Integrated circuit (IC)
2000	14.4	11.4
2001	17	13.8
2002	21.4	17.7

[13] XinXin Kong (National Research Center for Science and Technology for Development) finds that the China electronic industry production function: $Production\ (MW)=0.592*Capacity^{0.539}*Employees^{0.422}$

2003	30.7	25
2004	43.4	8.3
2005	56.5	46.4
2006	71	59.5
2007	88.9	73.9
2008	103.8	85.9
2009	101.2	18.1
2010	132	108.6

[a] Billion US$ at current prices.
Source: Price Waterhouse[14] (2011).

According to NREL analysis US manufacturing facility is automated as compared to China manufacturing facility which is more labour based, yet Chinese products have demonstrated 18 to 30 percentages[15,16]. This possibly shows that the inducted skilled force and their internal training can meet the final customers of the solar production value chain. This evidence of quality production that meets the end requirement shows that the technology transfer (1) through equipment manufacturers, (2) through licensing and research collaboration, and (3) know-how from the Chinese diaspora have been well absorbed and assimilated into useful process capability of solar manufacturing. For example, technology transfer from American, German and Swiss equipment makers has allowed Chinese manufacturers to initiate and scale the solar production lines into their factories in a short time span (Gordon Brinser et al., 2012). Thus it is convincing that China's labour force has acquired skills from other relevant industries and foreign direct invested MNEs.

2.6 Discussion

Moving towards a renewable energy adoption, China has coevolved a conspicuous Industrial strength to evolve solar PV manufacturing ability into order the growth and adoption and to evolve a new export market to cater the world needs. In a very short time

[14] www.pwc.com
[15] http://cleantechnica.com/2012/02/12/dumping-solar-study-sheds-light-on-solar-pv-trade-flows-us-China-manufacturing/
[16] http://www.americansolarmanufacturing.org/news-releases/02-07-12-casm-federal-research-lab.htm

span as seen in Fig. 2.1, it exhibited a rampant growth in production capabilities. Table A1 summarizes current state of China's leading solar PV manufacturing by order of real production, market share and price in 2011.

2.6.1 Comparative advantages

A broad investigation may show that China has the following advantages:

(1) Advantage of production scale

(2) Advantage of vertical integration

(3) Availability of cheaper skilled labour.

(1) Production Scale

China's core advantage in cell manufacturing can be seen to arise from scale and vertical integration. Comparing a 60 MW plant in USA and a 2000 MW plant in China shows that 10 percent reduction in material cost and 50 percent reduction in equipment cost from Chinese equipment vendors, due to supplier leverage and captive production strategies (NREL report, Goodrich et al., 2011).

According to Rob Wanless, Director of Business development, SOLON Corporation, most of the facilities in China of the leading manufacturers have larger facilities than the USA manufacturers (Gordon Brinser et al., 2012). The typical top tier manufacturing plant in China produces annually about 500 to 1000 MW which is higher than the typical manufacturing plant capacity of USA which ranges between 40 to 100 MW. Thus according to Melaine Hart, Policy analysts for Chinese Energy and Climate policy at the centre of American progress, China gets advantage as being a manufacturing powerhouse (Hart (2011)).

According to Goodrich of NREL[17] cost comparison of cell manufacturers shows:

(i) US 60 MW automated plant shows US$0.89 per watt.

(ii) China 60 MW plant shows US$0.85 per watt.

(iii) China 2000 MW plant shows US$0.82 per watt.

(iv) China 2000 MW plant with discounted equipment US$0.80.

(v) China 2000 MW plant with discounted materials US$0.73.

Thus purely comparing a 60 MW manufacturing plant of China versus USA shows a minimum of 4.5 percent which is primarily due to low cost of relevant skilled labour. Adding the advantage of scale and vertical integration and domestic equipment and materials supply, Chinese cell manufacturers show an 18 to 20 percent manufacturing cost advantage.

(2) Vertical Integration

The top tier Chinese solar manufacturers also aim to benefit from vertical integration. For example, manufacturing both cells and modules helps in manufacturer's economies of scale.

(3) Availability of cheaper skilled labour.

Published literature more relates production to the resources availability of a firm (viz., labour, capital and technology stock). For example, as per year 2011, labour rate in China solar work force costs US$2.13 per hour as compared to USA work force where it would be around US$13.33 per hour, similarly a manufacturing engineer annual salary is US$8,171 in China versus a similar capable engineer's annual salary of US$75,110 in USA (Goodrich et al. (2011)). Thus for 500 MW capacity of Cell and Module facility, a China factory has 1492 employees and 508 employees, respectively, as compared to a USA factory

[17] http://www.americansolarmanufacturing.org/news-releases/02-07-12-casm-federal-research-lab.htm

where it is 296 and 104 employees, respectively. The difference is attributed mainly to the automation in the manufacturing. Based on the export acceptance record by the West in the recent years, the quality of the Chinese solar panels can be deemed to be acceptable as that of the West's solar products, since they have been swappable in a final solar PV project, and can infer that the labour supply to the China solar factories have met the automated factory quality of USA solar factories, possibility with the necessary job based trainings and equipment and tools. However it interests us that how such apt labour force gets supplied to the China's solar industry is scalable in number in the short time span.

Researchers have identified the importance of tacit knowledge (or personal knowledge) in addition to the explicit form of knowledge that is available in the form of patents and international journal papers. Also literature shows the importance of externalities as a source of increasing returns and productivity growth. Technology spillovers exist and the R&D of nearby firms produce positive effects, so that firms could get large benefits from spillover (Griliches (1998) and Anon (1998)). These could come into a firm in the form of skilled labour hiring and training, use of firms of related industries' supply chain, manufacturing best practices that are borrowed from other related industries, etc. This presence of R&D spillovers result because the technology distance (Jaffe (1986)) between the firms that generates the spillover and the receiver is short. From such a view, we find that semiconductor industry has much technological similarities to solar industry and hence the manufacturing know-how or the personal knowledge of the labour becomes relevant. Such addition of semiconductor manufacturing trained people to a solar PV manufacturing firm enhances the absorption capacity (the capacity of the receiver to absorb technology from the other sector) and the assimilation capacity (the capacity of the receiver to assimilate and then utilize the technology absorbed from the other sector). The assimilation capacity has a direct impact on the speed of technology adoption and thus ramp up the production capacity of a firm. Fig. 2.8 clearly relates the role of learning to a whole dynamism in assimilation, innovation emergence, production increase and thereby price decrease of the product.

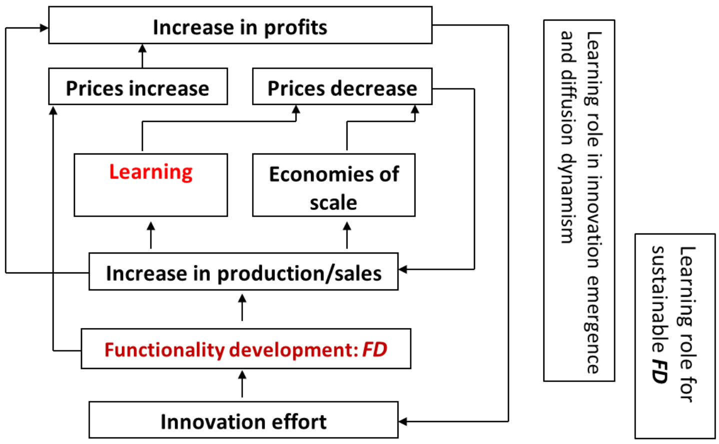


Figure 2.8. Policy's role in leveraging learning for price decrease.
Source: Watanabe et al. (2000).

The empirical findings in this study show that the external knowledge spillovers (FDI and external R&D) have proved elusive. Additionally, this study has pointed out that the domestic industries' know-how interacts with external technology through an integrated learning process and thereby the TFP (total factor productivity). The study elucidated the structural sources of the high level of conspicuous strength building in China's domestic solar firms. Focusing on their exploitation of semiconductor industry by the assimilation of spillover technology, the motivations of private firms and increases in production and price reduction are identified, particularly in domestic originated firms within a short time span.

2.6.2 Effective knowledge spillovers between industries

(1) Clear linkage of semiconductor and solar technologies.

In order to show the micro-evidence in the form of clear linkage between semiconductor and solar patent one could resort to compute the backward citations to show the knowledge spillage. However at this point, the China patent database does not have the backward citation and hence a different method was pursued. Technology can be classified by the International patent classification (IPC) code. Accordingly taking the top 100 technologies based on the IPC-4digit classification for semiconductor industry and comparing with solar industry, the numbers of patents in the two different industries were determined using Thomson database. Among these 100 IPC classes, study shows 80 IPC classes are common between semiconductor and solar industries. Table A5 lists the most common technologies between the semiconductor and solar industry and the number of patents originated from the solar and semiconductor industries. To propose that relevant knowledge stock from the semiconductor industry (*Pat_IPC_Semicon*) has a direct correlation to the knowledge stock in the solar industry *Pat_IPC_Solar*, a linear regression can be shown as follows:

$$Pat\_IPC\_Semicon = -268.291 + 0.898 Pat\_IPC\_Solar \qquad adj.\ R^2 = 0.930 \qquad (2.13)$$

$$(-3.34)^{**} \ (32.38)^{*}$$

* and ** indicates significant at the 1% and 3%, respectively.

Table 2.8 Top 25 technologies of China solar expressed as IPC codes (*2012*)

IPC (4 characters)	Patent Count
H01L	1109
C30B	246
C23C	87
C01B	73
B81C	60
G02B	54
B01J	52
H02N	48
B81B	45
G02F	42
H01M	41
G01N	41

H02J	39
C08L	39
A61K	38
C03C	35
C09K	35
C23F	31
C04B	31
B32B	30
H01J	29
B82B	29
C22C	28
C07C	26

(2) Evidence of relevant know-how from China's semiconductor industry.

Table 2.8 lists the top technologies (25 technologies) of China solar industry origin. Analysing these patents' IPC codes it is clear that they are common to semiconductor industry. Thus it is convincing that the know-how of the semiconductor industry is relevant to the inception and growth of the China's solar industry. For example, H01L is a focused technology classification in the field of semiconductor process and figure 2.9 shows how patents have been growing specifically from China solar firms in the recent years. This exhibits the absorption and assimilation trend within the solar industry from the semiconductor manufacturing know-how and further transforming into useful innovations to support solar manufacturing capability.

Taking patent count as one good measure to check how China has a good innovation base in semiconductor industry (Price Waterhouse (2012)) the total number of patents of China (*Pat_CS*) was regressed to the global number of semiconductor patents (*Pat_GS*) on a cumulative basis.

$$Pat_{CS} = -817.853 + 0.411 Pat_{GS} \qquad adj.\ R^2 = 0.980 \qquad (2.14)$$

$$(-3.05)^{**} \ (20.90)^{*}$$

* and ** indicates significant at the 1% and 3% level, respectively.

Thus equation (2.14) shows China has a healthy growing stream of patents similar to the global semiconductor patents. This shows there is a growing population of innovators in the semiconductor manufacturing field and thus could directly contribute to the manufacturing of solar industry due to the technical relevance as pointed out in earlier paragraphs. Accordingly we see enough reasons for the solar industry to induct the skilled innovators from the semiconductor industry which would have been a key causal reason for the solar industry growth. For example, Figure 2.9 shows the conspicuous strength of the H01L technology class from the solar industry since 2005 which possibly would have influenced by the presence of relevant knowledge stock and the people stock in the semiconductor industry, due to the common technology relevance as per equation (2.13).

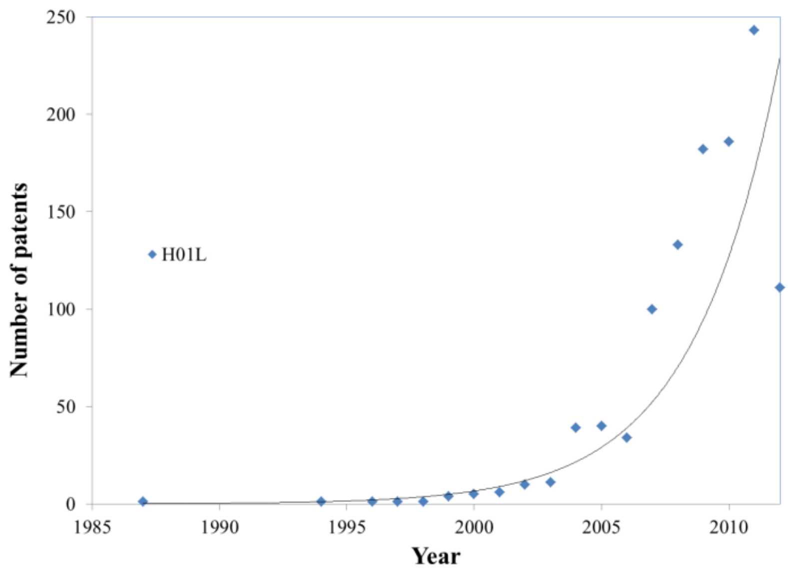


Figure 2.9. Technology trend in H01L patents from the China solar industry.

Also a specific keyword search of China’s academic publications specific to solar cells (in Engineering Village Database of international journals) shows the important frequently occurring keywords. These give a clue of their research focus. Fig. 2.10 shows the technical keywords searched specific to the solar cell technology and specific to China. The keywords signify the semiconductor related and process related keywords and that shows the focus of the academic research which is inline to the industry.

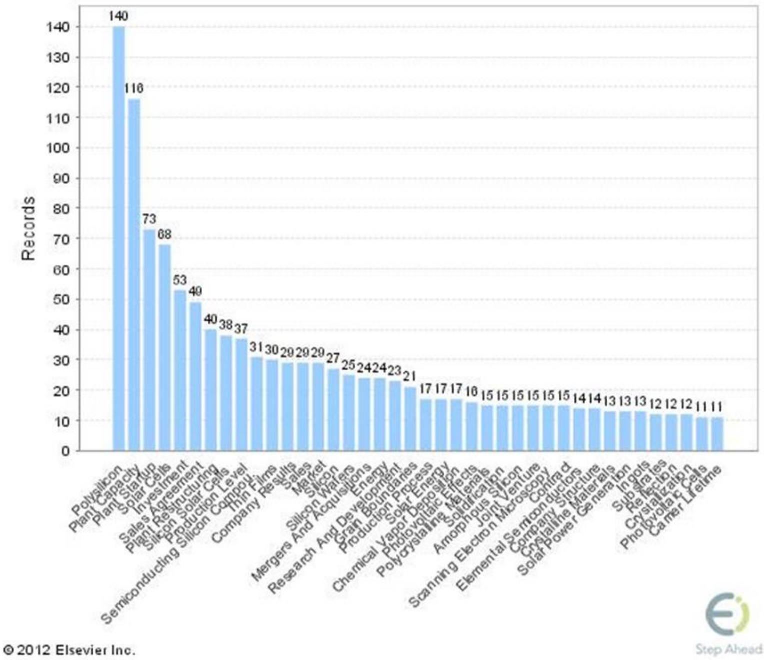


Figure 2.10. Frequent keywords of China originated solar journal papers.

The other promoting reasons for spillover are due to geographic proximity of placing the solar PV industry in the same industrial clusters of semiconductor industry. For example, one of the key presence of the PV industry cluster is in the pearl river delta (Mark Ng 2011) which is known for the semiconductor industry and this has a strong influence in supporting useful labour mobility, capital resources availability and easy identification of supply chain partners for the newly evolving industry.

2.6.3 China's national subsidy program

Subsidies are designed mainly to position China as the global leader in solar manufacturing and essentially not anti-competitive, according to Melaine Hart, Policy analyst for Chinese energy and Climate Policy at the Centre for American Progress. As Robert Petrina, Managing director at Yingli green energy Americas Inc., explained at the ITC conference, "Government incentives for solar projects have been very important in lowering net costs so that the projects can achieve these goals and are implemented. However with incentive levels declining on an unpredictable basis, there has been tremendous pressure to maintain the all in total cost for the projects at levels that continue to be economically viable and drive adoption, preferable, and ultimately without incentive support".

China's government has implemented three important policies to stimulate the solar PV industry; (i) feed in tariffs at national and regional level (ii) the tendering policies (iii) the renewable portfolio standards. The feed in tariffs accelerates development of the renewable energy infrastructure and the tendering policies are helpful to get competitive prices (Zhen et al. (2011) and Wiser et al. (2002)). Table 2. 9 summarizes the various subsidies and benefits provided by the government to its solar PV production chain.

(i) Rural electrification: Launched in 2002, it aimed to provide electricity to rural areas of China that lacked grid support. By the end of 2005, 721 wind-solar PV power stations were accomplished in west part of China and benefited 1.3 million people.

(ii) Feed in tariffs (FIT): Since 2006, the FIT price was determined as per "cost plus reasonable price" to electricity supply to grid system. The national feed in tariff was put on hold "indefinitely" because the cost of solar power was deemed too high in 2006. But in Aug 2011, the government reinstated the FIT for solar PV industry. In addition, favourable regional subsidies in terms FIT were announced in Zhejiang, Shandong and Jiangsu.

(iii) Golden sun: Launched in 2009, helps to cover 50 to 70 percent of costs to cover utility scale solar projects and other infrastructure and targets towards 1000 MW capacity build up.

China uses the national industrial policy[18] which is a very clear and specific strategic national policy that directs (and then promotes) the development of a specific industry. The

[18] Chinese Renewables Status Report October 2009, The Renewable Energy Policy Network for the 21st century.

pinnacle of industrial policy in China is the five year plan. China's 12th five year plan clearly articulates the China's goals for the industry. It identifies the solar PV as one of the seven new strategic industries for development. For example China plans to invest US$100 million to build power projects using Chinese solar panels in 50 African nations (Yang et al. (2010)). In its 11th five year plan it spent US$309 billion on energy efficiency and environmental protection measures and today four of the world's five largest photovoltaic solar cell manufacturers are Chinese domestic firms. Over the next five years, the Chinese central and local governments are expected to focus on resources and potential opportunities to further enhance.

The five year plan (2011-2015) developed by Ministry of Industry and Information Technology for solar industry was released in Feb 2012:

(i) Reduce the cost of domestic solar power to 0.8 Yuan (about US $0.13) per kwh by 2015 and 0.6 Yuan (about US $0.10) by 2020.

(ii) The cost of solar panels in China will drop to 7000 Yuan (about US$1100) per kw by 2015 and 5000 Yuan (about US $800) per kw by 2020.

(iii) The plan requires China's leading polysilicon manufacturers to reach a 50000ton annual production capacity (per firm) and leading solar panel makers to reach 5 gigawatts (annually per firm) by 2015.

(iv) China will further help solar companies increase their annual sales, with atleast one firm reaching 100 billion Yuan (about US$16 billion) in sales and 3 to 5 firms reaching 50 billion Yuan (about US$8 billion) in sales by 2015.

(v) Increase the conversion efficiency of monocrystalline silicon solar cell to 21 percent, polysilicon cell to 19 percent and amorphous silicon cell to 12 percent by 2015.

(vi) Eighty percent of solar equipment and auxiliary materials will be produced domestically.

(vii) Thereby it aims to have a minimum installed capacity target of 5 GW by 2015 and 20-30 GW by 2020 such that these large scale capacities is being planned to be placed in deserts.

Such plans that treated solar industry as its strategic focus are the key reasons for the China's solar manufacturers to conspicuously grow from just 2 percent of the market in 2003 to 45 percent in 2010. Other countries such as Germany and Japan have industrial policies too. China support has been on direct manufacturing policies including preferential loans, tax incentives (including sales/value added tax waivers, preferential tax rates, income tax credits, property tax credits, income tax credits, property tax credits, research and development support, central government planning, local and provincial policies, domestic proprietorship requirements and facilities, land and training grants. The other is indirect deployment policies designed to promote demand for photovoltaic solar, direct subsidies, feed in tariff and local and provincial policies.

In 2006, China made key solar PV technologies part of the pillar R&D support scheme which provided funding for the commercialization of solar technologies by Chinese manufacturers. Recipients include solar PV manufacturers, including Wuxi Suntech, Baoding Yingli green energy, Changzhou Trina Solar ad Xinjiang new energy, and silicon manufacturers including Sichuan Xinguang Silicon and Luoyang Silicon Technologies. The local government provides loans to solar PV manufacturers and not grants that need to be payable. According to Shah (Gordon Brinser et al. (2012)), the Chinese government gave US$30 billion to its solar firms by opening a line of credit to aid manufacturing cells and modules. According to online investment magazine Motley Fool, LDK solar has a credit line of US$8.97 billion, JA solar has credit of up to US$.4.42 billion, Suntech has up to US$7.29 billion,, and Trina solar another US$4.3 billion. Such financing is difficult to obtain in open market due to least competitive advantage. Thus it is convincing that China government focused between 2006 to 2011 mainly manufacturing and due to evidence of poor domestic installation, it mainly targeted the export market (West) and thereby diffused useful technologies and evolved a new industry in its soil. The economic literature is full of evidence that international trade is an important channel for technology diffusion (Bin Xu, (2007)).

Table 2.9 Credits, guarantees, subsidies and grants for solar manufacturers in China[19]

Features	**National Provincial and Local**
Domestic Proprietorship required	Yes
Sales/value added tax waiver	Yes
Property tax credits	Not applicable
Subsidized cost of debt	3-4.5%
Subsidized debt limit	80%
Delay in processing subsidized debt	<1 year
Facilities grant	100%
Land grant	Discount purchase (land use right)
Training grant (millions USD)	Yes
Effective corporate income tax rate	21%
Income tax credits	20 year holiday
Loans/ Loan guarantees	$30 billion total credit line from China development bank.

Sources: Alan Goodrich, Ted James and Michael Woodhouse, Solar PV manufacturing cost analysis: US competitiveness in a global industry, Stanford University, Precourt institute for energy, 10 Oct 2011.

2.6.4 Microanalysis: The case of Suntech Solar PV manufacturing capabilities

Suntech[20] was one of the early firms engaged in solar manufacturing and is now the leading firms in the world's silicon solar panel manufacturers. The firm started since 2001

[19] Chinese Renewables Status Report October 2009, The Renewable Energy Policy Network for the 21st century.
[20] Suntech: http://am.suntech-power.com/about.html

and has become global, spreading to 80 countries. Its founder Dr. Shi Zhengrong graduated from Changchu University of science and technology in China in 1983 and received masters in laser physics from Shanghai Institute of optics and fine mechanics in 1986 before entering University of New South Wales in Australia. He believed in research and development and had close cooperation with academia such as University of south wales (Australia) specifically in new generation technologies.

Suntech started production since 2002, and by 2005 it was ranked by Photon International magazine as the world's top 10 PV cell makers in 2004. In 2005, with the support of Wuxi government it was listed in New York stock exchange and later released into a fully-fledged private enterprise. It proved its technology to the nation by winning the contract to supply the solar panels for the revolutionary Bird's Nest of 2008 Olympics which was a 130 Kilo watt solar installation. Suntech technology delivers a 19 % for monocrystalline solar 17% conversion efficiency and for second generation (polycrystalline PV cells in 2009) it showed 17% efficiency. In 2011 it crossed the mark of 2 GW annual production capacity.

For example, the Suntech researchers brought in a complicated technology of the 1990s, that depended on sophisticated processes like photolithography and vacuum deposition from the labs of the University of South Wales, Australia, and showed a clever way of incorporating to a production assembly line with reducing cost with improvement of performance of 10% from the initial 205 watts range. They setup a pilot line in 2009 and faced challenges during production scaling.

A patent search of Suntech shows it has utility and application patents of 291in China patent office and in outside China it has submitted 1551 patents.

In 2010, the US secretary of state confirmed from his visit to Suntech Power that he observed the automation with advanced high efficiency product technology was a key in its success. Indigenously they have shown indigenous process innovations to reduce silicon consumption, for example Suntech's annual report says the production team has found ways to use thinner silicon wafers to enhance production by reducing the silicon wafer thickness (180 micron range)[21]. The manufacturing processes have been constantly revised to show that their learning process is enhancing. For example, the conductive metal lines that collect electric charge from the silicon aren't created with standard methods like screen-printing process; instead, Suntech uses a proprietary process to deposit much thinner, more closely spaced lines that are more efficient at extracting electricity from the cells. The changes have allowed the firm to reach efficiency levels and cost reductions that an industry road map released in 2011 had set as targets for 2020. As Stuart Wenham the chief technology officer at Suntech puts it, "When you put all those things together, we are not only doing better than what people are doing now, We are also doing better than what they think they could be doing in 10 years." This year Suntech is poised to increase production of the new generation cells, and annually generate 500 megawatts of power—roughly 2.5 million solar panels.

In 2010, when US secretary of Energy Steven Chu gave a speech to the National press club, he pointed out that he was impressed with Suntech manufacturing competence when he toured the factory and found it to be "high-tech automated factory" and mentioned that "it's not succeeding because of cheap labour" and it had developed a type of solar cell with world record efficiencies. This convinces us the state of indigenization of China is internationally good.

[21] Kan Sichao, Chinese photovoltaic market and industry outlook – part 1, IEEJ, April 2010, pp. 1-12.

2.7 Theoretical Implications

Published literature has dealt well with globalization and its impact through foreign direct investment and technology transfer to an emerging nation's capability development in manufacturing competence and to become a part of the global value chain (Sonobe et al., 2003). These studies ignored the impact of knowledge spillovers on the capability formation of the emerging nation. However, knowledge spillovers have substantial macroeconomic implications for growth and international trade (Romer (1990)). From this context, these implications result in R&D production and geographically localized knowledge spillovers which are found to be less investigated in earlier literature. Zucker et al. (2004) showed R&D spillovers as a major source of endogenous growth in recent "New Growth Theory" (NGT) models (Zucker et al. 2004). However the New Growth Theory models assume that these "spillovers" are almost automatic, without cost and not limited by geography (Acs, 2004).

These spillovers are positive externalities on the productivity of firms which neither made the discovery themselves nor licensed its use from the holder of the intellectual property rights. Thus they play a central role in the literature as causes of both economic growth and geographic agglomeration. Earlier Griliches (1992) surveyed the importance of R&D spillovers as a major source of endogenous growth in recent "New growth theory" models and the difficult empirical search for their existence. There have been significant fingerprints of increased firm's productivity that were closer to universities (Jaffe, Manuel, Trajtenberg and Henderson (1993)). The sources of such success were attributed to the formative years of outstanding scientists who combined brilliant scientific productivity with specific knowledge of the new techniques which formed the basics of industrial formation and transformation. Further evidence was observed from empirical relevance of geographically localized knowledge spillover in the case of biotechnology (Zucker (1997)).

Earlier studies of Zucker (1997) and Griliches (1992) utilized qualitative models to discuss the knowledge spillover and studied in the context of Industry to University alliances. However in this study, the evidence of technology spillover between industries was proven through empirical methods to show spillover took place from related domestic industry. Also the method was shown to be effective to quantify the technology spillover through effective utilization of global solar MNC's open information knowledge stock. The novel empirical indicator 'z' was effective to quantify and monitor the evidence of such knowledge flow based on technology distance which utilized technology classes of Patents. The use of technology classes for example through similar IPC classes of patents to identify technologically closer industries is a useful contribution of this study. Thereby the possible skills from technologically similar industries can be forecasted. For example, the skill acquired in the semiconductor wafer industry may be of value in the Opto-Led and solar industry since both need similar technology components to develop large scale wafer processing system for the specific application. Also the evidence of the skilled labor mobility can be observed by monitoring the pattern of the inventors between firms to act as carriers of technology. These methods help to visualize and quantify the technology spillovers between industries.

Few studies have focused to articulate that the mechanism of industrial development through inter-dependencies (Puge and Venables 1998, Rodriques-Clare 1996). However there is not much study in the formation of new industries through knowledge spillovers from other industries, especially in an emerging region (as explained in literature review of earlier and present chapters). The published literature showed in a monopolistic competitive market the cost reduces by increasing competition among the local players and that the benefits of decreased cost are passed to the downstream firms. China's low cost manufacturing was more portrayed as purely due to cheaper labor and excessive raw materials. In this study, the idea that knowledge workers in an industrial cluster with varied industries' background can help transmit knowledge across sectors has empirically found plausible in China's industrial scenario. Hence a complementary process may arise such that if new industries develop, they exploit the knowledge brought by the workers from similar technology relevant industries and thereby increase assimilation, absorption and recreation capability of the recipient industry.

The present study results has confirmed that the global know-how of a firm in the emerging region can access from the pre-existing regional firms of other industries through its people, technology components and value chain partners. In addition they can support in assimilating the global know-how such as the free access of the international patent database, technical standards and reports and academic publications in the knowledge development of the firms. This study brings light to the idea of integrated framework for an emerging nation to indigenize, produce, diffuse and export. It explains clearly how China's solar industry with minimal official technology transfer and no domestic market and initial poor government support, has yet been able to evolve a robust world leading production chain in solar PV production. In the forthcoming paragraph a 'co-creation model' is put forth to summarize the above observations.

Co-creation Model for Future Market Creation

Industrial clusters have received attention by economic geographers since the obvious characteristic of industrial cluster is in the spatial characteristics of industrialization. However the dynamic process of new industrial evolution has not been their main research theme. Economist's interest in the developing region does not cover how industrial clusters play a role in new industry evolution. For example, how China and India became well known in specific areas of manufacturing of renewable energy systems. In the early models of endogenous economic growth, it was identified knowledge spillovers supported sustainable growth (e.g. Lucas, 1988, Romer 1986, 1990a). Some identified such spillovers were in the form of imitation of innovation and thus not endogenous.

Published Literature has focused well on regional economics (such as industrial aggregations or districts) and innovation economics (such as innovation systems and networks). The identification of cluster rationale from an industrial evolution has been the main focus of the present study. China's manufacturing advantage is assigned to economies of scale; however the representation of the industry in cluster form has not been well discussed.

Based on the present case of China's Solar PV industry, it is clear that at the start of the efforts during 1990s, the country lacked resources such as raw materials and technology know-how to create the value chain. However as the industry exhibited as an Industrial cluster, access to the information and knowledge got improved from other similar industries and each firm benefited due to wider customer base and hence a good eco-system evolved. In addition labour mobility helped in adding to the skilled work force to bring the vital technology know-how and assimilated the global market's need and local semiconductor firms' know-how along with the open source information of competitors' information such as patent database and technical articles. Similarly, equipment suppliers of semiconductor industry were capable to provide customized machinery with their know-how and assimilated the solar industry's global know-how and global PV market needs. Thus China's solar firms were no longer isolated, unaware and passive; they become connected, informed and active. Prahalad and Ramaswamy (2004) showed such co-creation takes place between a consumer and company at individual level and is a new approach to value creation. However in this study, it was clear how innovative firms as the individual entity of an industrial cluster can act in a similar fashion to embrace this new approach of co-creation of new industry and market by exploiting the network externalities and technology assimilation of spillover from previous industries within the given industrial cluster.

Fig. 2.11 shows the overall framework of technology transfer and institutional relation in the technology search and assimilation process in the evolution of the China solar PV industry. It is clear that the drivers, establishing an environment, capturing ideas and involving customers, prove new insights to the concept of co-creation of innovation. Furthermore an alignment of three integrating elements, social cohesion, system and context is significant when establishing co-creation of innovation, and the drivers are important when wanting to sustain co-creation of innovation. Thus for an emerging nation, co-creation of industry through actors of related industry can evolve production chain and identify external markets. These contributions to the concept of co-creation of industrial evolution and indigenization along with the importance of technology spillover are the key contributions of this study that were neglected in the earlier literature.

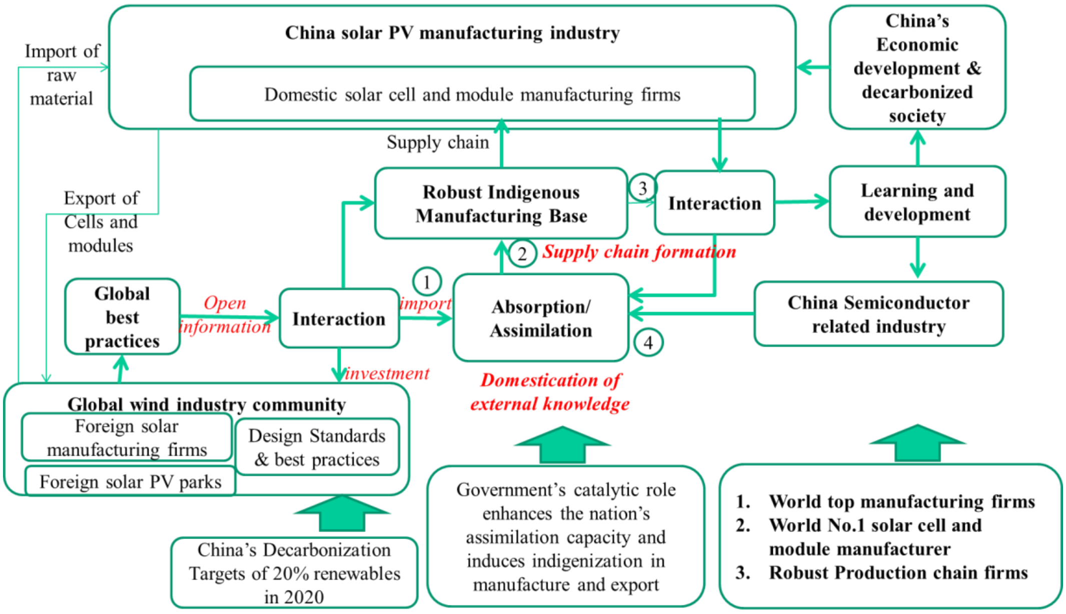


Figure 2.11. Overall framework of technology transfer and institutional relation in the technology search and assimilation process in the evolution of the China solar PV industry.

2.8 Conclusion

In light of a conspicuous strength in solar PV cell and module manufacturing in recent years and this study investigated the institutional sources of its strength. Empirical analysis was conducted focusing on the interaction between indigenous semiconductor manufacturing industry and newly emerging solar PV manufacturing industry in absorption of global best practices thereby fusion between them was demonstrated.

(i) Success of the fusion can be attributed to a joint work between industry's intensive effort in learning global best practices and existing know-how for exploring new business,

(ii) Technology contributes significantly to production increase in solar industry and thus an increase in technology stock by assimilation capability,

(iii) A set of 74 leading domestic solar PV manufacturing firms shows the evidence of positive knowledge spillage from the existing semiconductor industry,

(iv) The top 23 leading domestic solar PV manufacturing firms exhibits an assimilation capacity of 0.24 in learning the global best practices from global MNE solar firms,

(v) Improvement of assimilation capacity is essential for effective utilization of spillover technology, and this depends on the level of technology stock and skilled labour in the host,

(vi) A new way of identifying the technology spillover and competence growth using patent technology class has been demonstrated.

(vii) Government's catalytic role in supporting the solar manufacturing industry has aided the attainment of decarbonisation society for nation's sustainability,

(viii) The evidence demonstrates the possibility that developing countries can take an alternative path of development with green technology industries growing by its conspicuous strength and leapfrogging into global low carbon economy.

These findings provide important policy implications and suggestions to growing economies:

(i) From the success of China's solar industry evolution and growth, emerging economies such as India can evaluate their own conspicuous strengths based on the technology stock as a measure and devise roadmaps for possible new industry that can exploit these intrinsic know-how.

(ii) The present study showed convincing facts that the global MNEs knowledge spillover to the domestic firms helped to acquire global best practices and thereby reached export quality. Thus growing economies should promote the co-existence of foreign direct invested MNEs with domestic firm evolution to promote knowledge spillover, labour mobility and supply chain evolution.

(iii) It is appealing to find that China even with initial meagre domestic installations has demonstrated its conspicuous strength through enormous production capability to become the world leading manufacturer and exporter of solar PV cells and modules.

(iv) Presently the West (USA and Europe) views China's price reduction capability as an act of dumping of the solar PV products below the manufacturing price. If proven, this may affect the China's exports. Secondly, China's energy mix presently shows solar PV sources constitutes not even 1 %. Hence it is recommended that China can develop the domestic market to sufficient level such that it meets their growing energy needs, ensure a sustainable growth for its solar PV manufacturing industry, and ensure the country to become a decarbonized region.

(v) Having understood the technology relevance between any two different industries, growing economies should promote geographic proximity in accordance to the technology distance between two industries. This will aid knowledge spillover through labour mobility and easy supply chain formation. For example, the upcoming LED factories and sensor manufacturing industries of China can benefit from similar knowledge spillage of semiconductor industry.

Similar investigations taking a conspicuous development of China's wind power development advancement is strongly recommended as a next step together with further analysis of learning processes as well as investigate its roots of knowledge sources.

Appendices

Table A2-1 List of China solar firms (*2011*)

	Registered Name	Capacity (in MW)	Employees	Registered Year
1	Suntech Power Holdings	2400	8000	2001
2	Yingli Green Energy	2000	6000	1998
3	JA Solar Holdings, Co., Ltd.	3000	5458	2005
4	Motech Industries Inc	2000	1386	1981
5	Trina Solar Limited	1900	4600	1997
7	Hanwha SolarOne (formerly Solarfun)	1300	3989	2004
8	Neo Solar Power (NSP)	1300	500	2009
9	E-Ton Solar Tech. Co., Ltd	700	900	2001
10	China Sunergy Co., Ltd.	400	1800	2004
11	SHENZHEN TOPRAYSOLAR Co.,Ltd.(TOPRAYSOLAR)	190	848	2002
	Eging Technology Co., Ltd. Changzhou	250	800	2003
14	JETION SOLAR HOLDINGS LIMITED	250	900	2007
15	Anhui Tianyi Solar Energy Co., LTD	300	700	2010
16	Zhengrong Solar Company	170	600	2010
17	Bright solar energy Co, Ltd	400	500	2008
18	Best Solar Co., LTD	250	800	2007
19	BOMEX SOLAR NEW ENERGY CO.,LTD	150	600	2008
20	Nesl Solar Company	400	900	2006
21	UE Solar Co.,ltd	300	900	2007
22	Daqo New Energy Co.,Ltd	200	610	2006
23	Aode New Energy Co., Ltd	300	1200	2007
24	Risen Energy Co.,Ltd	300	1000	2002
25	Dongguan Quoncion Solar Energy Co.,Ltd	150	1000	2003
26	Jiangsu Jiao Sheng Photovoltaic Technology Co. Ltd	300	1300	2004
27	Dongying Fuda Solar Power Co.,Ltd	200	800	2007
28	Konca Solar (Wuxi) Co., Ltd.	100	1300	2005
29	Jiangyin Hareon Solar Technology Co., Ltd.	250	1500	2004
30	Hangzhou Blue Sun Solar Energy Technology Co.,Ltd	600	1500	2007
31	Chinaland Solar Company	200	1000	2007
32	Hebei JG Solar Energy Technology Co., Ltd.	200	1000	2007
33	Huayu electro-optic science and technology Limited	200	800	2009
34	GrandPower Solar INC	300	1500	2010
35	Hengji PV-Tech Energy Co.,ltd	250	1500	2007
36	Jiawei Solar China Co.,Ltd	500	800	1993
37	WinSun New Energy Co.,Ltd	350	1500	2008
38	Jiangsu Runda PV Co., Ltd.	200	1000	2009
39	Jiangsu Runner PV Technology Co., Ltd	300	1500	2009
40	Eoplly New Energy Technology Co.,Ltd	300	1500	2006
41	Sun Earth Solar Co.,Ltd	420	2000	1999
42	Realforce Power Co., Ltd	1250	1000	1999
43	Shandong Sunneeg Solar Power Co., Ltd	1100	900	2008

44	Shandong Thai haidai photovoltaic technology Co., LTD	200	700	1999
45	Shanxi Rishengda Solar Company	500	800	1999
46	Shanghai Alex Solar Industry	400	500	2007
47	SHANGHAI PUBSOLAR CO., LTD	150	1000	2005
48	Foxconn Technology Group	150	50000	1974
49	Shanghai Prairiesun Solar Technology Co., Ltd	700	350	2009
50	Winchance Solar (Fujian) Technology Co., Ltd	300	700	2007
51	Wuhu Mingyuan NewEnergy Technology Co., Ltd	200	700	2005
52	Jolar Technology Corporation	280	1000	2008
53	Upsolar Co. Ltd	300	1000	2006
54	Yunnan Tianda Photovoltaic Co., Ltd	400	1000	1975
55	Perfect Energy Technology Exhibition (Shanghai) Co., Ltd	400	1300	1994
56	Perlight Solar Co., Ltd	200	1300	2006
57	Zhejiang BLD Solar Technology Co.,LTD	150	800	2008
58	ZheJiang Beyondsun PV Co., Ltd	250	900	2009
59	CN Solar Technology Co., LTD	215	700	2007
60	Zhejiang Guangyi Optical Energy Technologies Co., Ltd	250	700	2007
61	Zhejiang Hengsheng Photovoltaic Technology Co., Ltd	250	1000	2007
62	Zhejiang Topoint Photovoltaic Co.,Ltd.	300	2000	2007
63	Leye Photovoltaic Co.,Ltd	200	1000	2009
64	Zhejiang Riyuewang Solar Technology Co., Ltd.	150	600	2004
65	ZHEJIANG RDM TECHNOLOGY CO.,LTD	120	600	2010
66	Longbai Group Zhejiang Co., Ltd	100	700	2007
67	Zhejiang Shinew Photoelectronic Technology Co.,Ltd.	200	900	2008
68	ZG-Cells Group (Hong Kong) Limited	400	900	2008
69	Zhejiang Aurora PV Solar Co., Ltd	200	900	2008
70	The 48th Research Institute	1000	1000	1964
71	CNPV Dongying Solar Power Co., Ltd	600	1000	2006
72	Zhongheng Technology (Tangshan) Caofeidian Co., Ltd	150	1000	2009
73	Chinalight Solar Co. Ltd	200	400	2005
74	ET Solar Group	250	3000	2007

Source: QResearch (2012).

Table A2-2 List of Foreign solar firms (*2011*)

Firm	Registered Name	Employees	Capacity (in MW)	Registered Year
1	First Solar, Inc.	4700	4000	1999
2	Q-Cells Associate Companies	2750	150	1999
3	Sharp Corporation	54000	1100	1963
4	KYOCERA Solar, part of KYOCERA Corporation.	66,496	1000	1996
5	SunPower Corporation.	5400	1300	1985
6	Sanyo solar	230	1000	1975
7	REC Solar	3400	400	1996
8	SolarWorld AG	2000	1250	1998
9	Isofoton	800	550	1981

Source: QResearch (2012).

Table A2-3 Major PV companies' knowledge sources in China (*2007*)

Firm name	wafer and ingot	PV module cell/module	PV system assembly	Notes on collaboration
Beijing Corona Technology Company ltd.			Yes	Controlled by chinese academy of sciences
Beijing new energy Technology Development Co.			Yes	Controlled by the Energy Research Institute, National development and Reform Commision
Soltech Corp		Yes		A Chinese US Taiwan joint venture
Beijing Yiwei Fengla Electronic Technology Co.			Yes	
Hebei Jinglong Group	Yes	Yes		A JA Solar Shareholder
Baoding Tianwei Yingli New Energy Resources co.	Yes	Yes	Yes	Working with Yingli
Hebei Ningjin Songgong Semiconductor Co.	Yes			A Hebei Jinglong group member
Tianjin Jinneng Solar cell co.		Yes		A pilot enterprise approved by the state development planning commisision to produce thin film non siliccon PV cells.
Jinzhou Xinri Silicon Materials Co.	Yes			Working with Monosilicon/ingot
JA solar Co.		Yes		JA Solar
LDK Solar Energy High-Tech co.	Yes		Yes	
Jingxing Electronic Material	Yes			A Hebei Jinglong group member
Linuo PV High Tech Co. (Shandong)		Yes		
Suntech Power Co.		Yes	Yes	Working with Suntech
Trina Solar Energy Co. (Changzhou)		Yes		
Nanjing China Power PV Ltd.		Yes		
Solarfun Co. (Jiangsu)		Yes		Working with Solarfun
Shanghai Solar Energy Science and Tec		Yes		
Shanghai Chaori Energy Science and Technology Co.		Yes		
Shanghai Linyang Solar energy Science and Technology Co.		Yes		Working with Solarfun
Zhengjiang Renesola Co.	Yes			Renesolar Ltd.
Ningbo Solar electric Power Co.		Yes		
Shenzhen topray Solar Co.		Yes		Products include solar water heaters as well.
Shenzhen Chuangyi Science and Technology Development co.		Yes		Thin film non-silicon cells, BIPV
Shenzhen Jiawei Industries Co.		Yes		Products include solar lamps as well.
Yunan Tianda Photovoltaic Co.		Yes		
China Xinjiang SunOasis Co.		Yes	Yes	Cooperating with Tsing Hua University

Source: The Renewable Energy Industry Development Report 2008.

Table A2-4 List of electronics industries in China (2005)

Category	Kf/K	K/L	K/Y	Revenue/Firm (RMB 10K)
Complete Radar manufacture	1.2311	1.9147	0.3122	59177
Special equipment and parts for Radar	1.7437	0.8224	1.5431	2321
Wireless transmission equipment manufacture	21.8544	5.1273	2.1657	30878
Exchange equipment manufacture	30.4337	8.4946	0.8575	24173
Wire communication terminal equipment	38.1237	3.113	1.1884	5812
wireless communication terminal equipment	32.8871	5.9971	0.2986	54825
Other communicable equipment	16.2522	3.6114	1.4	6457
Broadcast and TV equipment manufacture	2.9027	2.3128	2.5941	1705
TV set manufacture	28.4263	5.249	1.1604	30985
Radio and recorder manufacture	36.7231	2.9793	1.2106	10011
Video manufacture	47.223	17.3272	2.6633	42123
Other Broadcast equipment	21.777	4.1677	2.5588	2030
Complete computer manufacture	15.1064	5.0432	0.9118	24025
Computer exterior equipment manufacture	46.144	5.7214	0.9432	21388
Computer necessary accessories manufacture	16.1847	5.5873	1.0484	4654
Software manufacture	15.3015	7.5641	0.7766	5254
Calculator manufacture	45.7108	2.0051	1.2017	15477
Other computer accessories	69.5599	10.2727	2.1352	10099
Electronic micro-electrical machine	29.059	2.8293	2.668	3635
Electronic electrical wire and cable manufacture	12.0793	4.0294	0.9969	8008
Electronic storage battery	20.7358	1.6611	1.6275	5480
Electronic dry battery	78.8808	9.3314	1.5183	9131
Electronic component manufacture	29.4864	2.7553	1.3959	2821
Electronic component special material	39.4012	4.0928	2.5573	1872
Other electronic components	33.3621	2.1594	1.2209	1998
Electronic measuring instrument manufacture	6.0632	2.41	1.9358	1246
Others electronic measuring equipment accessories	23.0276	3.2736	1.4003	1848
Electronic special equipment manufacture	29.7506	2.6823	1.9611	2160
Electronic industrial mould and gear manufacture	24.1003	2.1395	2.1287	470
Others electronics special equipment accessories	19.352	2.4677	1.0885	2232
Refrigerator manufacture	24.9129	8.2622	1.7204	42421
Electric heating equipment	64.6789	3.9024	2.0183	8964
Electronic toy manufacture	28.8084	1.3434	1.5915	1669
Other household electronic appliance	42.9226	6.3778	1.3706	12547
Other household accessories	35.7514	3.739	1.5036	1692
Bulb manufacture	42.4407	4.0576	1.5461	2215
Electrical vacuum valve device manufacture	33.0177	9.7229	1.8327	39140
Semiconductor device manufacture	30.4874	2.3629	2.0408	1447
Integrated circuit manufacture	42.9847	11.1162	3.182	8984
Electronic device material manufacture	34.8098	5.7394	1.5287	6042
Other electronic device accessories	50.9389	8.3568	1.9293	7197

Source: Yingqi Wei, Xiaming Liu, Page 97, Foreign direct investment in China, Edward Elgar, USA, 2001. Notes: Kf/K is the share of foreign capital (%), K/L is the capital to labour ratio, K/Y is the capital to output ratatio, firm size is measured by the industrial sales revenue (RMB 10000) divided by the number of firms in each sub-sector.

Table A2-5 Dominant technologies Common to both global Semiconductor & Solar industries' patents (*2012*)

	Semiconductor Industry		Solar Industry	
Technology (IPC code)	Patent count	Patent share (out of top 100 technologies)	Patent Count	Patent share (out of top 100 technologies)
A01N	638	0.59%	169	0.23%
A61B	506	0.47%	172	0.24%
A61F	495	0.46%	188	0.26%
A61K	5412	5.04%	2364	3.26%
A61L	496	0.46%	177	0.24%
A61N	167	0.16%	99	0.14%
A61P	1399	1.30%	1174	1.62%
A61Q	656	0.61%	702	0.97%
B01D	895	0.83%	385	0.53%
B01J	3038	2.83%	998	1.38%
B05D	714	0.66%	933	1.29%
B22F	289	0.27%	183	0.25%
B23K	513	0.48%	258	0.36%
B24B	312	0.29%	80	0.11%
B24D	267	0.25%	82	0.11%
B29C	801	0.75%	471	0.65%
B29D	181	0.17%	87	0.12%
B32B	2048	1.91%	2593	3.58%
B41J	686	0.64%	92	0.13%
B41M	396	0.37%	140	0.19%
B65D	229	0.21%	97	0.13%
B81C	331	0.31%	87	0.12%
B82B	212	0.20%	556	0.77%
C01B	1615	1.50%	1610	2.22%
C01F	207	0.19%	122	0.17%
C01G	465	0.43%	681	0.94%
C02F	135	0.13%	234	0.32%
C03B	256	0.24%	130	0.18%
C03C	844	0.79%	893	1.23%
C04B	1425	1.33%	453	0.62%
C07C	2885	2.69%	753	1.04%
C07D	4310	4.01%	1529	2.11%
C07F	1270	1.18%	562	0.78%
C07H	562	0.52%	151	0.21%
C07K	629	0.59%	256	0.35%
C08F	2322	2.16%	698	0.96%
C08G	1408	1.31%	1052	1.45%
C08J	1022	0.95%	844	1.16%
C08K	1318	1.23%	1355	1.87%
C08L	2288	2.13%	1820	2.51%
C09B	210	0.20%	373	0.51%
C09C	299	0.28%	179	0.25%
C09D	793	0.74%	817	1.13%
C09J	274	0.26%	366	0.50%
C09K	1651	1.54%	1797	2.48%
C11D	670	0.62%	130	0.18%
C12N	780	0.73%	268	0.37%
C12P	216	0.20%	136	0.19%

C12Q	637	0.59%	145	0.20%
C22C	547	0.51%	198	0.27%
C23C	2557	2.38%	2768	3.82%
C23F	193	0.18%	117	0.16%
C25D	157	0.15%	206	0.28%
C30B	2088	1.94%	2008	2.77%
D01F	330	0.31%	194	0.27%
E21B	277	0.26%	426	0.59%
G01J	405	0.38%	177	0.24%
G01N	2005	1.87%	543	0.75%
G01R	486	0.45%	157	0.22%
G02B	2496	2.32%	1407	1.94%
G02F	2971	2.77%	1373	1.89%
G03C	680	0.63%	112	0.15%
G03F	1033	0.96%	210	0.29%
G03G	1298	1.21%	322	0.44%
G06F	428	0.40%	247	0.34%
G06K	261	0.24%	178	0.25%
G09F	384	0.36%	223	0.31%
G09G	1030	0.96%	229	0.32%
G11B	1555	1.45%	305	0.42%
G11C	1705	1.59%	224	0.31%
H01B	548	0.51%	1405	1.94%
H01G	284	0.26%	691	0.95%
H01J	1482	1.38%	548	0.76%
H01L	22732	21.16%	21627	29.84%
H01M	861	0.80%	1867	2.58%
H01S	921	0.86%	449	0.62%
H02N	212	0.20%	360	0.50%
H04N	502	0.47%	110	0.15%
H05B	782	0.73%	750	1.03%
H05K	678	0.63%	390	0.54%

Source: Computed from Thomson Database (2012).

Table A2-6 Cronology of significant PV policies in China

Year	Organization	Policy	Key Points
2005	Renewable energy law	Renewable energy law	The NPC passed the law in 2005 for its implementation in 2006.
2005	National Development and Reform Commision	Renewable energy industry development instruction list	The list spells out 88 renewable energy areas including 35 PV areas subject to support.
2006	National Development and Reform Commision	Provisional administrative measures on pricing and cost sharing for renewable energy power generation.	The document covers how to calculate feed in tariff for renewable energy and the feed in tariff system.
2006	National Development and Reform Commision	Adminstrative provisions for renewable energy power generation.	The document specifies the scope of management responsibility for the central and local goverments, the scope of responsibility fore central government organizations, and the responsibilities and obligations of electric power generation and transmission companies.
2006	Ministry of finance	Provisional administrative measures on the renewable energy development fund.	the document specifies the scope for support from the Renewable energy development fund and explains the procedures for applications for financial support and their acceptance. It also clarifies financial support methods and the scope of their applications and specifies the responsibility for monitoring and reporting uses of the fund.
2006	Ministry of finance and ministry of construction	Provisional adminstrative measures on the fund for renewable energy applications for buildings.	The document specifies how local government regulatory organizations should consider applications for subsidies for projects to use renewable energy in buildings and how they should appropriate those subsidies.
2006	Ministry of finance and ministry of construction	Instructions on deliberation process of pilot projects for renewable energy applications for buildings	The document specifies how local government regulatory organizations should deliberate pilot projects. Approved projects will announced annually.
2007	Ministry of science and technology, national development and reform commision.	Renewable energy and new energy international cooperation plan.	The plan promotes international cooperation in research on renewable energy and new energy priorities.
2007	National Development and Reform Commision	Temporary measures of regulation on renewable energy surcharge.	The document provides for how electric power transmission companies should collect and use renewable energy surcharges.
2007	National Development and Reform Commision	Medium to long term renewable energy development plan.	The plan sets renewable energy development goals for 2010 and 2020.

2008	National Development and Reform Commision	11th five year development plan for renewable energy.	Based on the medium to long term renewable energy development plan, the document sets renewable energy development goals (including modified ones) for 2010 and provides for specific action plans.
2009	Ministry of finance and ministry of construction.	Building PV subsidy policy	A subsidy of 2.90 US dollar per watt (in 2009) is provided for large scale (50 KW or larger) PV panels that meet minimum conditions (energy conversion efficiency at 16% for monosilicon PV cells , 14% for polysilicon PV cells and 6% for non silicon PV cells.
2009	Ministry of finance	Golden sun pilot project	The document provides for subsidies to be given to 500 MW or larger PV plant projects in the coming two or three years. A subsidy will cover 50% of a total project investment amount in principle. The percentage may be raised to 70% for some unelectrified regions.
2009	National People's congress	Revision of the renewable energy law.	The revised law was passed on December 26, 2009.

Source: "China energy development report 2009" and Kan Sichao, Chinese photovoltaic market and industry outlook, IEEJ April 2010.

Chapter 3

China's Leap into Wind Turbine Industry: Coevolution of Wind Turbine Manufacturing and Adoption into its Energy Sources.

Abstract

China has demonstrated as the world leading wind energy adopter in last five years and this can be attributed to its conspicuous strength to indigenously design and produce high performance wind turbine. This has transformed it as the world leading wind turbine producer with increased functionality and globally acceptable performance and quality. Empirical study shows the early involvement of the domestic manufacturing firms in this technology search and assimilation has helped develop indigenous product and co-evolve a domestic value chain. The early adoption of latest technologies into the indigenous product arise as a result of technology sourcing from foreign firms but early involvement of domestic players helped in early functionality development of the products through enhanced knowledge identification, absorption, assimilation and acclimatization. Success of this fusion of foreign technologies with domestic know-how was observed in increasing indigenous market share of domestic firms which can be attributed to a joint work between industry's intensive effort to learning and substitution for exploring new business and government's catalytic role to induce right partnership and players in this technology transfer for the attainment of decarbonisation society for nation's sustainability. Key theoretical implications are: (1) importance of domestic production chain in the technology diffusion (2) effective technology acquisition and assimilation through early domestic firm engagement (3) effect of relevant domestic firms involvement in technology transfer partnership to induce inter-industry spillovers (4) a unique patent-metrics methodology to evaluate assimilation capacity between actors (5) a possible framework for growing economy to develop new functionalities.

3.1 Introduction

3.1.1 China's conspicuous strength in wind turbine industry

Against the ambition of decarbonisation, China has become the world leader in wind energy adoption in 2010, to support its energy needs. In 2005, it had a meagre percentage of less than 1% of world installation and since 2007 it has demonstrated a significant rise in adoption reaching a cumulative installed capacity of 62 GW by 2011, which equates to more than 12 % of world installations[1]. Fig. 3.1 shows the cumulative installation of wind turbines in various countries, which clearly shows China's dominance in wind turbine adoption that has crossed USA in 2010 and became the world leader in 2011. This was primarily possible due to: (a) its rich land resources that amount to a terrestrial area of 200,000 square Km and wind energy being 100 Giga watt[2], (b) its internal demand for clean energy for a sustainable economic growth and (c) its parallel growth of manufacturing industry which co-evolved from inception to full stage supply chain within a short time span of less than a decade. Currently, 29 provinces and regions in Mainland China have wind farms. Inner Mongolia has 13.85 GW of installed capacity, the largest in China, closely followed by Gansu, Hebei and Liaoning Provinces[3] . China is the first nation outside of Europe to build offshore wind farms. By the end of 2010, its total installed capacity of offshore wind farms grew about 150MW and the total installed capacity of China's wind power sector is expected to reach 100 to 150GW (GWEC 2012). This clearly demonstrates its conspicuous strength and determination to achieve full-fledged wind turbine adoption into energy sources.

[1]Wu Qi, China takes grid-connected wind power, Windpower Monthly, 25 July 2012, http://www.windpowermonthly.com/News/MostRead/1142602/China-takes-grid-connected-wind-power-52GW/

[2] Source: Research in china (2012),

[3] China wind power outlook, 2011, www.greenpeace.cn

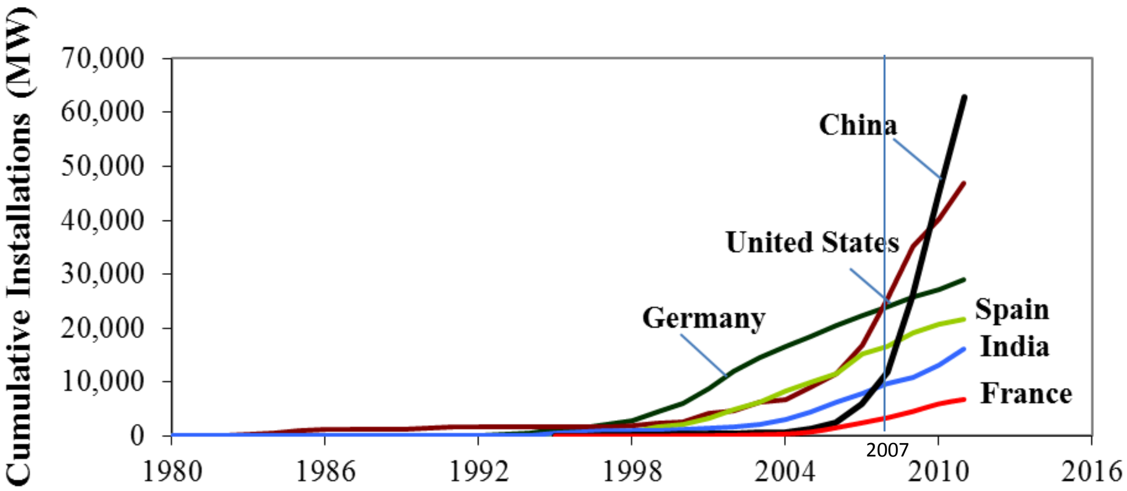


Figure 3.1. Cumulative installation of wind turbine in different countries (*2011*).

Source: Earth Policy Institute - www.earth-policy.org (2012).

3.1.2 China wind turbine technology and production chain

This study focuses on the "*Horizontal axis wind turbine*" as shown in Fig. 3.2 which has become the dominant design among the various design combinations and generally has more than 8000 components. The main components are blades, gearbox, generator, pitch and yaw mechanisms which are sub-modules by themselves and are as listed in Table 3.1 with their cost fraction with respect to total turbine cost. Today most of the China's domestic wind turbine manufacturers focus on system integration and increasingly favour on their local suppliers for key components.

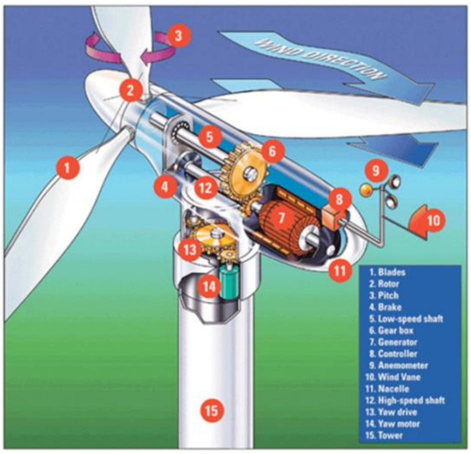


Figure 3.2. Typical horizontal axis wind turbine with its major components.

Source: Srikanth et al. (2010).

The production chain for wind turbine manufacturing is as shown in Fig. 3.3.1 and 3.3.2, where the raw materials such as steel and carbon fiber is converted into intermediate products and further into useful components and are formed into subcomponents before being integrated into wind turbines. It may be noted that as the turbine size increases the energy capture capacity increases[4] which demand for proportional increase in the respective component which challenges the whole supply chain. Thus the whole supply chain formation and its production capability in terms of maximum product size and production volume can become a barrier to the whole production chain diffusion if it cannot meet the production needs and to the wind turbine technology diffusion into the domestic market.

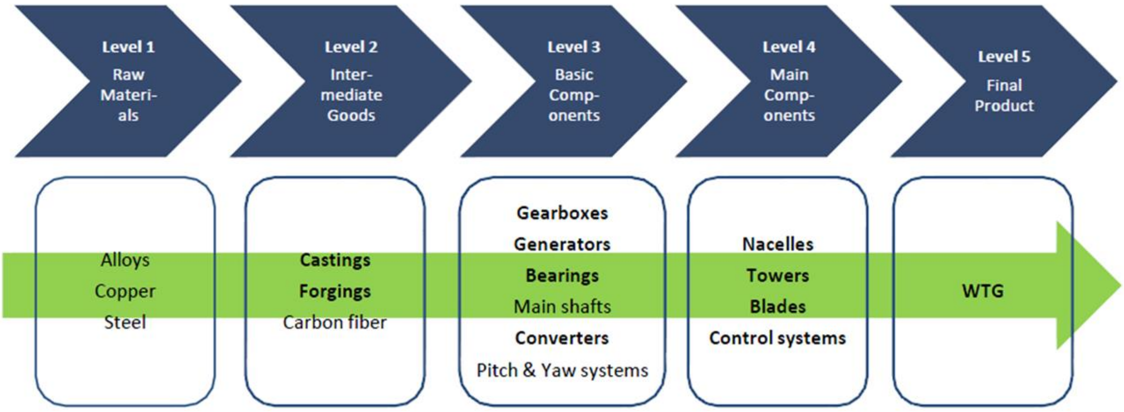


Fig. 3.3.1 China's various players in the wind turbine production chain.

[4] N. Srikanth, J. L. Funk, Geometric scaling and long-run reductions in cost: The case of wind turbines, Proceedings of the 1st International Technology Management Conference, ITMC 2011 , art. no. 5996044, 2011, pp. 691-696. (Presently being reviewed in Energy Policy journal).
N. Srikanth, Composite challenges in wind turbine application, JEC Composite, Vol. 47, 2008.

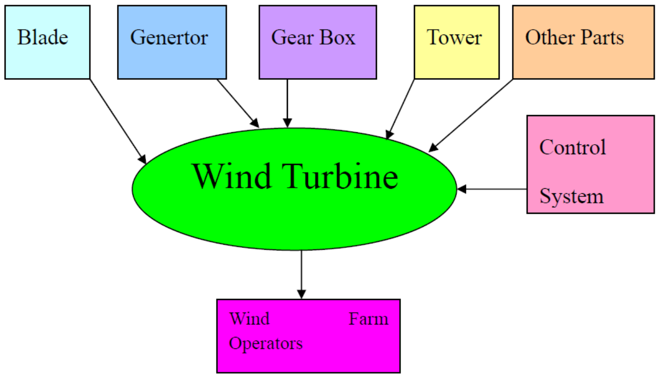


Fig. 3.3.2. China's domestic players' as system integrators in wind turbine production chain.

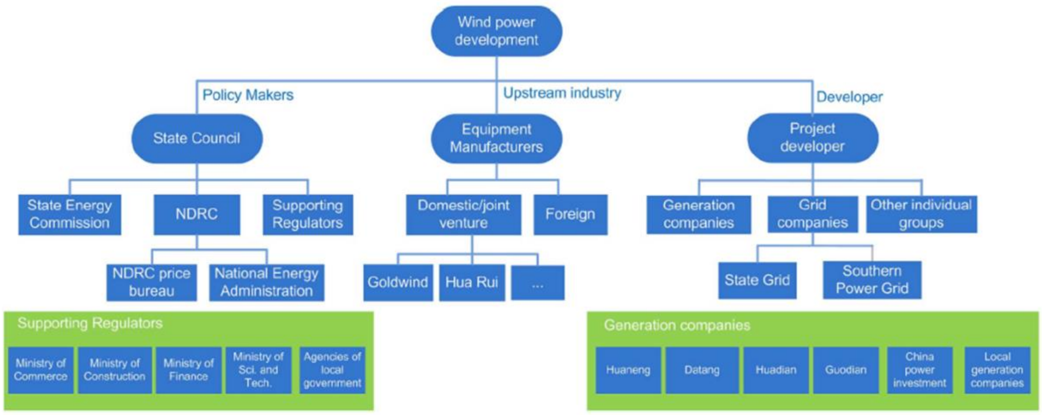


Figure 3.4. Structure of institutional system for China wind power.

Table 3.1 lists the cost share of the various key components. Hence in this study, the sources of key components in terms of suppliers and technology sources for indigenization is studied. China has developed an overall institutional system (see figure 3.4) involving the key actors of the nation to support the wind turbine production and adoption.

Table 3.1 Cost fraction of the main components in a wind turbine

No.	Components	Cost percentage (%)
1	Tower	26.30
2	Rotor blades	22.20
3	Gearbox	12.91
4	Power converter	5.01
5	Transformer	3.59
6	Generator	3.44
7	Main frame	2.80
8	Pitch system	2.66
9	Main shaft	1.91
10	Rotor hub	1.37
11	Nacelle housing	1.35
12	Brake system	1.32
13	Yaw system	1.25
14	Rotor bearings	1.22
15	Screws	1.04
16	Cables	0.96
17	Others	10.70
	Total	**100.00**

Source: GWEC (2009).

3.1.3 China wind turbine industry

China’s wind turbine equipment manufacturing has industrialized rapidly since 2006 and has further matured towards delivering large turbines with international quality by 2009. During 2006, the government set their policies towards a national goal of 10 GW expectations by 2010 and this target drove the domestic turbine manufacturers to accelerate their industrial expansion for two years in succession and scale their products. At global level wind power was relatively mature in technology only below 1MW capacity during year 2000 and the technology resided heavily with the advanced nations when China decided to enter into this industry (viz., Denmark, Germany, USA, Holland, etc.,). By 2005, there were few Chinese domestic wind turbine manufacturers who faced fierce market competition due to their production capacity and incompetent technology (quantified in terms of product size). They have grown significantly and by 2009 China had a total cumulative installed capacity of 25.8 GW (GWEC 2009a), in terms of cumulative installed capacity, the top three, five and ten companies respectively accounted for 55 %, 70 % and 85%.

The dominant turbine manufacturers, includes Goldwind (GW), Sinovel Wind Power (SI), Guodian United Power (UP) and Guangdong Mingyang (MY), have all established the necessary know-how to manufacture and have placed plants close to their wind farm customers. This reduces their transportation costs and ensures the timing of deliveries, which in turn had a positive influence on the development of the enterprise. In addition, regional governments motivated with supplemental policies to encourage the machine manufacturers to build plants in order to speed up the development of a local manufacturing industry and increase their tax revenue. Such local industrial support systems helped in the availability of human resources, supply chain formation and land resources to establish manufacturing bases.

Table 3.2 Newly Installed and Cumulative Market Share of top 10 Manufacturers (*2009*)

Firm name	Annual installation		Firm name	Cumulative installation	
	Capacity (MW)	Market share (%)		Capacity (MW)	Market share (%)
Sinovel	3495.00	25.32	Sinovel	5,652.00	21.90
Goldwind	2722.00	19.72	Goldwind	5,343.85	20.70
Dongfang	2035.50	14.75	Dongfang	3,328.50	12.90
United Power	768.00	5.56	Vestas	2,011.50	7.80
Mingyang	748.50	5.42	Gamesa	1,828.75	7.10
Vestas	608.75	4.41	GE	957.00	3.70
XEMC-wind	454.00	3.29	Mingyang	895.50	3.50
GE	322.50	2.34	XEMC-wind	792.00	3.10
Suzlon	293.00	2.12	Suzlon	605.25	2.30
Gamesa	276.25	2.00	Windey	594.00	2.30
Others	2079.71	15.07	Others	3,814.45	14.80
Total	13803.21	100.00	Total	25,805.30	100.00

Source: GWEC (2009).

In Year 2007, the China wind turbine manufacturers' efforts were:

(i) Xinjiang Goldwind Co. China's largest wind turbine manufacturer with a 20% market share manufactures 600 kilowatt and 750 kilowatt wind turbines and has made a prototype of 1.2 megawatt wind turbine with more than 400 units in operation.

(ii) Zhejiang Yunda Co. Manufactures 120 kilowatt, 200 kilowatt, 250 kilowatt and 750 kilowatt wind turbines with more than 45 units in operation.

(iii) Shenyang Industry University (Shenxin Co.) Manufactures 75 kilowatt and 200 kilowatt wind turbines and has been developing a 1 megawatt wind turbine.

(iv) Wandian Co. manufactures 600 kilowatt wind turbines with 6 units in operation.

(v) Shanghai Bluesky Co. manufactures 300 kilowatts wind turbines with 2 units in operation.

(vi) Dalian Heavy Machinery has been developing and manufacturing 1.5 megawatt wind turbines with German-based Furlander.

These turbines were aiming for the local wind farms in China which were being built by more than 30 Chinese companies, including the five large power generation companies. The total investment exceeded USD 1.24 billion. The largest wind power investor was Longyuan Power Co. under China Guodian Corporation. By the end of 2005, the installed capacity of wind power under Longyuan Power's operation reached 416 megawatts, 40% of the national total, and has another 564 megawatts of new capacity under construction as of 2012.

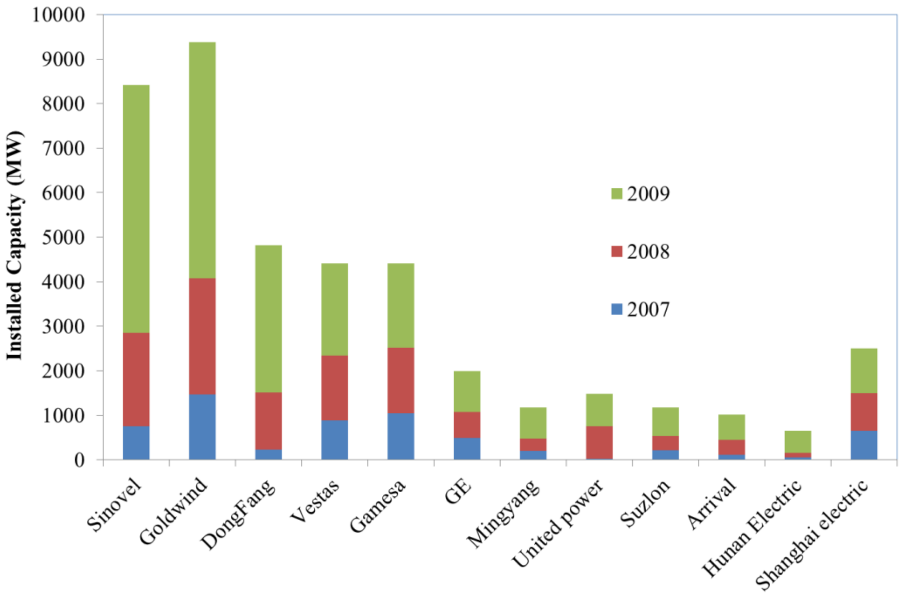


Figure 3.5. Local manufacturer's installations in China (*2007-2009*).

Source: China wind energy association (2010).

By 2009, the Chinese wind turbine manufacturers have reached world competence as shown in Table 3.2 and Fig. 3.5. The indigenization of the wind turbine industry with constant improvement in the domestic firms' skills has resulted in increasing market share of domestic firms with growing years, as listed in Table 3.3. One outcome of this skill improvement is the increase in product size as shown in Fig. 3.6 that exhibits itself in the average product size increase delivered to wind farms.

In China, the large cost drivers in WTG manufacturing are in downstream components such as gearboxes, blades and control systems (refer Table 3.1). This is a result of high investment costs and higher technical barriers in reaching world class quality. Other key components such as castings, forgings and towers have been mastered by domestic heavy industries while local electric and power production sectors also have relatively advanced technologies for generators. For example, the gearbox technology is a key component in a wind turbine and a firms' manufacturing capability decides the maximum size[5] that it could deliver. The existence of automotive and marine (shipping and offshore oil rig) industries in China helped to meet the domestic wind industry needs by forming the necessary supply chain and providing the gearbox components with required performance and quality. Hence their people and firm's know-how became relevant to the wind turbine industry.

Table 3.3 Market share breakdown of China's newly installed capacity (*2004-2010*): (%)

Year	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Foreign enterprises	75	70	55.1	42.49	24.4	13	10
Joint venture and domestic enterprises	25	30	44.9	55.91	75.6	87	90

Source: Li et al. (2011).

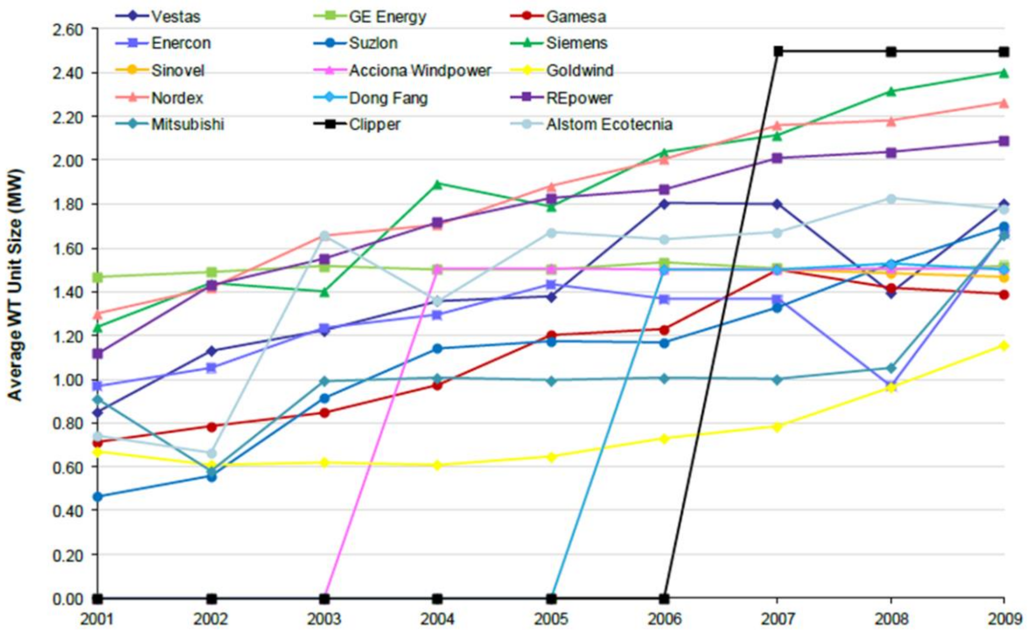


Figure 3.6 Average wind turbine size by top 15 firms at global level (*2001-2009*).

Source: IHS emerging energy research (2011).

[5] N. Srikanth, Material adoption practices of wind industry and its effect on product scaling trends, Proceedings of the 1st International Technology Management Conference, ITMC 2011 , art. no. 5996045, 2011, pp. 697-705.

This paper explores the strategies used by the domestic wind turbine manufacturing firms in China to develop indigenous products to reach world class. Section 3.2 puts forth the hypothesis drawn from the observation and in section 3.3 an analytical framework is constructed. Section 3.4 demonstrates through empirical and qualitative analysis to confirm these hypotheses about fusion of technology spillover from domestic manufacturing firms of the east and global wind turbine firms' explicit knowledge of the west to evolve and grow the indigenous domestic wind turbine industry. Qualitative analysis begins by reviewing the evolution and current status of wind power development and turns to the current industry leaders. It then examines how these firms acquired the technological know-how and Intellectual Property Rights (IPR) associated with their respective wind turbine designs, how the domestic and international contexts in which these companies acquired their technologies and integrated with their domestic know-how. In section 3.5, it concludes with an assessment of the outlook for the future development of the emerging economies' wind power industries and a discussion of the policy lessons for facilitating low-carbon technology transfer that can be drawn from this study.

3.2 Hypotheses

China's wind industry has emerged and demonstrated conspicuous strength through developing indigenous product and supply and accelerating diffusion of wind energy to create a domestic market. Based on the foregoing observations, the following hypothesis is postulated:

(i) The conspicuous strength resulted from learning the technical know-how and global best practices from foreign partners (“West”) through fusing with its domestic manufacturing industry’s’ tacit knowledge and the intensive effort in learning, absorbing and assimilating from global partners (“East”) that lead to indigenous capabilities (technologies, human capabilities and increased product performance).

(ii) Exploring new solutions to support domestic wind industry needs was through joint work between domestic industry’s intensive effort in learning, absorbing and assimilating from global partners along with the government’s catalytic role for the attainment of decarbonisation society for nation’s sustainability.

(iii) The dynamic relationship between innovation and institutional factors that helped to achieve the wind energy adoption and domestic market creation and further supporting through indigenous wind turbine production is the essence of co-evolutionary acclimatization stage, which is the final stage of the growth framework.

3.3 Literature review

Innovation is costly, risky and path dependent. Hence developing nations such as China and India have been lagging behind the developed nations during 1980s. However their recent economic progress through industrial development has interested the researchers.

Literature claims endogenous growth theory explains these emerging nations’ performance much better than neoclassical growth theory. The former is efficient as it holds that economic growth is primarily due to endogenous factors and not external forces. Thus it relates the R&D activities and investments to human capital, innovation and knowledge as the significant contributor to the long run growth rate. Labor capital formation and technology creation are usually seen as increasing returns or atleast as lower bound of diminishing returns to capital (Lai Mingyong et al. (2006)). One of the two popular models is the Investment based growth model which portray growth as associated to the positive externalities of accumulated physical and human capital (Romer (1986, 1987)). The second popular model is the R&D based growth model which portray role of technological progress for creation of economic good. Externalities are a source of increasing returns and productivity growth. In general endogenous growth theory has highlighted the understanding of technological investment, however previous works highlights that international technological spillovers are seldom modelled in the endogenous growth literature. Few exceptions have shown Grossman and Helpman (1991), Rivera Batiz and Romeer (1991), keller (1996) and Aghion and Howitt (1998) who modelled trade liberalization and economic integration on domestic technological change. Technology spillovers arise between firms helping to produce positive effects (Griliches, 1998, Anon 1998) and this arises due to the firm cannot appropriate the returns associated with its R&D capital (Shah 1995).

Griliches (1998) notes that earlier methods of using case study approach which uses a cost-benefit approach to calculate social rates of returns or spillovers, may be useful for only successful industries (Griliches, 1998). Empirical methods are also limited in arriving at production functions (primal approach) or a cost function (dual approach) (Mohnen, 1996). But they fail in capturing the spillover effect on the productivity. There is a need to evolve a quantitative method to arise a measurement method to quantify how much knowledge is spillable? As these spillovers are from non-rival technology and that technology imitation and spillovers are costless, these models have yet not reached key policy implications for emerging nations, possibly due to lack of empirical support (Barro, 1991 and Williamson (1991)).

Even though all countries may attempt towards technology transfer, yet their absorptive capacity becomes important and to further attract FDI and MNCs. It is generally assumed by FDI literature that technology transfer takes place seamlessly between a developed region to a developing region and the host knowledge is generally ignored. Borensztein, Gregorio and Lee(1988) confirmed the importance of host country's absorptive capability from the labor stock's ability to absorb the spillover from foreign firms' technology. Lai et al. (2006) studied 69 developed nations and showed the higher productivity of FDI holds only when the host country has a minimum threshold stock of labour force and the degree of openness on technology absorption. The higher of degree of openness enhances the imitation and learning capability from outside and it also enables the foreign firms to push the domestic firms' R&D investment (Holmes and Schmitz, 2001). This study focuses on the literature gap to describe the relation between international technological spillovers, domestic technology absorptive capability, endogenous technological change and the steady state economic growth rate. Compared to the previous findings, the predictions in this study explain the emerging nations well: the higher degree of openness and labor stock mobility has helped knowledge assimilation well.

3.4 Analytical Framework

3.4.1 Analytical model development

'Cost of energy' (COE) is the key metric of wind industry to adopt new innovations wherein it drives to reduce the capital cost, Overhaul and maintenance costs of wind turbines such that it ensures the in the eyes of a wind park owners and to end customers the price of wind renewables is competitive with fossil fuel based energy. Thus any new adoption of a product innovation or a technological process innovation or business process innovation is being adopted by its potential to reduce the COE. In this study, the adoption of increasing to geometric scale in Chinese wind turbines is investigated due to its potential to reduce COE and enhanced resource utilization (land, grid, etc.) (Srikanth and Funk, 2010).

(1) Learning and scaling of China indigenous wind turbines

As described in previous sections, the price of the Chinese wind turbine is observed to show a decreasing trend with cumulative capacity of production mainly due to the learning coefficient. Secondly with increasing geometric size or product capability the price of the energy is expected to decrease due to Economies of geometric scaling. Thirdly to capture the incentives of government towards larger wind turbines, a mathematical model $\left(a + b(\Phi - \Phi_s)\right)$ is assumed to mimic the government subsidy, where a and b are the constants and Φ is the turbine size in MW and Φ_s is the minimum size beyond which the subsidy is provided (>2.5 MW). The reason being the government would motivate towards larger system to wisely use land resources and grid establishments.

Thus, the price of the wind turbine capital cost can be expressed as a function of:

$$P(t) = F(\lambda(t), \Phi(t), Gs(t)) \quad (3.1)$$

where *P(t):* cumulative installations of domestic wind turbine in MW,

$\lambda(t)$,: dynamic learning coefficient (please refer appendix),

$\Phi(t)$: physical size of domestic turbines, and

$Gs(t)$: government subsidy approximated as:

$$(a + b\ (\Phi(t) - \Phi_s)) \quad (3.2)$$

a, b: coefficients, and

Φ_s: threshold size beyond which incentives are provided by government.

Equation (3.1) can be developed as follows:

$$lnP(t) = A + B\ ln\big(\lambda(t)\big) + C\ ln\big(\Phi(t)\big) + D\ ln\big(Gs(t)\big) \tag{3.3}$$

where *A*, *B*, *C* and *D*: coefficients.

(2) Assimilation ability of domestic firms

The increase in the market share is due to the product size which can be shown to have arisen from the tacit and explicit knowledge of the domestic firm's know-how and the explicit knowledge from the technology transfer and accessing the open technology such as patents of the global wind turbine gearbox that are accessible to the domestic firms. The domestic know-how depends directly on the skilled people's personal knowledge which can be related to the number of inventors of the domestic gearbox patents. Since it is these people who are the knowledge carriers to bring into the new industry with their tacit knowledge from previous related industries and help to assimilate the external knowledge. The present study extends the previous approaches (Cohen and Levinthal,1989; Watanabe et al., 2001), based on the present observations of China's wind industry that a firm makes every effort to maximize the contribution of assimilated spillover technology to production by embodying it into the manufacturing processes.

Provided that wind production (*W*) is governed by the labour and capital resources (*X*), and the gross technology stock of the domestic wind turbine industry (*WT*) can be depicted as follows:

$$W = F(X, WT) \tag{3.4}$$

Furthermore, since advanced wind turbines are technically driven, W can be approximated as follows:

$$W \approx F(WT) \tag{3.5}$$

Thus under a technology driven condition:

$$\ln(W) = c + d\ ln(WT) \tag{3.6}$$

where c and d: coefficients.

Since there should be no substantial difference with respect to assimilation (*z*) of foreign wind patent and similar technology class domestic patents of the domestic firms, the gross wind technology stock (*WT*) can be depicted as:

$$WT = T_i + z\ (FWP + DP) \tag{3.7}$$

where, T_i: indigenous technology stock,

FWP: foreign wind patent stock, and

DP: domestic wind patent stock.

For advanced products such as large scale wind turbines, the product size is proportional to the internal technology stock of the firm consisting of the explicit knowledge such as patents, standards, trade secrets and design guidelines and tacit knowledge of people. Thus, the level of indigenous stock T_i at time *t* can be approximated as a linear relationship between the technology stock and product size Φ_i is assumed as follows:

$$T_i(t) \approx m\Phi_i(t) \tag{3.8}$$

where *m*: coefficient. Substituting equation (3.8) for T_i into equation (3.7) and then substituting equation (3.7) for *WT* into equation (3.6) to determine *W* shows:

$$l\,n(W) = c + d\,ln\left(T_i + z\,(FWP + DP)\right) \tag{3.9a}$$

$$= c + d\,ln\left(m\Phi_i + z\,(FWP + DP)\right) \tag{3.9b}$$

$$= c + d\,ln(m\Phi_i)\left(1 + z\,(FWP + DP)\right) \tag{3.9c}$$

$$= c + d\,ln(m\Phi_i\,) + d\,ln\left(1 + z\,(FWP + DP)/(m\Phi_i)\right) \tag{3.9d}$$

Since $z(FwP + DP)/(m\Phi_i) \ll 1$, e2quation (3.9d) can be approximated as follows:

$$l\,n(W) \approx c + d\,ln(m\Phi_i\,) + d\,z\left((FWP + DP)/(m\Phi_i)\right) \tag{3.9e}$$

$$\equiv c + d\,ln(m\Phi_i\;\;) + e\left((FWP + DP)/(m\Phi_i)\right) \tag{3.9f}$$

where $e = dz$.

Thus taking the ratio of coefficient of second and third term, the domestic wind turbines firms' assimilation value z of using foreign wind firms' patents with know-how of domestic industries can be identified by the following equation:

$$z = (e/d) \tag{3.10}$$

3.4.2 Data construction

The patents of the wind turbines gearbox was obtained and classified based on their technology class. This helped to identify the key technologies to design and build wind turbine filed by the dominant MNC firms was obtained by searching the Thomson database. The available know-how in the domestic firms of China was identified by taking the patents originated in other industries of China (such as shipping, automotive and oil rigs) and similarly classified to identify the key technology classes. The patent count signifies the quantum of knowledge available in each technology class. Also the number of inventors in each technology class was identified as these are the key knowledge transporters between industries. The data concerning market share, turbine capacity and number of turbines of the domestic and foreign turbine manufacturers' installation share was obtained from China wind energy association and the official website and annual reports of the wind turbine firms.

Turbine list prices of 255 turbine models for 1991-2003 was obtained from the data compiled by Junginger (2003) that was adjusted using 2003 GDP deflator (IMF, 2005) with proper exchange rates of Euro as per 2001. Policy details were obtained from Chinese wind industry report and interviews with wind turbine manufacturers.

3.5 Results

3.5.1 Empirical findings

(i) Effects of learning, scaling and government subsidies.

Utilizing backward elimination method (BEM) with 1% statistical significance level, the learning coefficient of the domestic wind turbine manufacturing firm as showing in Fig. 3.7 was found to be:

$$\lambda(t) = (+0.098 + 0.058t - 0.005t^2 + 7.780\ (10)^{-6}t^4)$$

$$(5.22)^{***}\ (24.78)^{***}\ (33.64)^{***}\ (33.26)^{***}$$

*** Significance at the 1% level. *adj*. R^2 = 0.997 (3.11)

Thus, the relationship between price to learning, scaling and government subsidy of China's domestic wind turbine manufacturers is as follows:

$$ln(P(t)) = 3.767 - 0.244\, ln(\lambda(t)) - 0.352\, ln(\Phi(t)) - 0.152\, ln(Gs(t))$$

(7.57)*** (-3.56)*** (-7.04)*** (2.31)***

*** Significance at the 1% level. *adj.* $R^2 = 0.893$ (3.12)

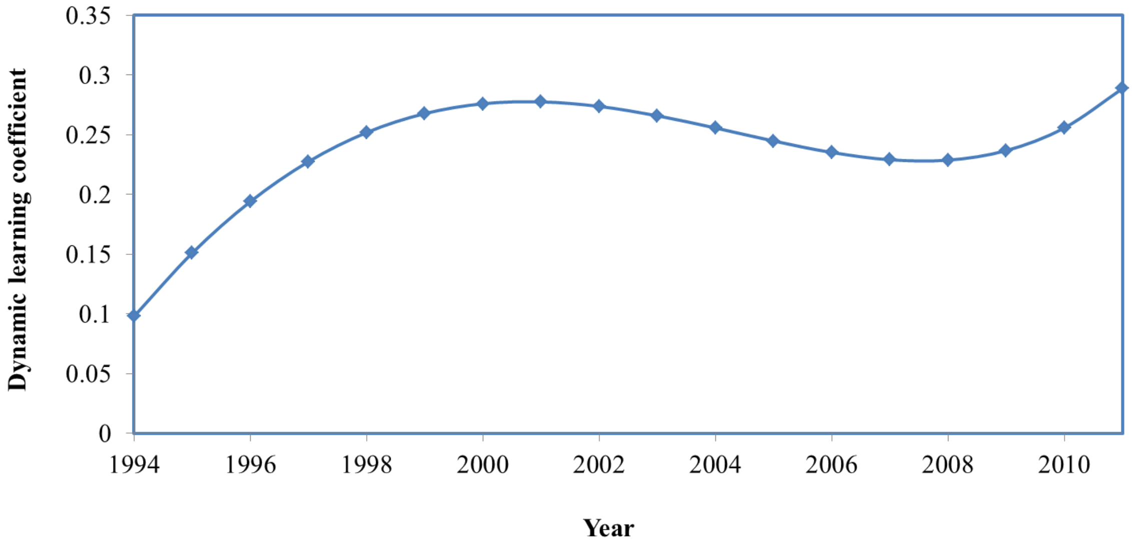


Figure 3.7. Dynamic learning curve of China's wind turbine manufacturing firms.

(ii) Assimilation capability of China domestic wind turbines

From equation (3.9f) the relation of scaling $\Phi(t)$ to the wind turbine production $W(t)$ can be identified as follows:

$$ln(W(t)) = -13.297 + 2.370\, ln(\Phi(t)) + 0.673\, \left((FWP(t) + DP(t))/\Phi(t)\right)$$

(-12.30)***(6.50)*** (8.85)***

*** Significance at the 1% level. *adj.* $R^2 = 0.926$ (3.13)

From equation (3.10) assimilation capability z can be identified as follows:

$$z = (0.673/2.370) = 0.29 \quad (3.14)$$

3.5.2 Qualitative analysis results:

(1) Technology learning from foreign firms and knowledge spill over from local industries

Knowledge of wind turbines is available in the explicit form such as patents, journal papers and technical standards. These are very useful for a new firm to leverage the foreign firm's know-how during its indigenization. In the case of patents, since they are appropriately classified into their IPC technology classes, we could evaluate the required technologies based on the foreign firms gearbox's IPC demands for the varied technologies and thereby compare with domestic gearbox industries' know-how which can be observed in the form of useful patents and products in the respective IPC classes which are evidences of the respective skilled people. Table A3-2 lists the key technologies of foreign wind turbine firms and China's domestic wind turbine firms.

Table 3.4 Evidences of Technology spillover in 15 technologies of wind turbine gearbox

Technology class (IPC)	**China Wind turbine gearbox Patent Count (P_{DW})**	**Foreign Wind turbine firms' patent count (P_{FW})**	**Domestic gearbox firms patents (P_{DP})**

F03D	224	3206	495
F16H	77	580	3388
H02K	29	496	555
H02P	20	645	98
G01M	15	81	232
F16C	11	112	254
F16D	11	11	52
H02J	10	198	185
F03B	9	404	128
F01D	6	209	40
F16N	6	26	76
B23P	5	111	147
B24B	5	42	170
F16J	5	15	132

Source: Thomson database (2012).

Evidence of technology spillover can thus be seen by observing the similar IPC classes in the domestic wind turbine patents and comparing with domestic wind turbine gearbox patents of other marine and automotive industries (refer Table 3.4). Observation of citation to those patents were seen with common inventors between the patents of different industries. This assures that labour mobility is a source of knowledge transport between industries along with their assimilation skill to customize and implement external knowledge along with their personal knowledge into useful wind turbine industry needs specific to the technical needs of China's wind installations.

(2) Cost competitiveness

Comparing the cost structure of a china domestic wind turbine to a foreign wind turbine (Fig. 3.8), the increase in cost lies with components that are either externally procured or high design cost to develop.

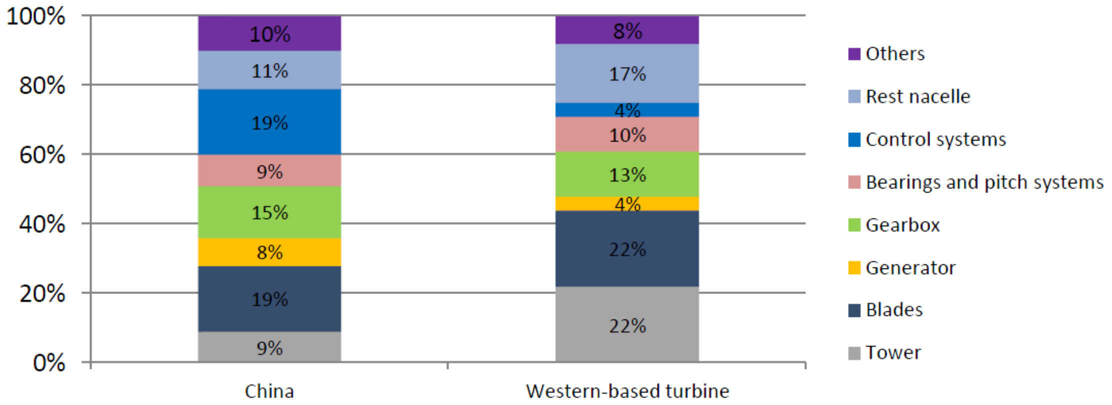


Figure 3.8. Cost structure of China domestic wind turbine versus foreign wind turbine.

Source: Make consulting report (2011).

Towers account for about 22% of the total cost of a WTG in the West, compared to 9% for towers in China. The reason being, the component does not have high technical barriers but does require heavy steel structure manufacturing capabilities, which Chinese manufacturers possess. As Table 3.5 shows the China's competence in steel production, it also helps the tower cost reduction. In addition, the low cost of labour allows domestic players to produce towers at lower price. Wind turbine manufacturers are therefore able to buy towers directly through a tendering process where the contract is awarded to the supplier with lower price to quality ratio and integrate into their system.

Table 3.5 China's global share of steel production

Year	1980	1985	1990	1995	2000	2005	2008
Steel production (million metric tons)	37.1	46.7	66.3	95.3	127.2	355.7	500.4

Source: Mu Yang et al. (2011).

However, components with high technical barriers, such as control systems, command a much higher cost in China at 19% compared to just only 5% in the West. Control systems require a high level of technology and this makes the entry barrier for this key component very high in China. The domestic market lacks the core technology capabilities and therefore relies primarily on imports which drives up costs and makes it one of the most expensive components of WTG manufacturing in China. The market is currently dominated by foreign firms such as MITA, ABB and Windtec.

A key component for the industry is blade systems. They account on average about 19% of the total cost of a WTG. As such, many WTG manufacturers choose to in-source at least some of their blades. The market for independent providers is currently dominated by three domestic players – Zhong Hang Huiteng and Zhongfu Lianzhong and Sinoma. Increasing market entrance by domestic players has increased price competition, driving down the cost of blades, while their production output has been growing with years (Table 3.6).

The old blade manufacturing process method is hand layup which is known for poor quality and involves large amount of labour, while the recent method is VARTM resin transfer process) which is relatively needed for the large wind turbines to avoid premature failure during its 20 year life.

Table 3.6 Leading wind turbine blade manufacturers and their principal technology

No	Capacity （MW）	2008	2009	2010	2011	2012
1	Zhong Hang Huiteng	3000	5000	8000	10000	12000
2	Zhongfu Lianzhong	1500	2200	3700	4500	6000
3	Vestas	800	1000	1300	1700	2200
4	LM	700	1000	1150	1300	1500
5	Gamesa	700	1000	1200	1500	1700
6	Suzlon	500	700	900	1200	1450
7	Shfrp	500	600	750	980	1280
8	Sinoma	360	610	900	1300	1820
9	Dongqi	300	400	800	1000	1400
10	Zhong Neng windpower	300	400	800	1000	1400
11	Nordex	300	400	550	800	1050
12	Xingfeng Energy	300	400	600	900	1200
13	Guo Dian United Power	225	413	620	1000	1220
14	Miracle Logistics	15	45	300	600	750
15	Huayi wind power	0	200	400	600	900
16	Tianwei wind power	0	250	400	500	600
	Others	480	1500	3000	4000	5000
	China total	9980	17018	26070	33580	42170

Source: China wind association (2011).

(a) Old blade manufacturing process (b) New blade manufacturing process (VARTM)

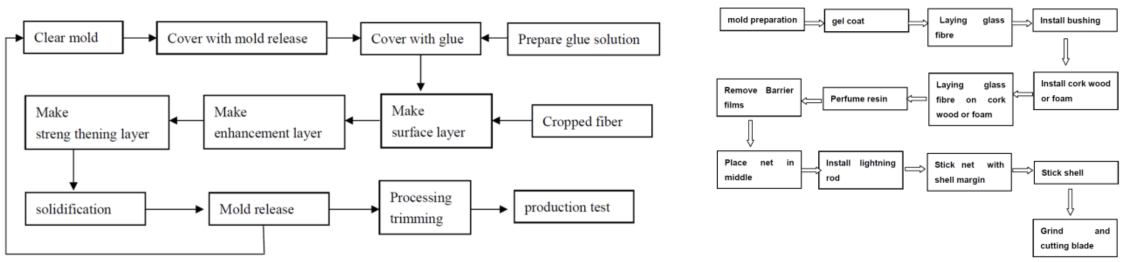


Figure. 3.9 Typical process flow chart of old manual blade manufacturing process (hand lay-up) and new resin flow transfer process (VARTM).

From the Table 3.7a&b, we can see that there are not many domestic firms use Hand Lay-up Manufacturing Technology in China at present, while all foreign firms are in the VARTM technology. As shown in Fig. 3.9 these old and new manufacturing processes require different skills and resources. Hence, new domestic firms directly involve in VARTM technology.

Foreign firms (like Vestas and Suzlon) with proprietary intellectual rights over key components such as blades and control systems tend to adopt vertical integration to protect their competitive advantages in design capabilities and ensure production quality. However, domestic players (Goldwind and Sinovel) have also outsourced their major components to local suppliers in order to capitalize on the growing number of qualified domestic component suppliers, the competencies of specialized component manufacturers, lower costs to exploit the domestic requirement policy and minimize import tax.

Table 3.7a China Domestic manufacturers preferred choice of technology for blade manufacturing (*2012*)

No.	Company	Manufacturing technology
1	Zhong Hang Huiteng	VARTM Hand Lay-up
2	Zhongfu Lianzhong	VARTM
3	Vestas	VARTM
4	LM	VARTM
5	Gamesa	VARTM
6	Suzlon	VARTM
7	SHFRP	VARTM, hand layup
8	Sinoma	VARTM
9	Dongqi	VARTM
10	Zhong Neng Windpower	VARTM, hand layup
11	Nordex	VARTM
12	Xinfeng energy	VARTM, hand layup
13	Guo Dian United power	VARTM
14	Miracle logistics	VARTM
15	Huayi Wind power	VARTM
16	Tianwei wind power	VARTM

Source: Trade magazines (2011).

Table 3.7b China Top 16 Wind Turbine Blade Manufacturers Capacity (MW) (2012).

No	Capacity （MW）	2008	2009	2010	2011	2012
1	Zhong Hang Huiteng	3000	5000	8000	10000	12000
2	Zhongfu Lianzhong	1500	2200	3700	4500	6000
3	Vestas	800	1000	1300	1700	2200
4	LM	700	1000	1150	1300	1500
5	Gamesa	700	1000	1200	1500	1700
6	Suzlon	500	700	900	1200	1450
7	Shfrp	500	600	750	980	1280
8	Sinoma	360	610	900	1300	1820
9	Dongqi	300	400	800	1000	1400
10	Zhong Neng windpower	300	400	800	1000	1400
11	Nordex	300	400	550	800	1050
12	Xingfeng Energy	300	400	600	900	1200
13	Guo Dian United Power	225	413	620	1000	1220
14	Miracle Logistics	15	45	300	600	750
15	Huayi wind power	0	200	400	600	900
16	Tianwei wind power	0	250	400	500	600
	Others	480	1500	3000	4000	5000

China total	9980	17018	26070	33580	42170

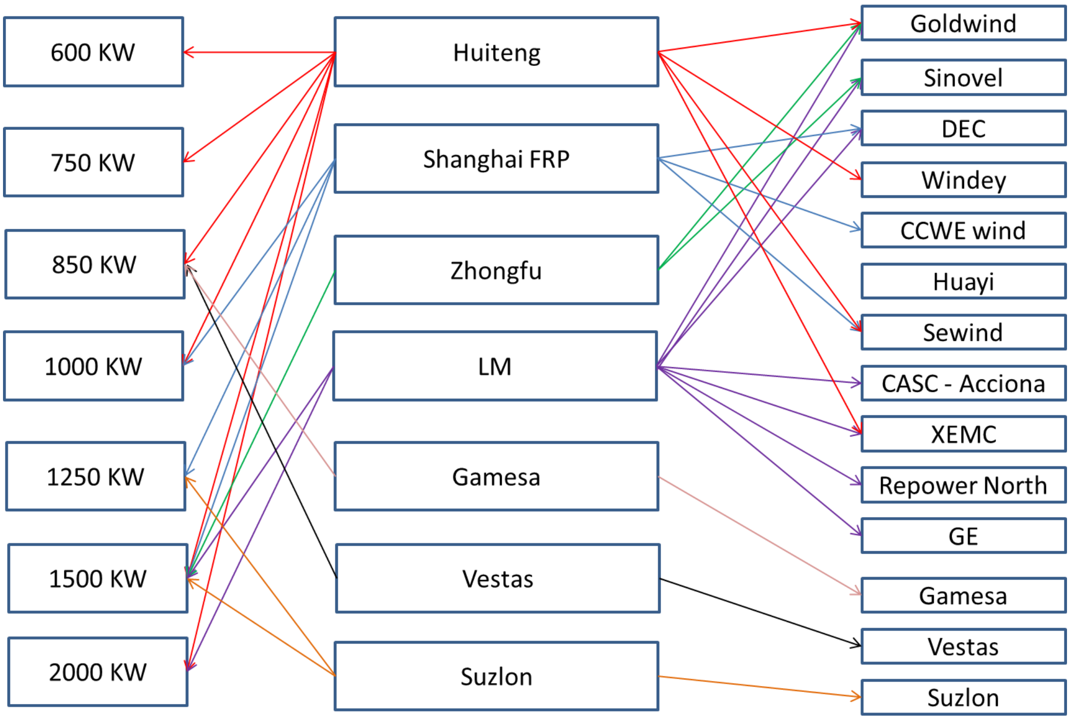


Figure 3.10. Production chain links of blade manufacturers indicating the indigenization and increasing capability of domestic suppliers (*2011*).

From the above figure it is clear that domestic firms (Huiteng, Shanghai FRP, Zhongfu) are less vertically integrated and are more capable to deliver larger product size as compared to foreign firms' blade manufacturing units (Vestas, Gamesa and Suzlon) which are more vertically integrated and are still producing relatively lesser product size.

As the industry matures with increasing R&D capabilities amongst domestic manufacturers, firms that have proprietary technology will likely use insourcing as well. Already, Goldwind and Mingyang have developed their own control systems while XEMC and Sewind produce their own generators. Industry consolidation will lead to smaller suppliers being eliminated and strengthening of cooperation between large suppliers and large WTG manufacturers. Merger and acquisitions can also occur resulting in higher level of vertical integration.

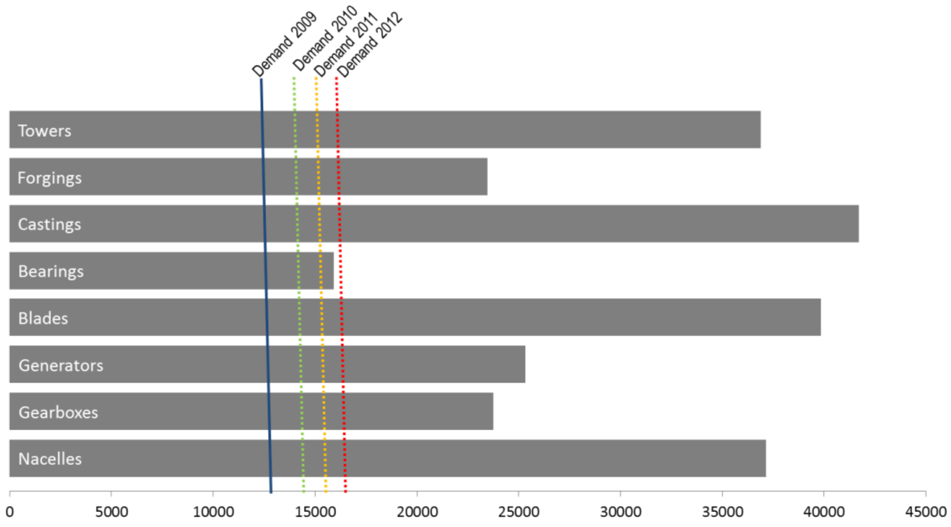


Figure 3.11. Total production capacity versus demand of China component suppliers (*2012*).

Source: Make consulting report (2012).

Wind turbine manufacturing firms are constantly experiencing cash flow due to unexpected downturn which puts pressure on supply chain management in terms of inventories, lead times, operational efficiency, e.t.c. This demands high execution efficiency in terms of faster pace to change and dynamically optimize the supply chain. From Fig. 3.11 it is clear that in China due to domestic supply chain being indigenously created and matured with an internal capacity capable to meet the nation's target of wind turbine installation. Currently, blade nominal capacity is almost 40 GW; bearings capacity is almost 16 GW; and castings production is enough to supply over 41 GW of WTG demand. Gearbox capacity is almost 24 GW; tower capacity is almost 37 GW; forgings capacity is about 23 GW; and generators can already achieve production capacity of 25 GW, far more than demand in 2012. This comforts that the supply chain will not be a barrier to wind energy adoption into its energy sources. However, some components such as bearings, control systems and gearboxes still face technical bottlenecks in the supply chain as offshore development and the growing size of turbines increase requirements for both WTG and components manufacturers.

(3) Increasing product size and capacity

The turbine size (in meters) and capacity (in watts) have been increasing remarkably to exploit the ‘increasing returns to geometric scaling’ in recent years. As a product scales it stretches the existing technologies of product and processes of a firm. Hence this also shows that the technology capability of the domestic wind turbine manufacturers and their suppliers are growing compared to their foreign counterparts. In 2005, Chinese domestic firms were capable to produce 750 KW and the actual installations showed MW-class wind turbines that accounted to 21.5% of that year’s annual installation capacity. As Chinese firms such as Dongfang and Goldwind mastered the wind turbine design and manufacture of more than 1000KW the domestic installation of China moved from 600 KW towards larger size and capacity (> 1 MW) (Li et al., 2009). In 2009, Sinovel and Ming Yang exhibited their capability to produce 3 MW machines and the market share of MW-level machines exceed 86% among domestic installations (Peng Ru et al., 2012). Even firms like Vestas took more than half-decade to increase product scale to reach from their V90-3MW model to a V126-7 MW model, while Sinovel, as we see in below Fig. 3.12, showed a product release in every 2 years. The increase in the product size or capacity helps in reducing cost significantly as shown in Fig. 3.9 (Srikanth et al., 2010).

The market share of domestic wind turbine (*DF*) to the foreign wind turbine (*FF*) can be seen as function of the ratio of the product capability which in turn depends on the R&D investments between the domestic and foreign firms and their accessible knowledge stock. One of the outcomes of the technical dominance for the R&D investment is in terms of patent count. The relationship between the turbine size (in MW) and the prices (in Euros) is shown in Fig. 3.12. Table 3.8 shows the increasing installation of wind turbines with larger size in growing years.

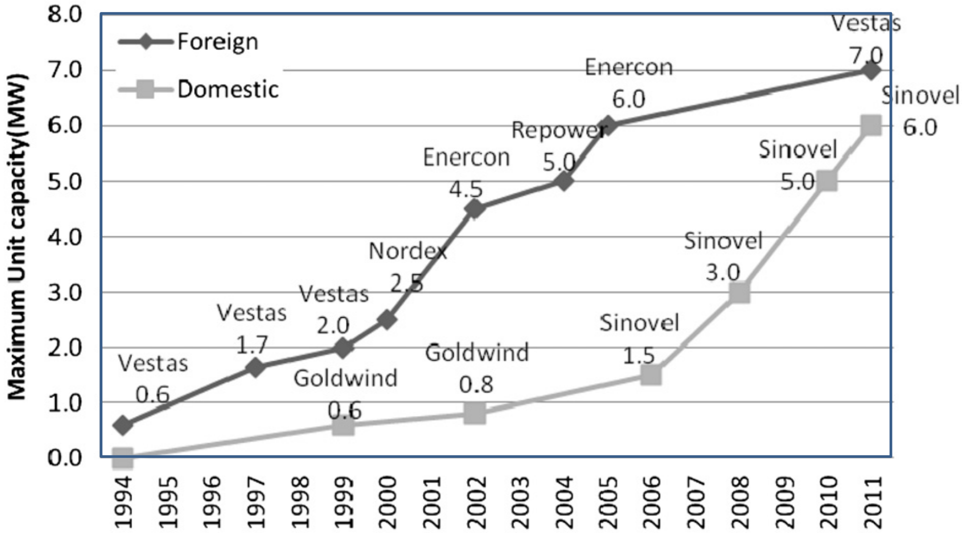


Figure 3.12. Wind turbine size comparison between domestic and foreign firms (*1994-2011*).

Source: Peng Ru et al. (2012).

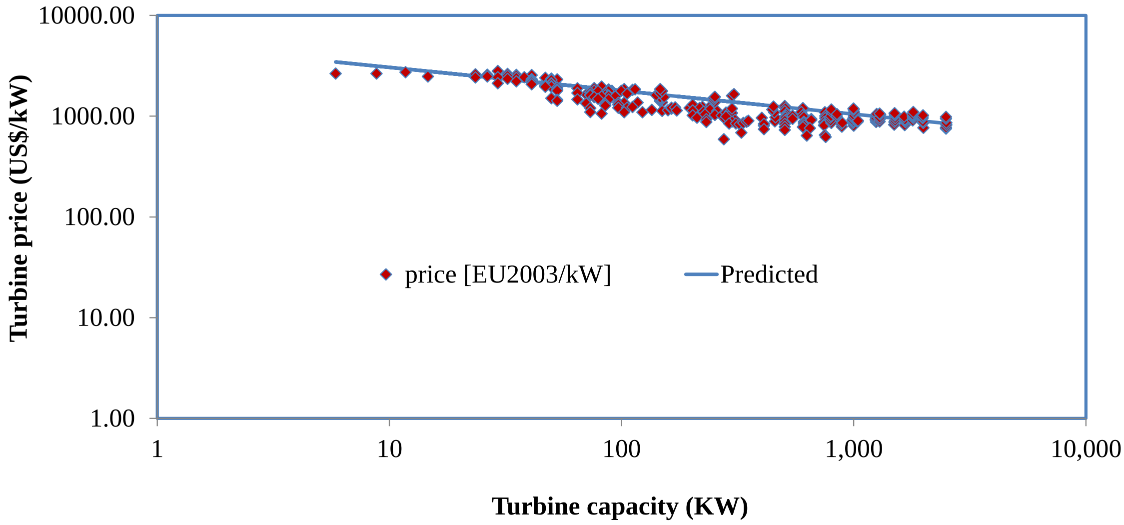


Figure 3.13. Wind turbine cost with capacity.

Source: Junginger (*2008*).

In china there has been government subsidies motivating towards domestic firms that demands wind turbine manufacturers to adopt atleast 70% domestic parts, else tariffs are imposed to imported parts similar to USA[6]. This encourages turbine manufacturers to source for domestic supply chain and hence become more indigenized at country level. Foreign turbine manufacturers such as Gamesa, Vestas and GE have been mostly importing precision parts such as gearbox and generator from Europe due to lack of trust on the domestic suppliers and hence their cost are relatively high. Comparing learning curve studies of foreign turbine manufacturers which generally show European wind turbine manufacturers have a progressive ratio of 94% (Nemet, 2009) and domestic China wind turbine manufacturers have a progressive ratio of 91% (Yueming, 2012) confirms the present findings for improved learning by the Chinese wind manufacturing firms[7].

Table 3.8 China's installed capacity (GW) and increasing wind turbine size.

Year	**1000 KW**	**1000-1300 KW**	**1500-1650 KW**	**>2000 KW**
2006	2.1	0.1	0.4	0.1
2007	3.7	0.3	1.7	0.2

[6] http://www.nytimes.com/2012/07/28/business/energy-environment/us-raises-tariffs-on-chinese-wind-turbine-makers.html

[7] Thus using the data of market share between foreign firms and domestic firms and the learning curve and size ratio, the following regression can be observed: $ln(DF/FF) = 4.540 - 8.336ln(P_f/P_d) - 0.024ln(S_f/S_d)$ *adj.* R^2=0.83

2008	5.7	0.8	5.2	0.5
2009	6.4	1	7	0.6
2010	7	1.3	9.3	2.3
2011	7.4	1.4	10.8	12.4
2012[a]	7.6	1.5	12.3	29.7

Source:www.globalintellegence.com (2012)   [a] forecast for 2012.

(4) Knowledge stock growth

Patent count is a useful measure of the knowledge stock specifically for wind turbine technologies and can be used to compare between the domestic and foreign firms (Soete etal. 1983, Acs et al. 2002, Johnstone et al., 2010, and Braun et al., 2010). Based on the patent data from China's state intellectual property office (SIPO) in 1985 there were only 13 patents in wind turbine while it has increased to 522 in 2002 and in 2008 it reached to 1132. Fig compares the patent count difference between the domestic and foreign applicants in China.

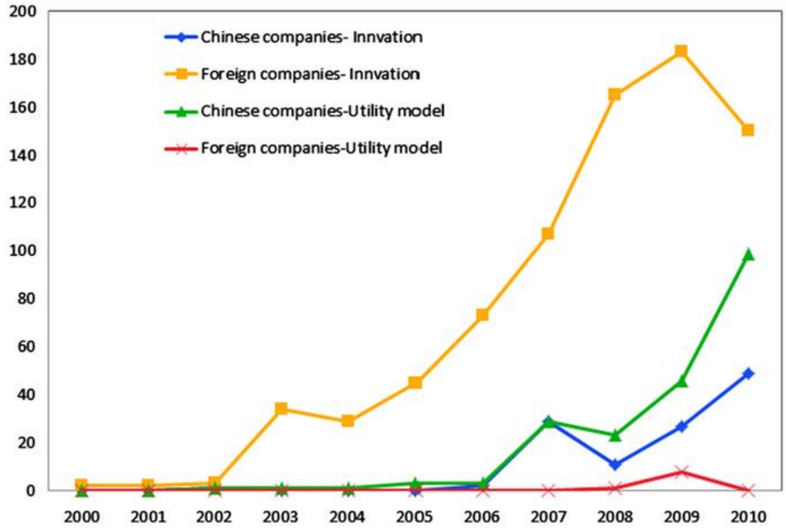


Fig. 3.14. Wind-turbine technology patents application in China (*1990–2010*). Sources: Soopatdatabase (*2011*) and Yuanchun Zhou (*2012*)

3.5.3 Case Study 1: Goldwind

Goldwind (Jinfeng) was China's first leading wind turbine manufacturer (Table 3.9). An investigation of how Goldwind acquired its wind turbine technology provides a clear example of how China is obtaining advanced wind power technology through international technology transfers. While every firm in China has adopted a different strategy and established different technology partnerships, most firms have used licensing, M&A and joint development strategies similar to that of Goldwind.

Goldwind, which began as Xinjiang Wind Energy Company, obtained its first wind turbine technology license from Jacobs, a small German wind turbine manufacturer that has since been purchased by REpower, to manufacture 600 kW wind turbines in 1999. In 2001, Goldwind also obtained a license from REpower for a 750 kW turbine and later another license from German company Vensys for a 1.2 MW direct drive turbine. Vensys is a design rather than a manufacturing company and was looking for a partner with the manufacturing capability to produce its turbine designs. The Vensys direct-drive turbine technology was then (and is now) still somewhat uncommon in wind turbine designs but is thought to have many advantages over the traditional gearbox design, including being lighter weight, which makes for easier installation, and using fewer components, meaning fewer things that can become damaged and require replacement (de Vries, 2007). When Vensys developed a low wind speed version with a larger 64 m diameter rotor that increased output to 1.5 MW, Goldwind acquired the license for that turbine as well. Goldwind is currently working with Vensys to produce 2.5 MW gearless turbines for onshore use and 5 MW turbines with a view towards offshore applications.

In the early 2008, when several other firms made a bid to purchase Vensys, Goldwind opted to purchase a 70% stake in the company outright so that it could continue its partnership. Becoming the controlling owner of the company gave Goldwind more control over the direction of the R&D of Vensys, as well as less constraints over access to its intellectual property. Goldwind, somewhat surprisingly, has opted to encourage rather than discourage Vensys' partnerships overseas, including its licensing arrangements with overseas companies that include Enerwind of Argentina, IMPSA in Brazil, ReGen Powertech in India, Eozen in Spain and CKD NOVÉ Energo in the Czech Republic and Slovakia. Wu Gang, Goldwind's CEO, believes that it is important to give the designers at Vensys the creative freedom that they need, and by allowing them to directly engage in the manufacturing process, they may improve the quality of their designs through more direct learning by doing (Wu, 2009).

As the company has expanded, it has become increasingly able to compete for the most skilled workers in the wind turbine industry and reportedly has been able to attract former employees of GE, Gamesa, Vestas and Siemens. Goldwind is currently manufacturing turbines for the Chinese market almost exclusively, but it is in the process of building a small demonstration wind farm in Minnesota and has plans to expand in the USA and Australian markets. The company reports they invested more than $17 million in R&D in 2009.

Table 3.9 Goldwind firm growth

Year	Production (MW)	Profit (RMB in millions)	Corporate revenue (RMB in millions)	Total Capital (RMB in millions)
2004	67	42	245	284
2005	140	112	506	626

2006	401	320	1530	1204
2007	755	630	3103	5468
2008	1373	906	6458	11211
2009	2036	1746	10738	14883

Source: data from QYResearch (2012).

3.5.4 Case Study 2: Chongqing gearbox manufacturer

The company was set up in 1966 and located in Jiangjin district 50 kilometers to the southeast of Chongqing city. The company has total assets of RMB 1.3 billion and occupies a total land area of 530,000m2. The number of staff and workers is more than 2000.

The company successively imported the design and manufacture licenses for GW, GC and GVA-series marine gearboxes from Lohmanstolterfoht Germany. After 20 years development, the company has integrated the imported technique and developed its own know-how. The company stands far beyond in the area of design and manufacture of high-accuracy and casehardened gears, as well as high & low-speed heavy-load gear transmissions in China and its products have come up to the equivalent level of the developed countries of Europe and America. The company can design and manufacture various gearboxes according to the demands of the clients. Today it manufactures the gearboxes necessary for the megawatt level wind turbines.

The company is one of 500-biggest enterprise in machinery industry in China and the first class enterprise of metrological management. It is capable of manufacturing yearly about 10000 sets of gearboxes, among them are 500 sets of big-size (unit weight over 50 tons), more than 2000 sets of medium-size gearboxes (unit weight over 10 tons).The annual production capacity of couplings and dampers is about 3000 sets.

“Snuggle up together, power the future” is the soul of the company culture.” Serve the national defence, dedicate to society, care for the staff and shareholder” is the company’s enterprise philosophy. Chongqing Gearbox Co., Ltd. adheres to ” Reinforce in strength, Enlarge in scale” as its development policy, providing high-quality product and all-round service to the client with the first-class technical level and the faultless quality system.

3.5.5 China’s national subsidy program

The Chinese government’s economic incentive policies in early 1990s and measures for developing wind power are the weakest among the major wind power countries. Many experts believe this is the single most important obstacle for wind energy adoption and lack of wind turbine manufacturing industry. The experts foresaw that cost of wind power could be cut by 15 percent if large wind generators were made in China and not imported.

Even though China’s wind power sector is more than 20 years old, it has only began to develop at a significant rate in 2003. The following are the key political reasons why the sector’s development has been so successful:

i. Clear development objectives and plans;

ii. Establishment of a clear legal framework;

iii. Involvement of a variety of investment sources in the sector.

For example the key driver was the National renewable energy law in 2003, which motivated wind resource concessions for government selected sites and for projects of 100 MW in size and had to used wind turbines over 600 KW in capacity that initially used 50% local content and later increased to 70%. In 2007, the mid and long term plans signified the importance of large scale wind power bases and in 2008 the 11th five year renewable energy plan aimed to build seven bases of minimum capacity of 10GW by 2020 in Gansu, Xinjiang, Hebei, Jilin, eastern and western Inner Mongolia and Jiangsu. The plan helped turbine manufacturers to move to those locations and plan sizes of 1.5 to 2 MW turbines.

Table 3.10 Important milestones in China wind power policies

Year	**Description**
2003	a. Wind Energy Resources Survey
2005	a. National Renewable Energy Law. b. Renewable Energy Industry Development Guidance Catalogue.
2006	a. Trial measures on management of cost-Sharing for renewable Energy power generation prices. b. expenses management rules related to renewable energy power generation.
2007	a. Mid- to Long-Term Development Plan for Renewable Energy.
2008	a. Renewable Energy Development Plan “11th Five-Year Plan”. b. Finance Ministry notice on the Interim Measures on Management of Special-Project Funds for the Industrialization of Wind Power Generation Equipment.

2009	a. 15% non-fossil fuel energy target. b. 40-45% carbon intensity reduction Target. c. Perfecting Policies on Grid-Connected Power Pricing for Wind Power.
2011	a. The Emerging Energy Industry Plan. b. 12th Five-Year Plan of Renewable Energy Development.

Also China implemented four feed in tariffs levels varying from 0.51 Yuan/kWh for most windy region to 0.61 Yuan/kWh for least windy region. For non-hydro renewables it set a specific obligation of 3% by 2010 and 8% by 2020 and this drives the large power companies to develop large wind power projects since 2008.

Concurrently, China took steps to co-evolve local wind turbine manufacturing, including policies that promoted joint ventures and technology transfers in large wind turbine technology and mandated local made turbines and imposed differential custom duties to discourage imported turbines. The Ministry of Science and Technology (MOST) supported the development of megawatt-size wind turbines, including technologies for variable pitch rotors and variable speed generators, as part of the "863 Wind Program" under the Eleventh Five-Year Plan (2006–2010). In April 2008, the Ministry of Finance announced to channel the taxes collected on raw materials and key technology import that lacked in the country for technology innovation and capacity building in the wind industry. Incentives was provided by for all domestic turbines over 1 MW with RMB 600/KW from the government if it was successfully tested by the China General Certification (CGC) and further put into grid connection and operation. In 2003, China imposed 70% local content and the visit of US department of commerce secretary Gary Locke, and convinced China government to ease this rule as it acts as a trade barrier to foreign turbines. However in 2010, Chinese ministry of industry and information technology imposed restriction on wind turbine manufacturers that did not have the capability to produce 2.5 MW or larger turbine with 5 year experience and with enough R&D, financial and quality control requirements (MIIT 2010, Baker Botts 2010).

Table 3.10 lists the milestone of government policies in China. Thus with the leveraging of above technology transfer modes from external and internal sources along with labour mobility, China was capable to exhibit its indigenization towards matured turbine scale. In 2005, MW-scale wind turbine generator systems ($\geq$ 1 MW) newly installed in China's wind power plants only accounted for 21.5% of newly installed capacity during the year. With the increase in the manufacturing of these turbines by domestic enterprises, however, the proportion of MW-scale machines reached 51% in 2007, 72.8% in 2008 and 86.8% in 2009. MW sized wind turbines have now become mainstream in the Chinese wind power market (see Figure 3.6).

Meanwhile, the larger wind turbine manufacturers in China have started to enter the competition for large-scale wind power equipment, encouraged by the international trend towards greater capacity machines. In 2009, China realised a new achievement in the research and manufacturing of MW ($\geq$2 MW) wind turbine generator systems. The 2.5 and 3 MW wind turbines manufactured by Goldwind Science & Technology Co. Ltd., for example, were both put into commission in wind farms. The 3 MW offshore wind turbine produced by Sinovel Wind Co. Ltd. was connected to the grid and began to generate power in the Donghai Bridge offshore wind park. The 3 MW wind turbine developed by the Shenyang University of Technology was also commissioned successfully. In addition, Sinovel, Goldwind, Dongfang Steam Turbine, Haizhuang and XEMC all started to research the manufacturing of wind turbines with a single capacity of 5 MW. China has therefore successfully entered in the field of multi-MW wind turbine generators. The sales price of Chinese wind turbine generators (WTGs) dropped 12% year on year (YOY), to average RMB 3,600/kW in 2011 amid competition[8] . And the lowest prices were offered by the two largest China domestic wind turbine makers; namely, Goldwind and Sinovel.

China's best wind resources are concentrated in the northern and western parts of the country where there is less electricity demand. This increasingly requires transmission to be built to bring the power to provinces that need it. However, the northern and western provinces, such as Gansu and Inner Mongolia, are less developed, and poor electric grids cannot manage the fluctuations in electricity production inherent in wind power (Wang, 2009). As a result, some problems with power delivery due to grid challenges have been reported. Hence complimentary technologies such as grids and energy storage technologies are barriers to wind energy adoption and should be concurrently addressed through policies.

3.6 Discussions

Technology leapfrogging of late comer firms into a market (Melissa Schilling, 2010) shows:

- Industries with strong network externality effects has their good's value has a positive function of how many other user possess good.
- Technology standard lock-in to form the dominant design through the self-reinforcing effects of the installed base and complementary goods.
- Even technologically superior products fail if they lack network externalities.

[8] Citigroup report on windturbine sales price in China.www.citi.com (April, 2012)

- The value to consumers of technologies characterized by network externality effects can be divided into technical functionality, size of the installed base and availability of complementary goods.

- The new entrant becomes successful if existing standard is satisfied and have good technological functionality apart from installed base and complementary goods.

In the context of an emerging nation it gets more challenging due to lack of technology, market (domestic or global) and lack of production value chain. However the detailed investigation of the present case shows what emerging nations should cut its risk in investment and urge to improve its domestic industries to co-evolve regional market, domestic production and develop indigenize products to meet its regional requirement to exhibit functionality development through capability development.

In the 1990s, China started work on medium to large wind generators, ranging from 120 kW to 600 kW. China has also strengthened research efforts on system design, installation, blade-manufacturing and system control. However, in 1998, the prices of China's wind power was not cost competitive compared to coal and the energy availability from wind was not high and hence the acceptance of wind as an energy source was challenging. Roughly the wind power costs were 0.7 to 0.77 Yuan/KWh versus coal price of 0.3 Yuan/KWh. Hence it resorted towards large scale wind turbines. However in 1998, large scale wind turbine technology was lacking in China and had to be imported from developed nations. The high cost of importing equipment experienced tariffs, value-added taxes, shipping and installation which contributed to the 0.60 Yuan/kWh cost. This was about 60 percent higher than in countries with mature wind power industries and this discouraged further wind turbine adoption. As per 1990s survey, the general comments of the 1990 China's wind technology (GWEC 2003) were:

(i) A 200-watt wind generator costs about 2,000 Yuan – almost the entire income earned by a herdsman in a year. As a result, only 20 percent of the local population can afford to buy a 200-watt generator, and less than 12 % population can pay in cash.

(ii) Lack of local government funds: Being strained for resources, local government are unable to provide a substantial amount of help. For example a wind- diesel batteries system requires an initial investment of 25,000- 64,000 Yuan/kW. A wind-photovoltaic system requires 70,000- 90,000Yuan/kW. Obviously, it is difficult for the town and villages' government and individuals to support such a high capital investment.

(iii) Short life of wind power generators: Chinese-made wind generators have a life shorter than their foreign counterparts. Foreign-made units can last for 20 to 25 years. China's small wind generators have a design life of 10-15 years, and the system may not last even that long.

(iv) Maintenance: Chinese users are often not aware of the maintenance these systems may require.

However by 2006, Many Chinese experts of the government sector believed that increased local production of wind power generators and expanded production scale could cause the costs of wind generation decline remarkably, based on the experience in other countries, costs were forecasted to decrease from 0.32 Yuan/ kWh to 0.22Yuan/kWh within two decades (Zhao Jiarong (1998)). Thus to strengthen China's wind power industry and improve the quality of the domestic production, the government turned to long-term cooperation with foreign companies through joint ventures and concurrently motivating through more indigenous research and improved designs by domestic firms of other industries, to produce larger generators at reduced costs. In 1986, Shandong Rongcheng imported three Danish Vestas 55 kW wind turbines to create China's first wind farm. China imported nearly 1,000 wind generators with an installed capacity of over 200 MW through technology trade, intergovernmental cooperation and joint ventures. In 1990, China had also established ten 10 MW grade wind farms and started seven joint venture enterprises (albeit very small ventures). These efforts had no doubt improved China's research and development capacity for large wind turbines. Thus china showed its strategy by evolving the market as the first step before initiating production and aligned foreign products to its initial regional needs. The prominent China's wind development and manufacturers are listed in Table 3A-1. Thus emerging nations can leverage foreign know-how and technologies to strengthen their internal demands before engaging into indigenization.

A common strategy has been to obtain a technology transfer from a foreign firm that has already developed advanced wind turbine technology. Technology transfers can occur through different models. One model is through a licensing agreement that gives the licensing firm access to a certain wind turbine model, often with some restrictions on where it can be sold. Another model includes establishing joint venture partnerships between two companies, either to share a license or for collaborative Research and Development (R&D). Firms also can opt to collaborate to jointly develop a new technology design and then share the associated intellectual property. If a firm has the capacity and means, it can also obtain access to technology through the purchase of ownership rights in a company with the desired technology or other forms of M&A.

Figure 3.8 depicts the dynamic learning coefficient expressed in the equation (3.11) obtained from regression studies. The results show the positive magnitude and its gentle fluctuations. Overall from year 1994 the trend is positive and since year 2007 a rising trend can be observed which matches with the conspicuous strength increase in production and adoption as seen in Fig. 3.1 and Fig. 3.5.

Regression analysis of equation (3.12) shows the importance of dynamic learning, product geometric scaling and government subsidy. The coefficients are found to be having a direct impact on cost reduction and thus the effect of learning and scaling has a direct impact on the price reduction of wind turbine. Government subsidies are also related to support functionality development such as wind turbine geometric scaling as observed in China where its government supported towards bigger wind turbines for installation as this may provide increasing energy production per unit of resource utilization. Example, the land and grid utilization will be utilized wisely when larger wind turbines are deployed rather than in the case of deploying smaller wind turbines. In common, both learning and scaling demands for increasing technology stock for the firm production. Accordingly, leveraging relevant domestic firm into this production equation enables learning and product scaling (functionality development) to be met. Equation (3.13) confirms this hypothesis that domestic firm with relevant knowhow can assimilate positively the external patents (FWP) and exploit domestic knowhow (DP) with a magnitude of 0.29 and thereby enhance the production and enhance functionality development (scaling Φ). Fig. 3.18 shows the functionality development of domestic wind turbines in terms of geometric scale with growing years. This methodology to quantify assimilation is a unique contribution of this study. One suggestion is for emerging nations to adopt this method to compute the assimilation of their existing industries so as to monitor and further induce useful policy measures or mechanisms.

Based on the present research findings, Fig. 3.13 depicts the technology seeking, identifying, acquiring, learning and assimilation process of China's wind industry. Due to lack of internal knowledge condition and increasing energy demand situation, China's national innovation system resorted to link its large internal demand for power and external availability of wind technology through domestication by leveraging its domestic know-how in other industries through formation of industrial clusters and placing the wind turbine manufacturing factories and their suppliers more closely thereby aiding labour mobility (Bert et al. 1995). This helped at a larger domestic context exhibiting the country's ability to adopt the external technology and apply it internally thereby demonstrating its absorptive capacity. The concept of absorptive capacity is well discussed by Freeman (1995), Lall (1998) and Amsden (2001). Thus it exhibited technological 'catch-up', a concept that in the most dramatically referred to as technological 'leapfrogging', which has been documented across industries and technologies (Lee and Lim, 2001; Lee, 2005; Gallagher, 2006; Nelson, 2007). Studies have hypothesised that learning networks are a crucial determinant to achieve such firm's ability to obtain success with a new technology (van Est, 1999; Kamp et al., 2004; Karnoe 1990). Also, exploration and exploitation strategies (Teece 1997) have discussed the importance of leveraging external know-how but their studies did not discuss the importance of the role of actors on the final outcome. The present studies elucidate the role played by domestic firms in the technology acquisition and industry evolution which is a theoretical implication of this research.

Chinese Wind Turbine Manufacturers leveraged the know-how from foreign firm through licensing their technology. For example:

(i) Dongfang Electric Group. Developing and manufacturing 1.5 megawatt wind turbines with German company REPower's license.

(ii) Baoding 550 Co. Developing and manufacturing 1 megawatt wind turbines with the German-based Furlander Corporation's license.

(iii) Xi'an Weide Co. a joint venture of Xi'an Aero Engine Co. with the German-based Nordex Corp. manufactures 600 kilowatt wind turbines.

During this period the major domestic large wind turbine manufacturers that collaborated were:

(i) Danish NEG micon – Inner Mongolia wind Power Company founded in 1996, joint venture mainly assembling of 600 KW turbines.

(ii) Danish Micon Zhejiang power equipment manufacturer founded in 1996, mainly assembling large wind turbine of up 17 machines.

(iii) German HSM Luoyang Tractor Company, founded in 1994, joint venture in designing and manufacturing large wind generators such as 250 KW wind generators. Ten units produced in 1995 with full German technologies. The planned 60 units output unrealized as the result of fund shortage.

(iv) Spanish Lude-Luoyang Tractor Company founded in 1998, joint venture designing and manufacturing 600 KW wind turbines; plans to produce 2x 600KW in 1999 with a localization rate reaching 70 percent.

(v) Beijing Wandian Co. Ltd. Founded in 1996 with Austria PEHR, designing and manufacturing large wind generators. Purchased one FLODA636 sample generator. Prototype unit produced in 1998 with Chinese blades and tower and remained in operation in Huitengxile Wind Farm. Planned to produce 10 units in 1999 and 30 units in 2000.

(vi) Xinjiang Wind Energy Co. Its subordinated wind farm was located in Xinjiang Dabancheng. At the end of 1998, its installed capacity reached 40 MW. Through more than a decade operation, rich operational and maintenance experiences were accumulated with strong technical strength. In 1997 it purchased designing technology of Jacobs 600kW and made indigenous units which worked smoothly in Dabancheng.

Its generator, gear box and yawing system are all Chinese made with the components such as blades, high speed brake, hydraulic system and safety mechanism imported.

Table 3.11 summarizes the sources of knowledge into China domestic wind turbine manufacturing firms. Figure 3.10 shows the technology partnership of foreign-domestic pairs' technology partnership modes and how they interlink to form a cluster to support the wind industry. Due to space constraint not all the suppliers are shown in the figure. However their mode of evolution and their maturity is described in figure 3.17 and 3.19. For example gearbox and blades suppliers have evolved world class products indigenously without obvious partnership, while generator demanded technology transfer from foreign firms.

Figure 3.16 portrays the technology seeking, absorption, internalizing, and assimilation and further acclimatization process in China's wind industry. Thus the external knowledge has an impact on the national innovation system (figure 3.4 & 3.15).

During the advent of the horizontal axis wind turbine into China the product has reached a dominant design with modular architecture. This has enabled to clearly specify the components' requirement to meet the overall system needs with clear interface requirements (Sanchez et al. 1997, Sanchez et al. 2001). The present study shows, china's supply chain exploits the modular architecture of the product into useful modular organization of the supply chain and thereby evolved into a horizontal structure, where in each domestic turbine manufacturer is in business link with few domestic suppliers. This is contrary to the foreign subsidiaries in China, where vertical hierarchy is practised and less use of foreign firms. This results in poor bidding from supply side and hence poor cost-reduction and poor capability to scale up of production under demand.

The market share of domestic wind turbine to the foreign wind turbine (Table 3.3) can be seen as function of the ratio of the product capability which in turn depends on the R&D

investments between the domestic and foreign firms and their accessible knowledge stock. One of the outcomes of the technical dominance for the R&D investment is in terms of patent count, number of technology class and the number of patents in each technology class. Thereby the originality, breadth and depth of patents can be visualized and compared between firms. However in the present study, the China patent database lacks key information of citations, inventor's unique identification, e.t.c. Hence this technology class method was put forth.

Table 3.11 Sources of knowledge into China's domestic wind turbine manufacturing firms

Technology transfer type	**Case in Example**
Purchase drawings or technology licence from oversea market (Local)	Purchase wind turbine drawings or technology licence from oversea companies. Or design new wind turbine together with oversea partners,and then produce wind turbines in China. This kind of company such as Goldwind 1200kW.1500kW wind turbine,Zhejiang Huayi.Guangdong Mingyang.Guodian Lianhe Dongli 1500kW,Chongqing Haizhuang. China SEC 2000kW etc.
Totally purchase manufacturing licence from oversea companies (Local)	Purchase manufacturing licence from oversea wind turbine companies and produce wind turbines in China local.such as Goldwind 600kW.750kW,Zhejiang Windey 750kW, Sinovel. DFSTW 1500kW,Chongqing Haizhuang 850kW,Boading Huide.Wuhan Guoce.Wuzhong Yibiao 1000kW,China SEC 1250kW,Beizhong 2000kW etc.
Joint-venture with oversea partner	Joint-venture by China and Foreign partners,produce wind turbines in local China.such as CASC-Acciona. Nordex China 1500kW, XEMC. REpower North (China) 2000kW etc
100% foreign own wind turbine companies	In order to satisfy China wind turbine demand, most wind turbine manufacturers have built up their China local factories or started their China business with China local partners.some of them built up their 100% own factories such as Gamesa 850kW.Suzlon 1250kW.GW Wind1500kW.Vestas 2000kW etc.
Purchase licence from China local university	Shenyang University of Technology is their best wind turbine research center in China, some China local wind turbine manufacturers purchase licences from Sheyang University of Technology,such as Sheyang Huachuang,Jiangsu Xinyu.Zhejiang Windey 1500k,Shanghai Wande 1000kW.Nantong Xielian 2000kW etc.

Source: data from GWEC(2011).

In addition to the companies listed above, other enterprises were engaged indigenously in turbine level and component level manufacturing large or medium wind turbines, gear boxes, control system and towers:

(i) Turbine Manufacturing: Hangzhou Power Generator Manufacturer, Xiangtan Power Generator, Lanzhou Power Generator and Shanghai Power Generator.

(ii) Gear Box, Control Systems and Tower Manufacturing: Hangzhou Gears, Sichuan Gears, Nanjing High Speed Gear Box and Xian Aviation Generator; Nanjing Institute of Automation produces control system and Ruian Pressure Container, Guangzhou Shipyard and Anshan Iron Tower produces towers. Table 3.12 lists the gearbox, generator and blades' suppliers and their technology acquisition mode.

Among the five types of transactions identified by Gereffi et al. (2005) modular type transactions are prominent in the case of China's wind turbine industry. Modularization can both decrease the requirements for interaction between product development and production and thereby shorter lead time and fewer mistakes in the process and facilitate capability building and functionality development by allowing various actors to focus on various tasks of the value chain where their competitive advantage exists (Baldwin and Clark, 2000). In the context of this study, modularization is predominant in the evolution of the technology platform, which encapsulates the increasingly challenges of functionality development such as product scaling. As observed in the case of the wind turbine as the product scales in geometry and size, yet the main parts such as Gearbox and Generator and Blades reside and are being championed by individual actors. This indicates the modularity in product can be observed as a modular organization of the value chain.

Table 3.12 Main component suppliers in China (*2011*)

Company	**Firm**	**Technical resource**	**Stage**
Gear box	Nanjing High-speed & Accurate Gear Group Co. Ltd	Own research & development	Batch production
	Chongqing Gearbox Co. Ltd	Own research & development	Batch production
	Hangzhou Advance Gearbox Group Co. Ltd	Own research & development	Batch production
	Lanzhou Electric Corporation	Own research & development	Batch production
	Haerbin Hadian Wind Power Equipment Co. Ltd	Own research & development	Batch production
	Beiche Group Yongji Electric Motor Factory	Own research & development	Batch production
	S h a n g h a i E l e c t r i c G r o u p Shanghai Electric Motor Co., Ltd	Own research & development	Trial production: batch production started in the first quarter of 2007
Generator	Shangxi Fengxi Heavy Industry Co. Ltd	Own research & development (1.5MW) T e c h n o l o g y i n t r o d u c e d (transferred from Germany for 2MW by license)	Batch production
Blades	Shanghai FRP Research Institute	J o i n t d e s i g n (G e r m a n y Company)	Batch production
	C h i n a C o m p o s i t e s G r o	Technology transfer (purchase	Batch production

	u p Corporation Ltd	the technology from NOI)	
	LM Glasfiber (Tianjin) Co. Ltd	Sole foreign proprietorship Own research & development	Batch production
	ZhongHang (Baoding) Huiteng Windpower Equipment Co. Ltd	Own research & development	Batch production
	B e i j i n g C o r o n a S c i e n c e & Technology Co. Ltd（Institute of Electrical Engineering Chinese Academy of Sciences）	Own research & development	Batch production
	Hefei Sunlight Power Co. Ltd	Own research & development (joint development with Hefei Industry University)	Trial production Batch production will start in 2008
Electrical control	Nanjing Automation Research Institute (Nanrui Group)	Own research & development	Trial production

Source: data from QYResearch(2011).

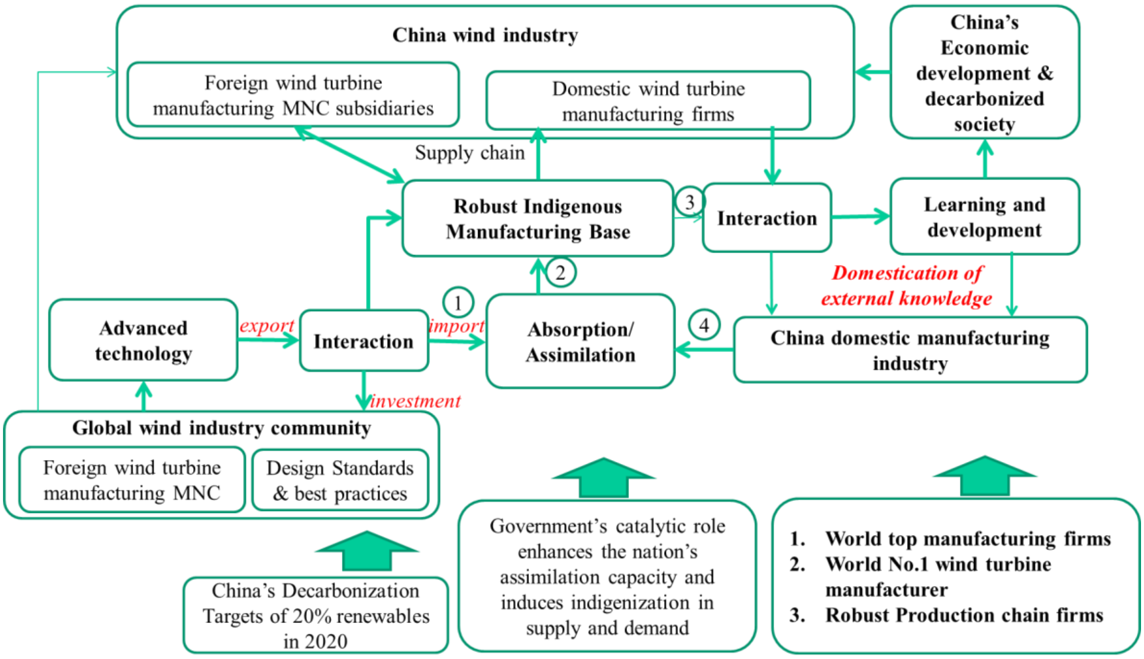


Figure 3.15. Technology acquisition and assimilation process of China's wind industry to meet the nations and entrepreneurial goals.

3.6.1 Theoretical implications

The current thinking of technology transfer in published FDI literature assumes that when a technology is provided to a region it can start producing without further support. However to every technology there is a tacit part of the knowledge that cannot be codified which is generally termed as *personal knowledge*. Researchers have proven that it can be imparted only through 'learning by doing' such as training or hands-on work. In practise it can be accelerated if the work force arrives from a related technology domain from another firm with necessary technical skills. Economists have often contended that technology transfer will suffice economic growth and new industry evolution. For example, growth theory has consistently linked technology improvement and long run growth (Aghion et al. 1998). Hall et al. (1999) and Klenow et al. (1997) have focused on the need of total factor productivity to the introduction of improved stock of technology in the country and the subsequent improvement of firms' revenue (Griliches 1998, Parisi et al. 2006, Evenson et al. 1995). The present study has shown the importance of the local know-how and the means to support the assimilation of the external technology transferred through exploiting the skilled labor and firms of similar industries to create the necessary value chain.

Griliches (1979) contends firms' level of technology knowledge depends not only on internal R&D investment, but also on the knowledge stock developed by other firms or industries. These external effects are referred to as technology spillover. Especially this gets enhanced when the firm is in an industrial cluster that enhances agglomeration. In this study, the idea pursued is that the overall productivity effects of FDI of a new industry may depend on the firms of pre-existing industries. In examining the productivity impacts of foreign owned transnational corporations, this study focuses on china's growth in the new industries such as wind industry and investigate why it greatly differs from other underdeveloped country's industry growth or its own underdeveloped period (such as before 1990s). First, does the new industry growth depend on the productivity spill over effects from previous similar industries? Second, does FDI within an industry is a good metric to show the presence of an active industry on which a newcomer industry can thrive. Studies such as Liu et al. (2000) and Buckley et al. (2002) showed knowledge spillover scenario at the industry level at a certain snapshot. The previous studies more focus were on the impact of FDI on GDP growth or on domestic firms alone. A distinctive feature of the present research is that it examines the relation between the growth of an evolving industry and pre-existing industries in a region and further examines the impact of inward FDI on overall productivity for industry specific effects.

In addition, researchers are focusing into how technology and organization setups within a sector develop concurrently in a co-evolutionary way for a given business climate (such as geographic region or country) (Van den Bergh and Stagll 2003; Garnsey and McGlade (2006) and Mckelvey (1997)). In parallel, network externalities and increasing returns may guide due to path dependency and irreversible change that lock up the sectorial systems into inferior technologies (Arthur 1994). For example in places like China, when the diffusion of land lines was slow, the wireless handphone spread became good because it dictates less education to use such device as compared to using a laptop computer or a PDA where the prior knowledge of the user needs to be high. In similar lines, we could say that the use of fossil fuel for energy purpose is an inferior technology due to its incompliance to clean energy definition and low efficiency rates. Yet these regions have become locked up to these sources and coming out from these committed technologies is difficult due to sunk costs.

Figure 3.16 shows the China's wind industry approach through initial identification of a domestic market for clean energy and further adopting imported foreign turbines, thereby familiarized technology usage. Further the industry resorted to develop domestic production chain through various technology transfer mechanisms such as technology leasing, joint venture and/or through merger and acquisition with government support. Using the skilled labor and value chain partners of similar industry the technology assimilation of the foreign know-how was achieved. The assimilation was further fused with the related domestic industries' know-how and open source information such as technology standards and patent database. Figure 3.17. shows the co-evolutionary acclimatization of external and internal knowledge during the industry evolution. This resulted in products from pure initial imitation of foreign turbines towards an innovation stage where indigenized product development in tune to the regional wind needs was achieved. Further government and industry supports helped the indigenization towards functionality development which was measured through product's geometric scale to improve performance and reduce cost. The functionality development was observed in terms of increasing wind turbine sizes that exceeded even the foreign turbine manufacturers product limits (>7 MW). This resulted in increasing market share such that the domestic industry products reached a market share of beyond 90%. Finally these domestic firms matured towards global firms such that they setup subsidiaries in foreign soil to extend their exploratory efforts for new innovation and new markets so as to feed into their innovation cycle and functionality development. Figure 3.15 shows the overall framework of technology acquisition and assimilation process obtained through an institutional innovation of the China's wind industry to meet the nations and entrepreneurial goals.

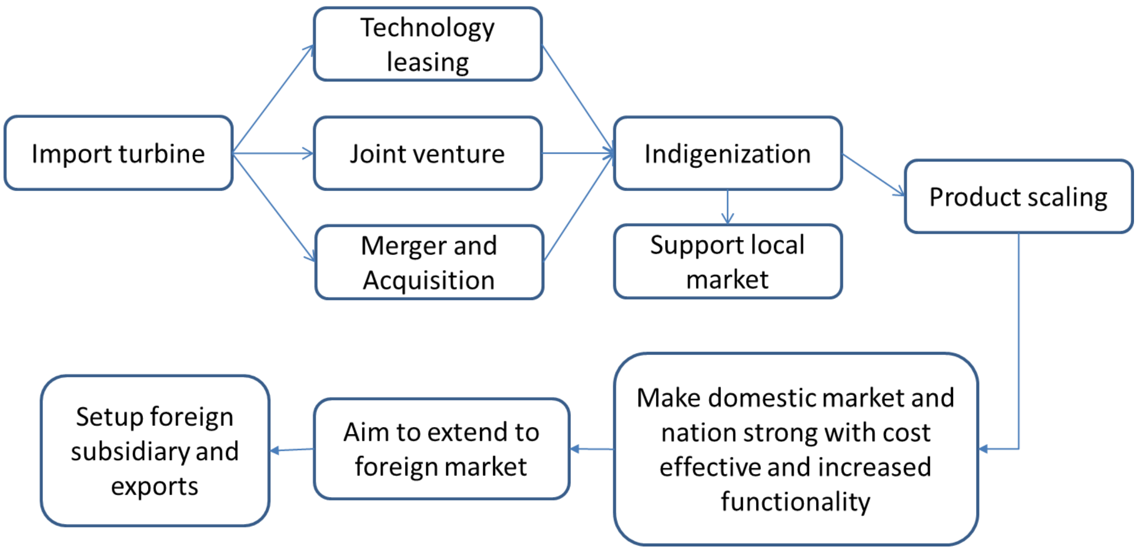


Figure 3.16 China wind industry technology acquisition, internalization, and indigenization and evolve markets.

Foreign affiliates is generally seen to exhibit higher levels of productivity than local firms (Aitken and Harrison 1999) the reason being firm specific assets of transnational corporations (TNCs) increase productivity in FDI receiving firms (Egger and Pfaffermayr, 2001). Also, empirical research shows foreign equity participation outperform firms that are locally owned (Blomstrom and Sjoholm 1999). The second influence of FDI arises in terms of knowledge and/or productivity spill over to the host country's home grown firms (Kokko

(1996) Aitken and Harrison (1999) and Buckley et al. (2002), but their reasons are not still well investigated.

However, in emerging regions there is a predominant hatred to globalization due to fear of job scarcity becoming high and domestic industries to become poor performers (especially government sector). This has been attributed to the opening up of economy and infusing FDI into the country (Deepti, 2010). Hence the domestic firms and skilled labor generally object to government's globalization plans. The present study's findings show on the contrary, the early involvement of domestic firm's participation to fuse foreign MNCs technology with domestic know-how and coevolving domestic market for these products helps to enhance the R&D spillover and the growth of the local industry. This will help improve energy sufficiency to meet economic demands, increased economic growth & foreign exchange, and further helps to increase jobs and energy per capita for people needs, along with further support to the region through customized product design.

Published literature has dealt well with globalization and its impact through foreign direct investment and technology transfer to an emerging nation's capability to enhance the manufacturing competence and to become a part of the global supply chain (Sonobe et al., 2003). These studies ignored the impact of knowledge spillovers on the capability formation of the emerging nation. However, knowledge spillovers have substantial macroeconomic implications for growth and international trade (Romer (1990)). These implications result in R&D production and geographically localized knowledge spillovers, which were less studied from this context. Zucker et al. (2004) showed R&D spillovers as a major source of endogenous growth in recent "New Growth Theory" models (Zucker et al. 2004).

Positive spillovers are known to arise when the leading edge technologies of foreign MNCs influence and improve the productivity of locally owned firms (Feinberg and

Mujumdar 2001). Negative effects are also studied (Aitken and Harrison 1999) specifically in pulling the demand from the home grown firms. These are in the context that the locally originated firms within a closed economy tend to have weak technological capabilities. Such deficiencies will disable them to appreciate the value of externally generated knowledge and restrict their absorptive capability to intake the knowledge spillovers by foreign spillovers. Thus positive spillovers may primarily occur from “demonstration effect”, “contagion effects”, people movements, and through pro-competitive effects. Also it is seen that locally owned firms are concentrated in the standard technologies where the foreign firms avoid.

The present study elucidated an elegant approach in the form of *Co-creation model*, which can thus be generalized as a framework for emerging economies. The emerging region can coevolve market and production through a two pronged approach. It could identify its market needs to attract foreign players. Further it could initially choose any of the technology transfer models as an initial part of their technology roadmap and leverage domestic industry know-how to enhance assimilation, absorption and recreation by fusing with existing technology spillover and evolve production value chain from its related domestic industry to build their own competitive strengths and adapt technology for localization. Thus government policy and the co-creation of the required institutions become important to aid the diffusion of the foreign knowledge from established technology developers. Further they could setup as industrial clusters to aid agglomeration of know-how from domestic previous industries to support spillover and assimilation of the technology transfer along with domestic know-how. Thereby firms involved in other industries with similar technology capabilities can widen their market by participating in the new industry and identify the domestic market and its social needs and evolve new products for commercialization. In parallel, firms with internal research department are to be embraced in the national innovation effort to assimilate knowledge spillover and global know-how to bring out their indigenous products to meet their market demand along with similar functionality development trajectories to compete with global players. These two mechanisms can work in tandem to support an aspiring emerging nation to meet its market demand.

Few studies have focused to articulate that the mechanism of industrial development through interdepencies (Puge and Venables 1998, Rodriques-Clare 1996). They showed that in a monopolistic competitive market the cost reduces by increasing competition among the local players and that the benefits of decreased cost are passed to the downstream firms. The idea that knowledge workers transit knowledge across sectors has empirically found plausible. Hence a complementary process may arise such that if new industries develop, they exploit the knowledge brought by the workers from similar technology relevant industries and thereby increase assimilation, absorption and recreation capability of the recipient industry. The present study results shows the global know-how that a firm in the emerging region can access from the pre-existing regional firms of other industries and/or the global know-how such as the free access of the international patent database and academic publications can be of great support in the knowledge development of the firms. This study brings light to the idea of integrated framework for an emerging nation to indigenize, produce, diffuse and export. Similar technology classes can be identified for example through similar IPC classes of patents. For example, the skill acquired in the marine gearbox industry may be of value in the wind turbine gearbox industry since both need similar technology components to develop large scale gearbox for the specific application. These spillovers are positive externalities on the productivity of firms which neither made the discovery themselves nor licensed its use from the holder of the intellectual property rights. Thus they play a central role in the literature as causes of both economic growth and geographic agglomeration. Earlier Griliches (1992) surveyed the importance of R&D spillovers as a major source of endogenous growth in recent “New growth theory” models and the difficult empirical search for their existence. There have been significant fingerprints of increased firm's productivity that were closer to universities (Jaffe, Manuel, Trajtenberg and Henderson (1993)). The sources of such success were attributed to the formative years of outstanding scientists who combined brilliant scientific productivity with specific knowledge of the new techniques which formed the basics of industrial formation and transformation. Further evidence was observed from empirical relevance of geographically localized knowledge spillover in the case of biotechnology (Zucker (1997)). Other instances of geographically localised knowledge spillovers are in fact also instances of appropriation and market exchange by discovering scientists then both interpretation of prior studies and their strong policy implications need to be re-examined. However there is not much study in the formation of new industries through knowledge spillovers from other industries, especially in an emerging region. In this present study we develop a novel empirical indicator to quantify and monitor the evidence of such knowledge spillover.

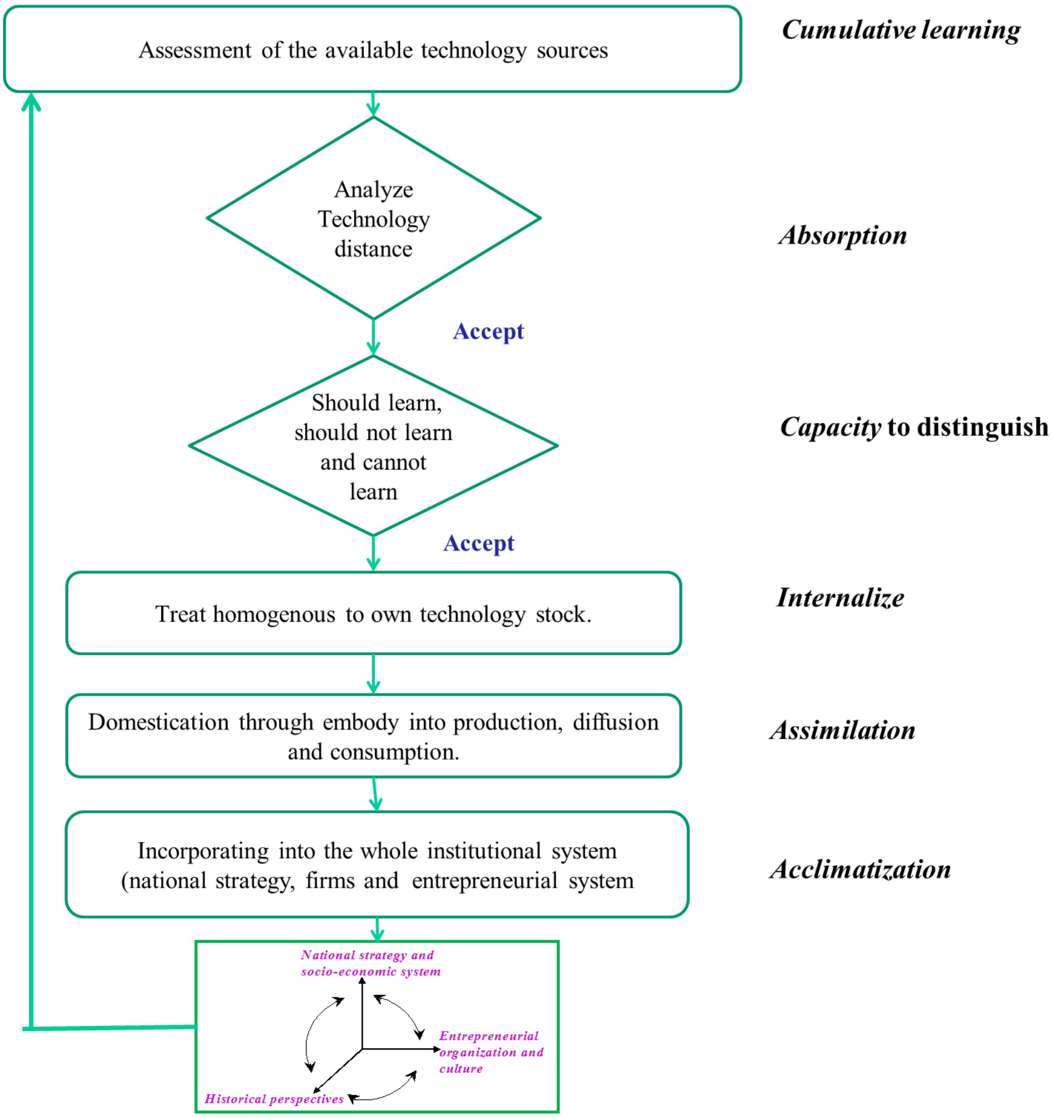


Figure 3.17. Co-evolutionary acclimatization of external and internal knowledge in industry evolution.

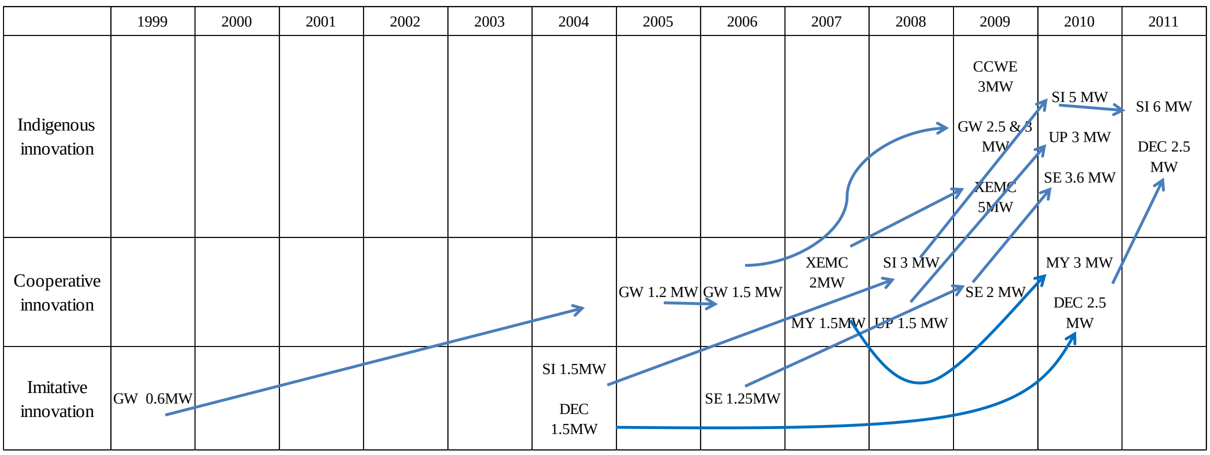


Figure 3.18. Transition of innovation modes of China's domestic wind turbine manufacturers (*1994-2011*)[a].

[a] Abbreviations SI: Sinovel, GW: Xinjiang Goldwind Science and Technology, DEC: Dongfang turbine, UP: Guodian united power technology, MY: China mingyang wind power group, SE: Shanghai electric group, XEMC: XEMC windpower and CCWE: China creative wind energy.

Source: data from Peng Ru et al. (2012).

Few studies have focused to articulate that the mechanism of industrial development through interdepencies (Puge and Venables 1998, Rodriques-Clare 1996). They showed that in a monopolistic competitive market the cost reduces by increasing competition among the local players and that the benefits of decreased cost are passed to the downstream firms. The idea that knowledge workers transit knowledge across sectors has empirically found plausible. Hence a complementary process may arise such that if new industries develop, they exploit the knowledge brought by the workers from similar technology relevant industries and thereby increase assimilation, absorption and recreation capability of the recipient industry. The present study results shows the global know-how that a firm in the emerging region can access from the pre-existing regional firms of other industries and/or the global know-how such as the free access of the international patent database and academic publications can be of great support in the knowledge development of the firms. This study brings light to the idea of integrated framework for an emerging nation to indigenize, produce, diffuse and export. Similar technology classes can be identified for example through similar IPC classes of patents. For example, the skill acquired in the marine gearbox industry may be of value in the wind turbine gearbox industry since both need similar technology components to develop large scale gearbox for the specific application. These spillovers are positive externalities on the productivity of firms which neither made the discovery themselves nor licensed its use from the holder of the intellectual property rights. Thus they play a central role in the literature as causes of both economic growth and geographic agglomeration. Earlier Griliches (1992) surveyed the importance of R&D spillovers as a major source of endogenous growth in recent "New growth theory" models and the difficult empirical search for their existence. There have been significant fingerprints of increased firm's productivity that were closer to universities (Jaffe, Manuel, Trajtenberg and Henderson (1993)). The sources of such success were attributed to the formative years of outstanding scientists who combined brilliant scientific productivity with specific knowledge of the new techniques which formed the basics of industrial formation and transformation. Further evidence was observed from empirical relevance of geographically localized knowledge spillover in the case of biotechnology (Zucker (1997)). Other instances of geographically localised knowledge spillovers are in fact also instances of appropriation and market exchange by discovering scientists then both interpretation of prior studies and their strong policy implications need to be re-examined. However there is not much study in the formation of new industries through knowledge spillovers from other industries, especially in an emerging region. In this present study we develop a novel empirical indicator to quantify and monitor the evidence of such knowledge spillover.

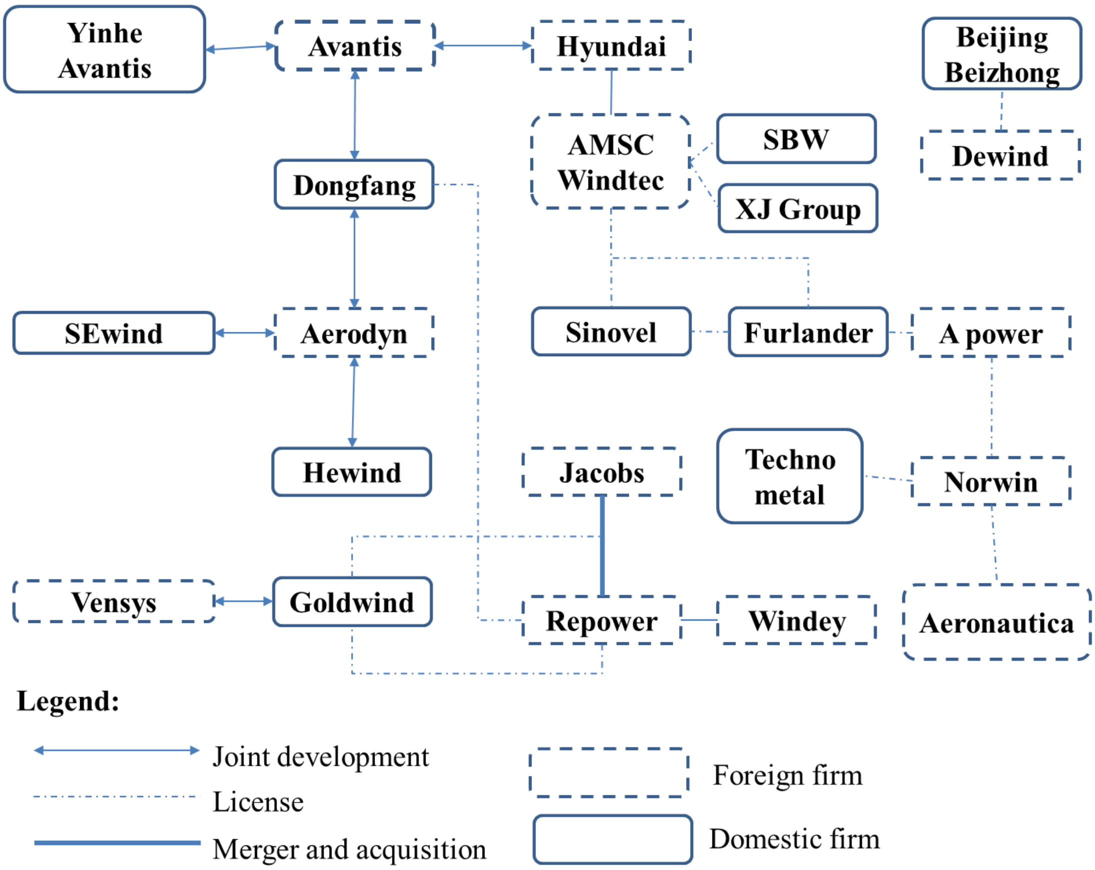


Figure 3.19. Wind power technology transfer networks in China with foreign collaborators.

Source: data from Joanna Lewis (2011).

The idea of open innovation has been discussed by Chesbrough (2005) discusses the benefits of a firm to exploit the external know-how and resources. However this study further elucidated to evolve a modular supply chain that enhances the robustness of production supply to meet the market demand. The partners of the supply chain focus on their core strength and migrate to latest technology to support the industry (example the blade manufacturers migrate to latest process technology). This results in a competitive environment resulting in cost effective and high functionality production. The findings of this research has highlighted the idea of utilizing domestic firms in technology transfer which results in enhanced assimilation both tacit and explicit knowledge and also induce inter-industry technology spillover from domestic industries, induce cost competiveness through bringing relevant skilled labour stock and evolve early functionality development and thereby induce enhanced production. A new quantitative method of identifying assimilation factor using patent technology class has been introduced.

3.7 Conclusion

The present study shows the conspicuous strength in wind turbine manufacturing and internal market development in recent years. Empirical analysis was conducted focusing on the interaction between indigenous manufacturing industry and newly emerging wind turbine manufacturing industry in absorption of global know-how thereby fusion between them to develop MW-level gearbox for the wind industry.

(i) The industry evolution and useful supply chain can be attributed to a joint work between industry's technology transfer partnership and exploiting existing know-how of related industry to explore new business,

(ii) Internal market demand contributes significantly to indigenization and thus an increase in technology stock by assimilation capability,

(iii) The set of leading domestic wind turbine manufacturing firms shows the evidence of positive knowledge spillage from the existing manufacturing industry,

(iv) A new way of identifying the technology spillover to evolve a new product from existing sources using patent technology class was demonstrated.

(v) Existing industry's exploitation of know-how minimizes the barriers to technology adoption.

(vi) Government's catalytic role in supporting local manufacturing industry through evolving new industries and supporting through domestic market has been successful in evolving the conspicuous strength.

(vii) The evidence demonstrates the possibility that emerging economies can co-develop the internal demand for a product and its supply chain together thereby the benefits to the sustained growth of the country.

These findings provide important policy implications and suggestions to growing economies:

(i) From the success of China's wind industry, it shows how the domestic market helps to exploit the domestic know-how and understand the gaps to leverage the foreign best practices through technology transfer.

(ii) The present study exhibited China's ability to exploit foreign firms strengths to meet the local market demand to leap frog into global low carbon economy and motivate indigenization with required performance and quality to retain the skills within its soil.

(iii) It is appealing that China with its initial meagre wind turbine manufacturing skills leveraged the technology transfer and foreign direct investment to draw foreign firms and later assimilate through utilization of local manufacturers to evolve necessary domestic supply chain.

(iv) In order to exploit the technology transfer that arrives in the explicit knowledge form, more local industries' labour force know-how could be exploited to act as carriers of tacit knowledge and induce new innovations. This could be done by comparing the patent's technology classification as a means to find the technology distance between industries.

(v) As national governments consider policies and regulations to promote a wind power industry, these cases show that companies in China has benefited from not only policy support for wind power deployment but also direct support for local manufacturers.

Theoretical implications from this study include:

(i) Conventional FDI literature does not discuss the completeness of technology transfer to include the tacit part of the knowledge. In the case of China wind turbine industry which is new, the assimilation capability has been enhanced by leveraging the domestic firms with relevant know how.

(ii) The effect of globalization on local firms is well studied and hence globalization of a nation has been resisted by the local firms. The present study elucidates a path to leverage the local firms in globalization and bring back indigenization.

(iii) Government's catalytic role to fuse the foreign technology source with knowledge seeking domestic firms to exploit the external know-how and domesticate to the market needs.

(iv) Role of domestic firms help in inducing inter-industry knowledge spillover to result in early functionality development and cost-effectiveness.

(v) Importance of actors in exploration and exploitation in technology seeking paths has been clarified and the role of domestic firms has been highlighted.

(vi) Modularity of product enhances supplier creation and results in a robust supply chain that meets performance and production capacity. This evolves a modular organization of domestic firms on an open innovation network.

(vii) A method of bringing in produce size or equivalent metric (such as capacity) in to the production function to model *increase in returns to geometric scaling* has been put forward in the present study which is a key contribution. This was highlighted by researchers like Winter (2010) that the present production functions fail to explain certain products rampant increase (Srikanth and Funk, 2010).

Appendix A3.1 Dynamic Learning Coefficient

Using relative price of production P and cumulative production Y^*, market learning in fusing global best practice can be depicted by the following function:

$$P = A \cdot Y^{*-\lambda} \qquad \text{(A-1)}$$

where A: scale factor and λ : learning coefficient.

Learning coefficient λ can be depicted simply by the following equation:

$$\lambda = -\frac{\partial \ln P}{\partial \ln Y^*} \qquad \text{(A-2)}$$

Since learning coefficient λ is a function of successive coefficients during production, distribution and utilization phases in their dissemination process as demonstrated in **Figure A3-1**, these coefficients can be depicted as a function of time trend *t* as:

$$\lambda(t) = \lambda(\lambda_1(t), \lambda_2(t), \lambda_3(t), \cdots, \lambda_n(t)) \approx \sum_{i=0}^{n} a_i t^i \qquad \text{(A-3)}$$

where a_i is the coefficient of time trend *t*.

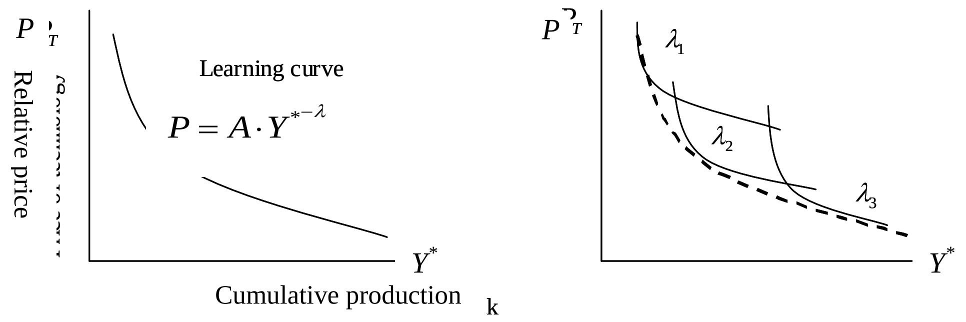


Fig. A3-1. Concept of Successive Learning.

Dynamic learning coefficients λ_1, λ_2 … λ_n depict learning effects in a serial process of production, distribution and utilization as effects of market learning including education (x_1), experience (x_2), innovation (x_3) and other effects contributing to improve productivity, and can be enumerated as follows:

$$\lambda_i = \lambda_i(x_1, x_2, x_3, \cdots) \quad i = 1, 2 \ldots n.$$

Substitute $\lambda(t)$ depicted in equation (A-3) for λ in equation (A-1), and take logarithms; the following equation can be obtained:

$$\ln P = \ln A - \sum_{i=0}^{n} a_i t^i \cdot \ln Y^* + \varepsilon \qquad \text{(A-4)}$$

where ε is disturbance term which is independent from $\lambda(t)$.

Taking differentiation of equation (A-4) by ln Y^*, $\lambda(t)$ can be computed as follows:

$$\lambda(t) = -\frac{\partial \ln P}{\partial \ln Y^*} = \sum_{i=o}^{n} a_i t^i + \ln Y^* \frac{\partial \sum_{i=0}^{n} a_i t^i}{\partial \ln Y^*} \approx \sum_{i=0}^{n} a_i t^i \qquad \text{(A-5)}$$

Table A3-1 List of wind farms in China (*2003*)

No.	Facility	Capacity (KW)
1	Hebei Zhangbei Wind Farm	9.8
2	Inner Mongolia Zhurihe Wind Farm	4.2
3	Inner Mongolia Xilinhaote Wind Farm	30.7
4	Inner Mongolia Huitengxile Wind Farm	1
5	Inner Mongolia Shangdu Wind Farm	3.8
6	Liaoning Donggang/Hengshan Wind farm	17.2
7	Zhejiang Hedingshan Wind Farm	10.2
8	Zhejiang Sijiao Wind Farm	0.3
9	Shandong Rongcheng Wind Farm	0.2
10	Hainan Dongfang Wind Farm	8.8
11	Shandong Changdao Wind farm	0.1
12	Guangdong Nan'ao Wind Farm	42.4
13	Fujian Pingtan Wind Farm	1.1
14	Xinjiang Dabanheng Wind Farm	64.1
15	Jilin Tongyu Wind Farm	7.2
16	Shanghai Zongming Wind Farm	NA
17	Jiangsu Qidong Wind Farm	NA
18	Zhejiang Linhaiguocangshan Wind Farm	19.8
19	Jiangxi Panyanghu Wind Farm	19.8
20	Guangdong Shantou Huilai Wind Farm	12.0
21	Gansu Yumen Wind Farm	1.2

Source: Zhang Zhengming (2003).

Table A3-2 Wind equipment public companies (*2009*)

Company name	**Code number**	**Description**
Goldwind	2202	China Cumulative installed wind turbine Market share top1
DEC	600875	Leshan city MW class Wind power project capacity reach 1500 set MW class Wind Generator
Huayi wind	600290	Published 600KW,750KW Wind control system, cooperated with Goldwind for batch production and installed it to Goldwind 750KWWind turbine
Yixing energy	862	Batch production of Wind turbine, also focus on gearbox control system etc related components. focus on MW class Wind equipment localization
Wolong electric	600580	Join in annual capacity 30 MW wind power equipment localization project
TWBB	600550	Developed 1.5MW Wind turbine and Wind turbine blade business
Changzheng Electric	600112	Established AVANTIS-Yinhe Wind Co.,Ltd focus on Wind power sales and manufacturing and their wind turbine localization rate reach or more than70％
XEMC	600416	built up Hunan Hara XEMC Windpower manufacturing (Japan Yuanhongchan quit in 2008 because finance problem) Co.,Ltd with apan Yuanhongchan Cooperation focus on 1.5MW,2MW Wind Generator and wind turbine
Miracle Logistics	2009	Focus on bamboo materials Wind turbine blade
Sinoma	2080	Sinoma Wind turbine blade focus on 600MW Wind turbine blade project
DEC	600875	Wind turbine blade generator etc business
SEC	600627	Focus on wind inverter with partner one Canada company
Great Wall Electric	600192	Wind power equipment and generator
Huitong Group	415	Xinjiang huitong Wind equipment co.,ltd
LengGuang Industrial	600629	Shanghai FRP Research Institute joined LengGuang Industrial focus on wind blade
Xinmao S&T	836	Purchase 45% shares of Xinfeng Energy

Data source: Wind Trade magazine (2010).

Table A3-3 Top IPCs of foreign wind turbine manufacturing firms and China's domestic gearbox manufacturers

Foreign Wind turbine Gearbox			China Gearbox		
IPC	**Patent count**	**Percentage**	**IPC**	**Patent Count**	**Percentage**
F03D	3206	37.6	F16H	3388	20.8
H02P	645	7.6	B60K	1482	9.1
F16H	580	6.8	A01B	694	4.3
H02K	496	5.8	H02K	555	3.4
F03B	404	4.7	F16D	536	3.3
F01D	209	2.5	A01D	532	3.3
H02J	198	2.3	F03D	495	3.0
B64C	189	2.2	B62D	320	2.0
G06F	115	1.4	E21B	302	1.9
F16C	112	1.3	B62M	285	1.8
B23P	111	1.3	B23B	260	1.6
B63H	104	1.2	B60W	254	1.6
F02C	97	1.1	B23Q	237	1.5
F04D	95	1.1	G01M	232	1.4
H02M	91	1.1	A01C	218	1.3
F16D	87	1.0	B60L	185	1.1
G01M	81	1.0	B24B	170	1.0
F03G	63	0.7	B23P	147	0.9
B64D	49	0.6	B63H	144	0.9
G05D	47	0.6	B29C	140	0.9
E04H	47	0.6	B66D	140	0.9
G05B	47	0.6	B60T	137	0.8
B60L	44	0.5	F16J	132	0.8
F04B	43	0.5	B65G	131	0.8
F16F	42	0.5	F03B	128	0.8
B24B	42	0.5	F04B	127	0.8
B60K	40	0.5	F16C	127	0.8
G01L	40	0.5	B60R	125	0.8
F02B	39	0.5	A63H	111	0.7
B66C	38	0.5	E02F	111	0.7
H02H	37	0.4	F16F	107	0.7
G01R	34	0.4	B21D	104	0.6
B63B	33	0.4	F16K	101	0.6
G01B	33	0.4	F02D	99	0.6
C10M	29	0.3	F04D	99	0.6
B32B	28	0.3	H02P	98	0.6
G01D	28	0.3	F02B	97	0.6
E21B	28	0.3	B60P	94	0.6

G01P	27	0.3	B23D	94	0.6
F16N	26	0.3	B66C	91	0.6
G01N	24	0.3	B66F	89	0.6
G06Q	24	0.3	B25F	87	0.5
E02B	24	0.3	B23K	86	0.5
F02K	23	0.3	B01F	85	0.5
B29C	22	0.3	B02C	83	0.5
F01M	22	0.3	A01G	82	0.5
F02N	22	0.3	B62K	81	0.5
F25B	20	0.2	G01N	78	0.5
B23F	20	0.2	B30B	78	0.5
H01F	19	0.2	G05B	78	0.5
B05B	19	0.2	F16N	76	0.5
G01H	19	0.2	B65H	76	0.5
H01L	19	0.2	H02J	73	0.5
F02D	18	0.2	A01F	72	0.4
B01D	18	0.2	B60B	69	0.4
F01K	18	0.2	F15B	69	0.4
F24J	17	0.2	B25B	69	0.4
B21D	16	0.2	A61H	67	0.4
F16J	15	0.2	B28B	67	0.4
C23C	14	0.2	C02F	66	0.4
H02N	14	0.2	A01M	66	0.4
C08F	14	0.2	B21B	64	0.4
H01R	14	0.2	E01H	63	0.4
A01G	14	0.2	F04C	63	0.4
C10N	14	0.2	F03G	62	0.4
F01C	13	0.2	B23C	59	0.4
B08B	13	0.2	E01C	57	0.4
F16L	13	0.2	B60S	57	0.4
B60T	13	0.2	G09B	56	0.3
F04C	13	0.2	E05F	54	0.3
H05K	13	0.2	H01H	54	0.3
F01B	12	0.1	E06B	53	0.3
G01S	12	0.1	B61C	52	0.3
F15B	12	0.1	B08B	51	0.3
C02F	12	0.1	F02N	50	0.3
B23B	11	0.1	F02C	50	0.3
C01F	11	0.1	G01B	50	0.3
B65H	11	0.1	G05D	49	0.3
B66D	11	0.1	B01D	49	0.3
E04B	11	0.1	B25J	48	0.3
F16M	10	0.1	B66B	48	0.3
G01W	10	0.1	A01K	47	0.3

F25D	10	0.1	B25D	46	0.3
F15D	10	0.1	F01M	45	0.3
G01C	9	0.1	E21C	44	0.3
C04B	9	0.1	B60G	44	0.3
B25B	9	0.1	B21C	44	0.3
B62M	9	0.1	B64C	43	0.3
F16B	9	0.1	B65B	43	0.3
B60R	9	0.1	A47J	43	0.3
H01Q	9	0.1	B28C	42	0.3
C07C	9	0.1	B22D	41	0.3
E02D	9	0.1	F01D	40	0.3
C21D	9	0.1	B21F	40	0.3
C22C	9	0.1	B26D	39	0.2
F28F	9	0.1	A61G	39	0.2
B60W	8	0.1	B28D	38	0.2
B64B	8	0.1	A47L	38	0.2
G08B	8	0.1	A61B	37	0.2
B21K	8	0.1	B61F	36	0.2

Source: Thomson database (2012).

Table A3-4 Prices of China’s wind and coal power (*1998*): *Yuan/kwh*

	Wind power	Coal power	Ratio
Xinjiang	0.70	0.32	2.19
Inner Mongolia	0.71	0.35	2.03
Liaoning	0.95	0.45	2.11
Shandong	0.80	0.45	1.78
Zhejiang	0.79	0.50	1.58
Fujian	0.79	0.55	1.44
Guangdong	0.77	0.60	1.28

Source: Zhao Jiarong (1998).

Table A3-5 Popular MW class turbines in the wind industry

Technical Spec.: Name/types:	Capacity kW	Rotor diam. m	Energy MW/m^2
Acciona AW 77/70	1500	70/77	9358
AccionaAW 3000	3000	116	51398
Dongfang, DEC, 1.5 MW	1500	70	9358
Dongfang, DEC, 1.5 MW	1500	77	11324
Ecotechnia 1.67 MW	1670	74	11644
Ecotechnia 1.67 MW	1670	80	13608
Econtecnia 2.0 MW	2000	80	16297
Enercon E66, 1.8 MW	1800	70	11230
Enercon E66, 2.0 MW	2000	71	12837
Enercon E70, 2.0 MW	2000	70	12478
Enercon E82, 2.0 MW	2000	82	17123
Enercon E82, 3.0 MW	3000	82	25684
Enercon E112, 4.5 MW	4500	112	71872
Enercon E112 , 6.0 MW	6000	112	95829
Enercon E126, 6.0 MW	6000	126	121284
Fuhrländer FL MD77	1500	77	11324
Fuhrländer FL 2500	2500	100	31831
GAMESA G80	2000	80	16297
GAMESA G83	2000	83	17543
GAMESA G87	2000	87	19274
GE Wind 1.5s,sl,se	1500	70.5 / 77	9492
GE Wind 2.3	2300	82	19691
GE Wind 2.5	2500	104	34428
Goldwind 1.5 MW	1500	70	9358
Goldwind 1.5 MW	1500	77	11324
Hunan XEMC XE72	2000	72	13201

MHI, MWT 62	1000	62	4894
MHI,MWT 92	2400	92	25864
Mingyang MY1.5se	1500	77/82	11324
Nordex N60/N62	1300	60/62	5959
Nordex S70/77	1500	70/77	9358
Nordex N90, 2.3MW	2300	90	23720
Nordex N90, 2.5MW	2500	90	25783
Nordex N100, 2.5 MW	2500	90	25783
REPOWERMD77/MM70	1500	70/77	9358
REPOWER MM82	2000	82	17123
REPOWER MM92	2000	92	21553
REPOWER M5, 5 MW	5000	126	101070
Sewind W1250	1250	64	6519
Siemens SWT-1.3-62	1300	62	6363
Siemens SWT-2.0-76	2000	76	14708
Siemens SWT-2.3-82	2300	82.4	19883
Siemens SWT-2.3-93	2300	93	25328
Siemens SWT-3.6-107	3600	107	52478
Sinovel 70-1500	1500	70	9358
Sinovel 77-1500	1500	77	11324
Sinovel 82-1500	1500	82	12842
Suzlon 1.25 MW	1250	64/66	6519
Suzlon 1.5 MW	1500	82	12842
Suzlon 2.1 MW	2100	88	20706
VESTAS V82	1650	82	14126
VESTAS V80-1.8MW	1800	80	14668
VESTAS V80	2000	80	16297
VESTAS V90-1.8/2MW	1800/2000	90	20626
VESTAS V90	3000	90	30940

WinWind 1 MW	1000	62	4894
WinWind 3 MW	3000	90/100	30940
Windey WD77	1500	77	11324

Source: Data collected from various catalogue.

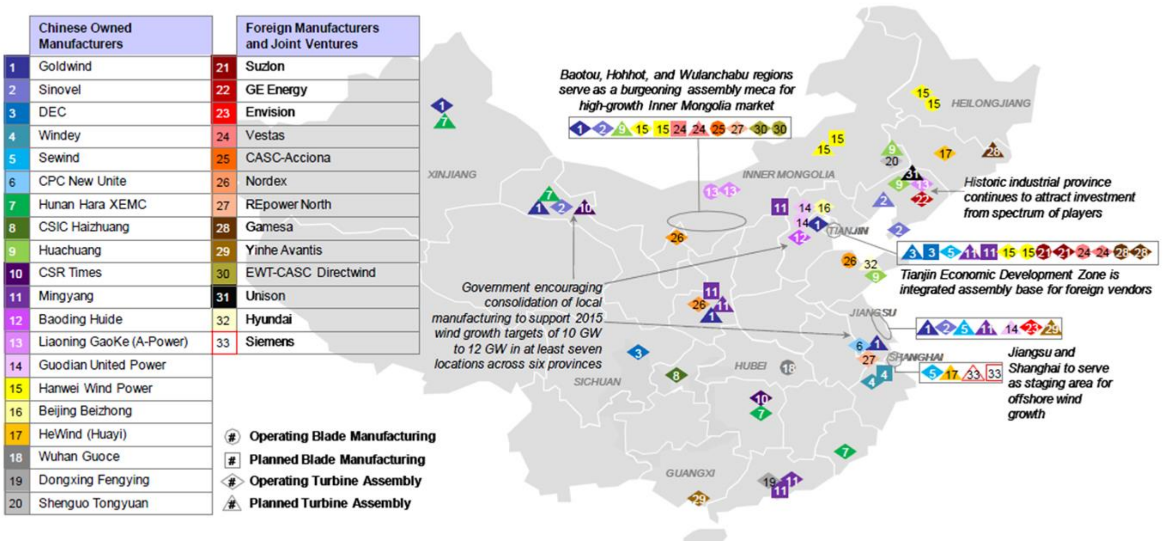


Fig. A3-2 China wind turbine production facility locations, operational and planned by companies (2011).
Source: Make market report (2011).

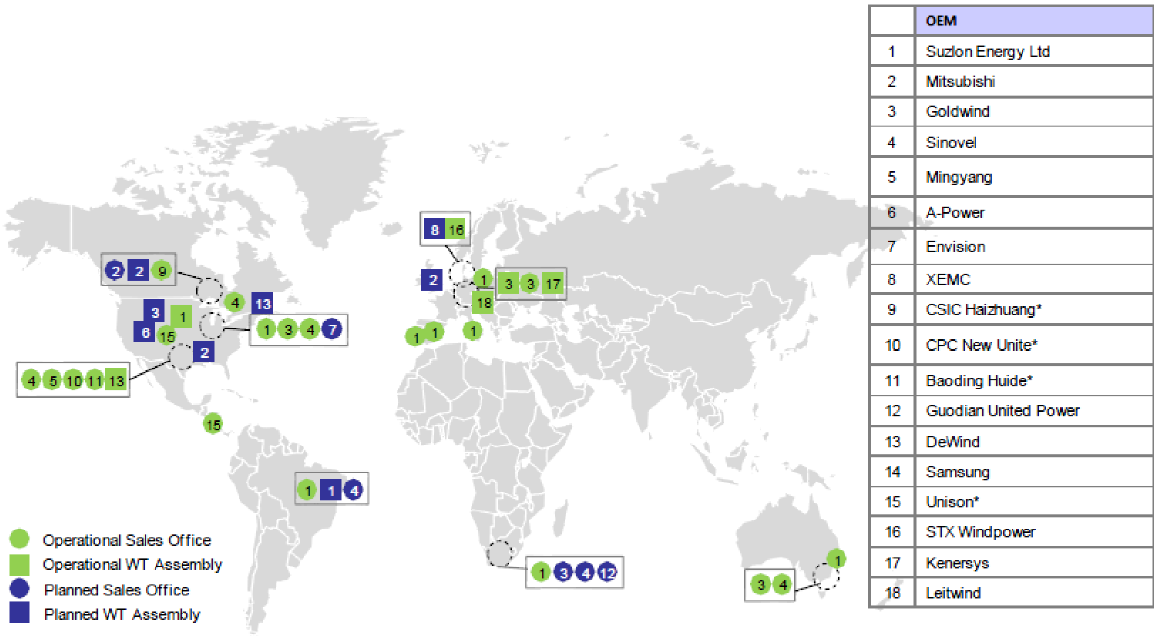
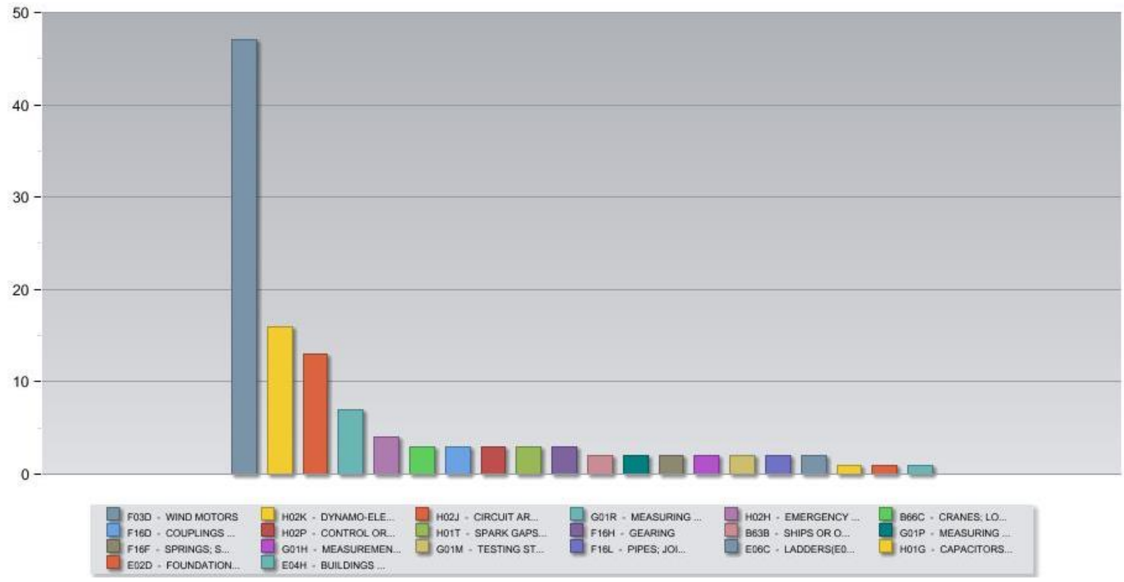
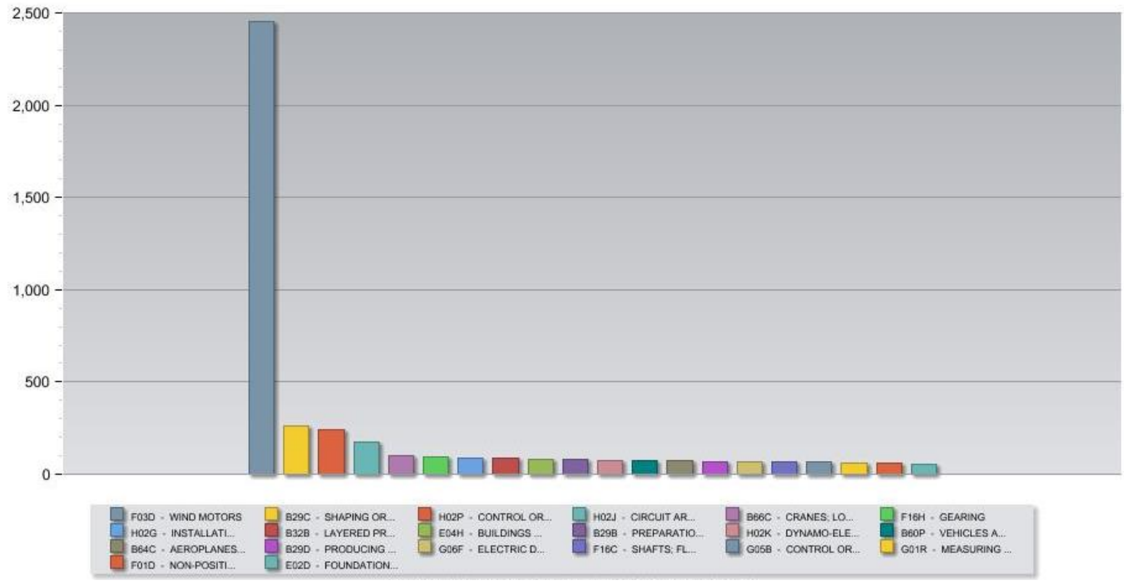


Fig. A3-3 China and other Asian global wind turbine production facility locations (2011).
Source: IHS emerging energy research report (2011).



(a)



(b)

Figure A3-4 Patent count for Top 20 IPCs of Goldwind and Vestas wind turbines (*2012*).
Source: Thomson database (2012).

Chapter 4

Government's Catalytic Role in Emerging Economy:

Critical Comparison of China's Conspicuous Strength in Wind and Solar Industry

Abstract

In light of a conspicuous strength in China's solar and wind industry in recent years this paper analyses the catalytic role of the government in inducing the institutional source of its strength. Critical comparison of the two industries shows the China's renewable energy policies for wind industry was more effective than the solar industry through adopting a self-propagating functionality development through fusing the external technology with domestic industries know-how to co-evolve both production and diffusion through effective assimilation. This suggests a new insight for growing economy to devise effective policy framework to develop global competitive industry.

Keywords: Fusion, learning, global best practices, growing economy, global competitiveness

4.1 Introduction

China policies have been praised by the world community[1] including the Europe and USA, mainly the implications of the Chinese twelfth five year plan for the global race towards low carbon technology competiveness (Worldbank (2013), IEA (2013), REN21 (2010), Wharton (2011)). For example, after the renewable energy law was passed in 2005

[1] http://www.worldbank.org/projects/P067625/china-renewable-energy-scale-up-program-cresp
http://www.iea.org/

(NREL (2009)), the renewable energy uptake has been significant as shown in Figure 4. 1 and the total adoption of wind energy has reached 66 GW by 2011. This has been supported by conspicuous domestic production capacity that has been moving towards indigenized with least import of components. This was achieved through China government's catalytic role in inducing stimulation through right policies such as renewable energy law in 2005 and setting sincere targets such as 15% renewables by 2015 (APERC (2009)). For example in wind energy it is focused to achieve at least 100 GW of wind energy by 2015[2] and with its accelerated pace it may reach the target much earlier.

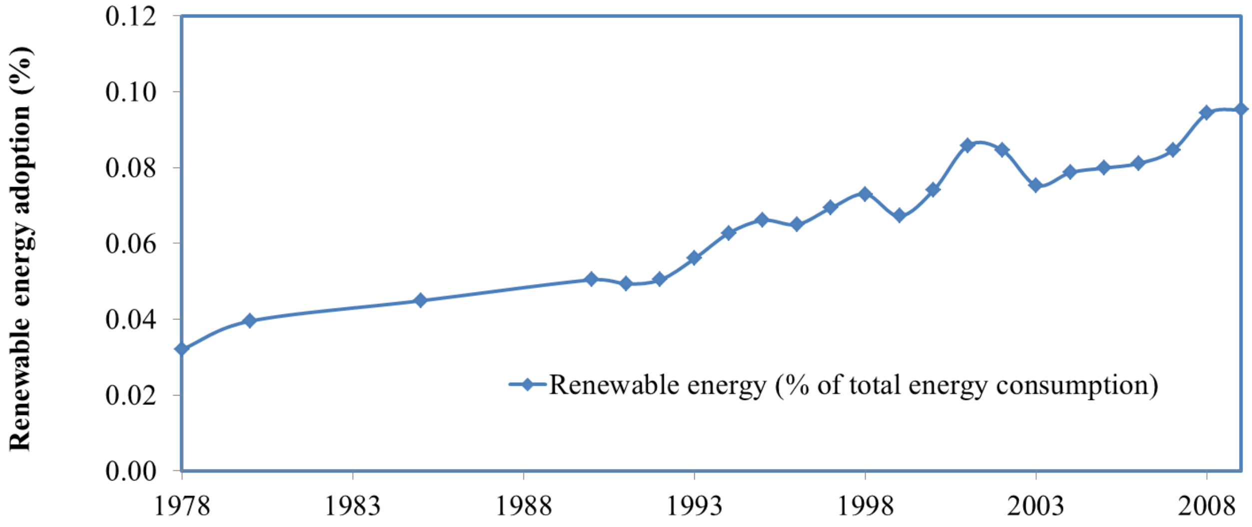


Figure 4.1 Renewable energy adoption in China (*1979-2009*).

What interests the research community is in understanding the underlying mechanisms and working methods behind such catalytic role of government to achieve such goals as an emerging nation compared to its policies in year 2000 (Sinton and Frindley (2000)). Hence forms the focus of this research. One observation is that China has setup a virtuous cycle between assimilation capacity increase and acceleration in the emergence of

[2] http://www.reuters.com/article/2012/08/14/china-power-targets-idAFL4E8JD2WV20120814

the functionality development[3] (Watanabe (2003)). Since its opening its domestic market in the 1980s, China has been constantly investing its research and development up to 2% of the GDP (ERI (2009) and Buijs (2011)). This has helped in the growth of industrial enterprises, research institutes and higher educational institutes. Such institutes have been planned as clusters over the years that today China has more than 100 clusters spread across its 41 provinces with 500 over production centres, 30 university technology parks and 20 business foundation parks, etc. (Frost, 2010) that contribute to significant manufacturing output at various levels viz., light, medium and heavy industry output as shown in Figure 4.s 2 and 3. Appendix A1 lists the table A1, A2 and A3 that lists the high technology firms and their gross output, total income and exports, their enterprises growth and healthy pipeline of raw material growth and finished product growth which indicates their value addition.

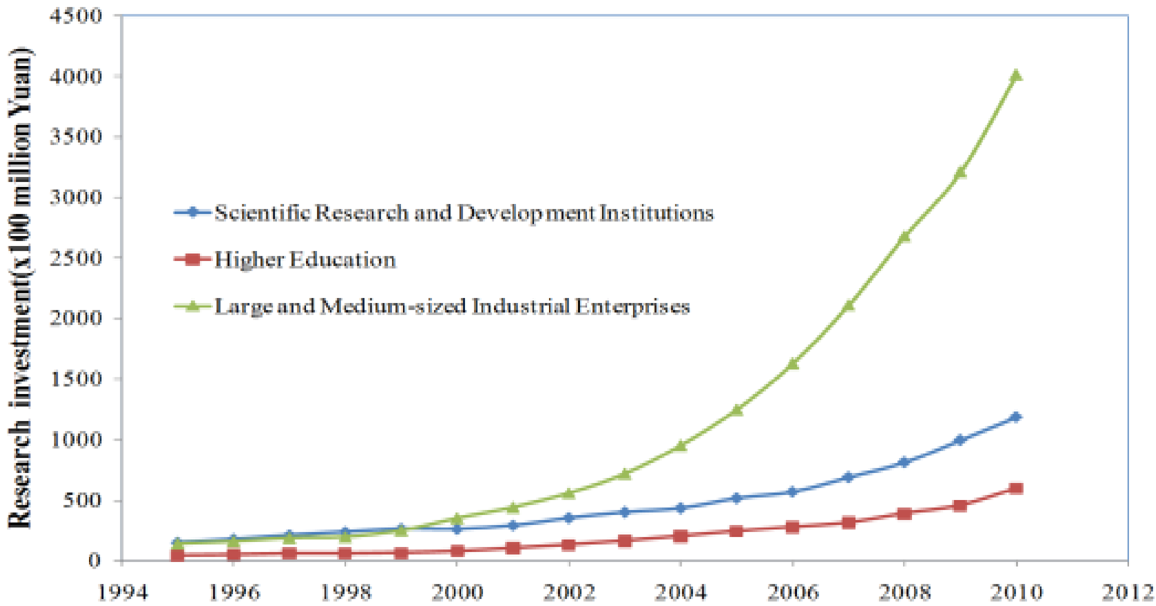


Figure 4.2 Growth of education and research institutions and industrial enterprises in China (*1995-2010*).

[3] Functionality development may imply: "Ability to improve performance of production processes, goods and services by means of innovation" (Watanabe et al., 2003).

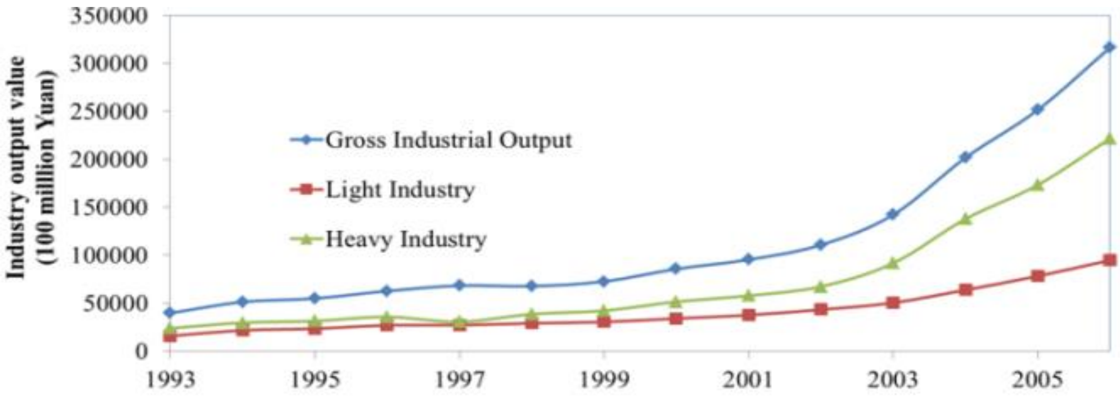


Figure 4.3 Growth of education and research institutions and industrial enterprises in China (*1993-2006*).

Foregoing observation prompts us that China's recent renewable energy initiatives[4] (Bogaert (2010), NREL (2013)) can largely be attributed to its conspicuous accomplishment in its renewable energy as follows:

(i) Renewable energy law in 2005,

(ii) Higher target15% renew energy by 2015,

(iii) Insist in 90% domestic parts,

(iv) Support formation and navigate goals of industrial clusters, and

(v) Setting up consortia between academia and industries.

Such stimulants have helped to induce its industrial clusters towards assimilation of knowledge spillover from earlier foreign direct investment (FDI) and analyse relevance of earlier domestic innovations developed for other industries to transform towards new industry needs. Partly these lie with the skilled labour trained in earlier industries with similar technologies. The result of such assimilation is in increasing the acceleration of production

[4] http://www.nrel.gov/docs/fy04osti/35786.pdf

such that emergence of new functionality development has been observed. In the case of China's wind industry such functionality development has been observed in terms of size of the wind turbines growing in geometric size as a consequence of sophisticated design, increased production and installation ability that has reached top world level, etc.

Similar observation with China's solar industry confirms the early study on the fusing behaviour of the domestic firms with their know-how along with global free open access information such as patents and design standards in solar cell and module PV manufacturing, due to knowledge spillover from relevant industries such as semiconductor and integrated circuit manufacturing industries (Srikanth and Watanabe (2012)). Secondly, estimates confirm that China has healthy solar natural resources as shown in further section. However, in terms of installations, China has failed to exploit in adopting solar PV as a significant energy source into its main stream of clean energy.

4.2 China's Energy and Environment Policies

Over 30 years from 1979 to 2009, the average annual growth rate of primary energy consumption in China is 5.6%, while the average annual growth rate of Gross Domestic Product (GDP) was 9.9 percent[5] (Kahrl and Holst (2009), Zhang and Zhao (2006) and EIA (2013)). The goal of quadrupling GDP was achieved basically with the support of a doubling of energy consumption with unprecedented attention to energy conservation efforts. According to the economy's basic policy, the resource-saving target was set so that during the period of the 11th Five-year Plan the unit energy consumption GDP would be reduced by about 20%. In order to accomplish the goal of energy conservation, China's government established a series of policies, legal and economic measures. In 2005, the government

[5] http://www.eia.gov/todayinenergy/detail.cfm?id=8070

promulgated the Renewable Energy Law, which aimed at supporting the wind power projects. Since then the number of installations have been doubling every year (Chow, 2007). In 2009, China pledged the UN climate change[6] summit in New York to increase non-fossil fuels by 15 percent by 2020 and reduce greenhouse gases by 40 to 45 percentage comprises to that level in 2005 (Pew (2013) and Fas (2013)). Progress has been made towards achieving the 20% energy intensity reduction target, having achieved reductions of 2.74% in 2006, 5.04% in 2007, 5.20% in 2008 and 3.61% in 2009, respectively (revised according to the 2nd national economic survey), for a total reduction of more than 15% so far.

4.2.1 Factors favouring the renewable energy adoption in China

A comparison between solar and wind energy in terms of geographic resources, technology readiness of external know-how and China's intrinsic manufacturing know-how can be reviewed to understand how China sees the two energy sources before adoption and diffusion for its energy needs.

4.2.1.1 Resource assessment

(i) Wind

China balances farmland to the wind power. For example, lands with slopes greater than 4 percent are not considered for wind power development and estimated potential installed capacity shows a potential of upto 5 megawatts per kilo meter square (Li Junfeng (2012)). The onshore technical capacity potential is 2380 GW and a capacity of 25 percent and the estimated technical potential is 5.2 million Giga watt hour per year at a turbine height of 50 meter height which was more than 1.5 times China's electricity generation as of 2007.

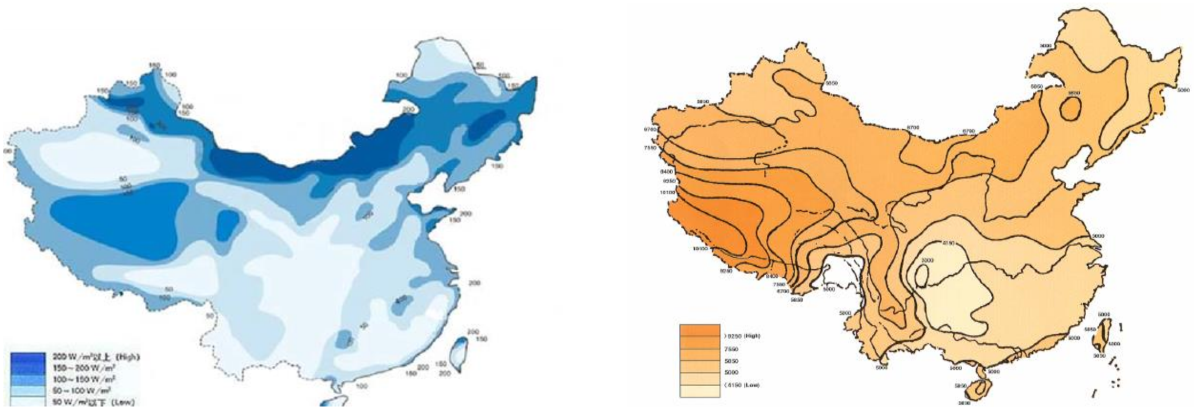
[6] http://www.c2es.org/docUploads/country-pledge-brief.pdf
http://www.fas.org/sgp/crs/row/R41919.pdf

With increase in tower height to 80m the harvesting power increases to 30 percent more. China has rich offshore wind resource and are suitable for grid connected wind farms up to 2380 GW capacity. Figure 4. 4(a) shows the dispersion of wind energy potential.

(ii) Solar

As per 2007 estimates, China has ample solar energy sources that could provide 1.4 billion Giga watt hour per year. With a 10 percent conversion efficiency, only 0.23 percent of the land area are need to generate the 3.2 million GWh of electricity (Zhang et al. (2012)). At present, one fifth of the rooftop area of China (10 billion meter square) can suffice the energy need to provide 2200 GW even with a10 percent conversion efficiency. On an annual basis, it can amount to 2.9 trillion kWh even with 3.6 hours per day of sun.

Above facts provide sufficient evidence that China has the necessary potential for energy sufficiency to support from the renewable energy sources. Figure 4(b) shows the dispersion of solar energy potential.



(a) Wind (b) Solar

Figure 4. 4. Wind and Solar resources of China.
Source: Li Jiufeng (2012), Wang (2008), China solar PV report-2007, Greenpeace and DBCCA analysis 2011.

4.2.1.2 Technology readiness and change towards wind and solar energy

A major barrier to mass deployment of a new product such as wind turbines or solar photovoltaic (PV) equipment is their relatively high cost, lack of know-how, and lack of suppliers, lack of intellectual property. The levelized cost of energy (LCOE) generally reflects all the costs including capital cost, maintenance, changes in auxiliary systems such as grid system (e.g., balancing services or backup generation). Ultimately, the LCOE of the new technology (renewable energy) such be cost-effective than the incumbent technology (fossil based energy).

United States has demonstrated to derive energy of more than 70 trillion watt hours in 2009 which met 1.2 percent of their energy needs. In similar lines, China aimed at achieving 15% of its energy needs from renewable energy by 2015.

China adopted wind turbines and solar energy during a stage when they were externally available as a dominant technology in the western world. For example, China focused on solar crystalline silicon based technology which was a first generation technology in solar PV industry and on the three bladed horizontal axis product architecture in wind turbines industry which was a matured technology from the developed nations. Hence the product innovation was well matured and available for technology licensing from multinational firms and thus helped certainty in investment and technology spillovers. Thus, China had much relevant external know-how opportunities for direct knowledge transfer through joint ventures and collaboration and to promote learning from free-open sources such as patents, and technical standard and academic publications when it decided to adopt and domesticate these technologies.

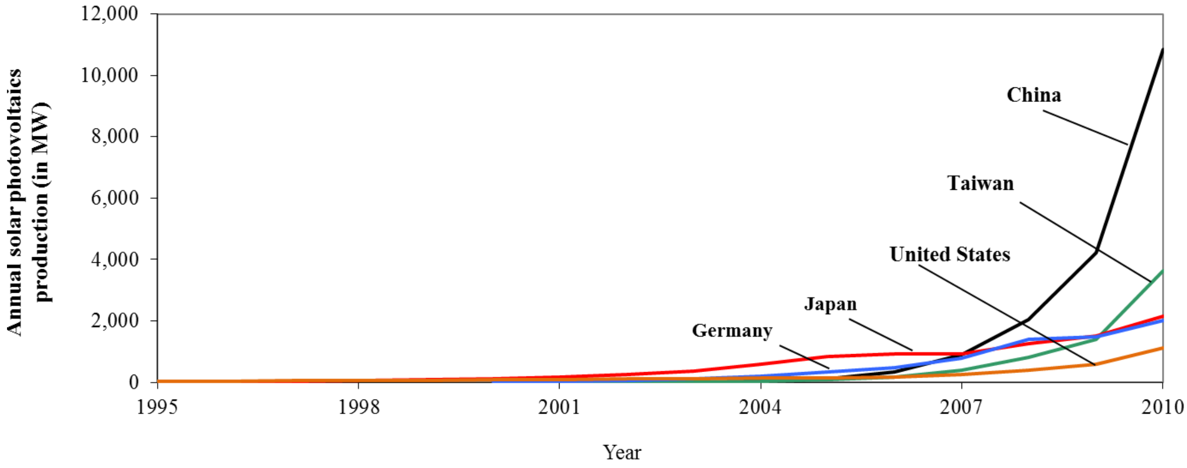


Figure 4.5 Annual photovoltaic production in major countries (*1995 - 2010*).
Source: Earth Policy Institute (2012).

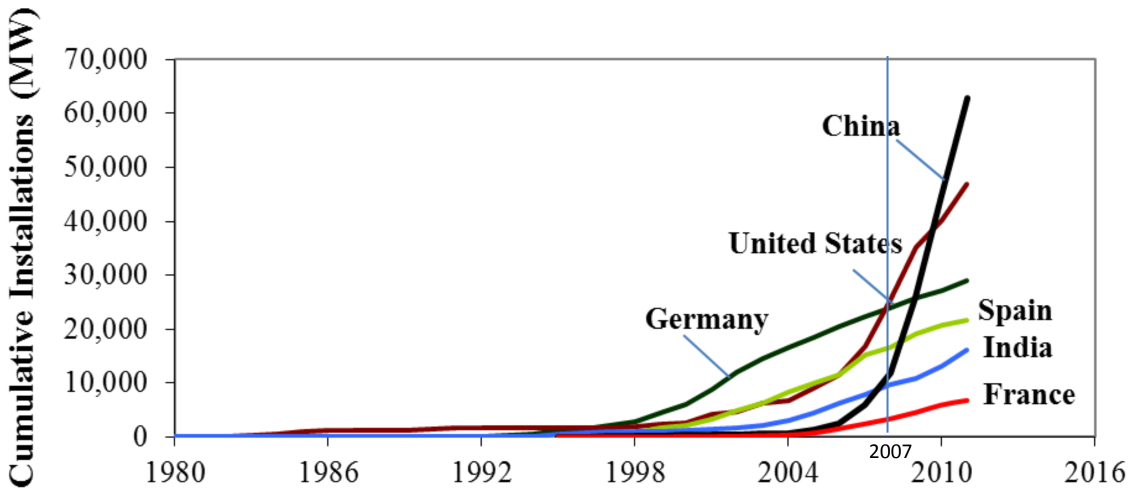


Figure 4.6 Cumulative installation of wind turbine in different countries (1980-*2011*).
Source: Earth Policy Institute - www.earth-policy.org (2012).

4.2.1.3 China's conspicuous wind and solar energy production

Supported by the foregoing comprehensive endeavours, China has demonstrated its conspicuous strength in the solar PV manufacturing and wind turbine manufacturing technology and has evolved a robust supply chain that meets international production quality as seen in Figures 5 and 6 compared to other parts of the world. However, China has ample resources of wind and solar energy potential and the ample energy demand due to the industrial growth that the two industries can flourish within the country and support the economic growth in a decarbonized fashion.

From demand side, solar PV diffusion (in terms of deployment and energy generation) lags behind wind power in terms of installed capacity by about five to six years in China. If we overlook the still-unresolved issue of high production costs, PV sector has grown to a large enough scale that the preconditions now exist for a rapid development like that enjoyed by wind power five years ago. In 2010, China produced 10 GW of PV modules, while total installed capacity in the mainland did not even reach 1 GW. It is now imperative for China to actively develop its domestic PV market, and for this it can learn valuable lessons from the development of wind power. These lessons include introducing incentives, establishing initial market conditions, and most importantly, drawing up feasible development goals, ensuring the pricing mechanism benefits all parties and setting up an overall mechanism that would help connect PV power generators to the grid.

From the technology supply side, the solar PV has not leveraged the technology licensing and joint venture opportunities with the global counterparts. One reason being the crystalline silicon was matured and had reached a commodity state. Secondly, without sufficient government support the private firms cannot leverage with the external know-how from the global firms' explicit and tacit knowledge and wisely combined with the semiconductor know-how to develop useful products. These products were disruptive in nature with inferior technologies. However, some process know-how developed for semiconductor industry was useful such as dicing the wafer finer thickness helped increase the production volume from the same input stock. These dicing machines and other process machines were common to semiconductor industry and hence the same suppliers of the other industry could neatly align to the needs of the new industry. Example, ASM™ Technology

(Shenzhen) was an established firm making integrated circuit machines, started entering into solar cell packaging machines. Similarly, Applied Materials ™ started entering into solar wafer producing machines. Thus, the support from the government policies for the initial knowledge seeking stage was lacking. Secondly, the internal market during the inception of the solar market was poor in China. Only in the past few years China has been motivating the domestic installations. The industry has purely grown in the support of the export markets. At the same time, China must continue to promote the PV production industry and work towards lowering production costs.

Production costs for wind and solar power are falling: Solar power is already close to grid parity. In some areas, wind power is already economically competitive with coal. Renewable energy, such as wind and solar, has been taking on greater responsibility due to Japan's nuclear accident and unrest in oil production areas. The persistence of electricity grid bottlenecks remains the biggest uncertainty facing wind and solar energy.

According to UNEP (2011) estimates, the technical wind potential in China is 2780 GW and solar PV potential is 2200 GW. From the above discussion, it is clear that while wind power adoption has achieved rapid growth, the solar PV adoption has been significantly poor. In contrast to wind, solar PV power adoption was slow due to high development cost, lack of domestic market creation despite with rich solar energy resources.

4.2.2 China's favoured wind energy adoption compared to solar PV

In China, the renewable energies have been rapidly adopted in the last decade (Leggett (2011)). However, the fossil based fuels like coal still dominates. There is an increasing level of awareness of the advantages of renewable energy in China such as wide distribution of resources, greater utilization potential, less environmental pollution and alternative energy sources. China introduced the "Renewable Energy Law" in 2005 being effective from January 2006, which encouraged development of wind, solar and hydro, biomass, geothermal and ocean energy (Lin (2007)). Table 1 demonstrates their contribution in the recent years taking four major sources of renewable energies in China that gained different levels of developments. Hydro has been a renewable source of power in China and biofuels have non-energy related issues such as land use changes that could lead to higher food prices (Tilman et al., 2009). Next to hydro power, which was considered to be a matured technology, the domestic market installation within China showed a preferable adoption towards wind as compared to solar PV (see Figure 4. 7) which was equally being preferred by countries such as Germany during the same time period and China was capable to supply to the foreign market with the necessary technical requirements and quality. Table 2 critically compares the production and domestic market of wind and solar-PV capability in China, which shows the mismatch and creates a curiosity to understand the reasons such as the policy differences and other related reasons between solar and wind installations. Appendix B1 gives additional details of the China's renewable energy policies specific to solar and wind industry.

Table 4.1 Electricity generation from renewable energy sources (*2003-2008*)

Type of renewable power	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Small hydro	95.62	92.32	91.93	90.11	85.40	78.00
Wind power	1.76	2.07	3.06	5.59	10.51	17.32
Biomass	2.47	5.43	4.84	4.13	3.91	4.47
Solar PV	0.15	0.18	0.17	0.17	0.18	0.21

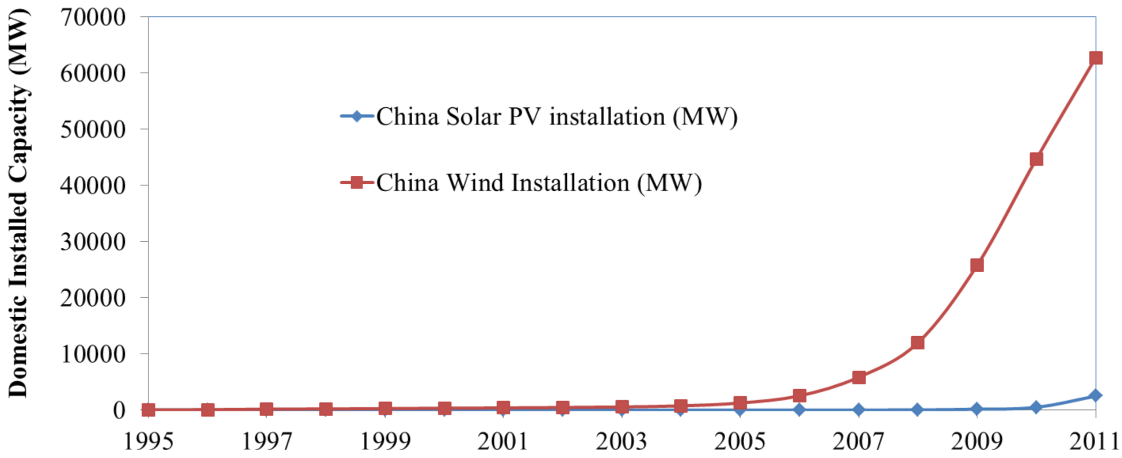


Figure 4.7 Domestic installed capacity of Solar and Wind installations in China (*1995-2011*).

Table 4.2 China's wind and solar PV status: domestic market and production capacity (2011)

Renewable source	**China's progress**
Wind	Installed Capacity (i) China is the world's largest market, with 13.8GW added in 2009 , more than one third of the global market. (ii) Wind capacity was doubled in 2009 in pursuit of an ambitious target of installing 30GW of wind by 2020. Domestic industry capacity (i) Large scale wind market is taking shape rapidly and the domestic industry is booming. (ii) China remains the largest market for small wind tubrines (2009).
Solar	Installed Capacity (i) Total capacity in 305 MW in 2009 (one-third provided by independent producers off-national grid). (ii) Major imbalance between PV production and domestic market. However rapid expansion planned setting up ambitious midterm targets for domestic market, 1800 MW installed capacity by 2020.

Domestic industry capacity

(i) PV industry has been growing rapidy. China is the leading manufacturer of solar PV panels, with more than 40% share of global PV cell production in 2009and about 50% in 2010.

(ii) 95% of production is exported.

(iii) Most raw materials and equipment are imported.

Source: UNEP, Enhancing information for renewable enrgy technology deployment in brazil, China and South Africa, 2011.

On the basis of the foregoing observations, aiming at understanding the causes for the difference in adoption rate, the resource availability technology maturity and commercialization potential are compared. This provides strong evidence that the policy framework affects the renewable energy developments significantly. Therefore, a contrasting study of solar and wind related policy is focused for detailed discussion in this paper.

4.3 Analytical Frame work

4.3.1 Hypothesis

Based on the above discussions, following hypothesis can be postulated:

While conspicuous increase in production of China's solar PV and wind can be attributed to effective learning and assimilation of spillover technologies in existing industries, contrasting adoption between wind and PV can be attributed to learning from related domestic industry and foreign wind industries with government's priority inducing policies.

4.3.2 Existing works

The diffusion of renewable energy technologies have been discussed (Jacobsson and Johnson (2000a)) and the role of policy and key actors was discussed. Traditionally Chinese energy policy emphasized on energy efficiency and energy conservation in the last two decades, from 1980 to 2000, during which GDP quadrupled but energy consumption increased twice in order to continue this growth trend from 2000 to 2020, China found its steep energy demand and promoted energy efficiency and set to reduce 20% reduction target intensity into its 11th five year plan (between 2005 to 2010) (NDRC (2010), Kahrl and Holst (2009)). Presently, Chinese energy policy has been formulated based on energy security which based on its intrinsic energy sources (Buijs, 2011).

A second objective is to limit coal-fired power generation and establishing a strong domestic industry in wind, solar and nuclear energy (Buijs(2012)) in addition to hydropower which is the mainstay of renewable energy. The nonhydro renewables are stimulated by policies including feed in tariffs and a renewable energy portfolio standard (RPS) for grid and power companies (Martinot and Li, 2007). For wind energy, the total installed capacity has been doubling in the last four years in a row and the government has revised target of 120 from initial target of 30 GW by 2020. However, for solar energy the advancement has been poor of less than 1 GW by 2009 with a target of 1.8 GW for 2020 although it is possible to set above 10 GW.

China government's policy reforms mainly focused the allocation of capital investment to energy efficiency through instruments such as low interest loan programs, interest subsidies, tax credits, tax reductions and exemptions and setup of energy conservation service centres (Wang (2006) and Lin (2005)).

Nations invest in technologies to support industries. But over time, due to cost reasons the industries drift to other regions. The invested complimentary advantage, people assets, IP, e.t.c goes wasted if the technologies are not match made to new industry needs. Example Singapore invested in disk drive, IC packaging, and other industries. It established material research institute, manufacturing research institute, e.t.c today the old industries drifted and hence the new industries with similar complimentary knowledge are sought, example energy sector, water research and aerospace repair technologies. These are being promoted to be pulled in to take advantage of the existing complimentary technologies.

Earlier studies have shown the importance of role of domestic industries in supporting the growth of domestic industry (Est (1999), Jacobsson and Johnson (2000b)) highlighting that a country evolve an industry to support its own economic and social agenda through its own home market (Connor, 2004). In addition to the existence of the home market and relevant know-how in the domestic firms, the key is in the policies which will be dealt in the further sections of this study. However, the aim of this study is to show how policy tools promotes the uptake of wind and solar renewables into the energy sources and in the creation of domestic firms and accelerates uptake of the domestic components into the capital infrastructure of these energy sources. This helps to understand the importance of the pre-existing relevant know-how and importance of policies to co-evolve the supply chain in order to grow a new industry in a given region.

Technology has both tacit and explicit knowledge components (Nonaka and Toyama (2003)). To bring appropriate technology to a region, it requires absorptive capacity of the local firms, and skills and mobility of local employee (OECD, 2009). The mandate is to give domestic firms access to new product and process technologies of the MNEs, and to facilitate the use of local content and skills in the development of technology by MNEs (Feinbergy and Majumdar, 2001). Rai, Belle and Pedersen (2010) showed co-creation as an alternative to technology transfer and demonstrated how co-creation of ICT innovation can enable the emergence of future markets. Agglomeration theory of clusters, typical of knowledge clusters, often attracts direct investments from outside (Lorenzen, 2002). MNEs enter particular cluster to benefit from agglomeration economies that they facilitate (Porter (1998), Saxanian (1994); Krugman (1991); Frost (2001)). They want access to whole group of suppliers and customers, knowledge institutions which are not owned by other firms (Lorenzen and Mahnke, 2002).

In order to support our co-creation of indigenization of future technology supply to support future market conjecture the paper is organized in discussing the case studies of solar PV and wind energy technology adoption into China under the same time period. In the co-creation mode, it could be argued that technology transfers acts as an initial alignment opportunity where the transferred technology aligns growth and markets of developing countries to the knowledge base of the transferring entity to suffice the market impact (Rai et al. (2010)). Further which the indigenization through co-creation of supply chain by the recipient country helps its indigenous technology supply for the future growth and sustenance of its sovereignty and industry growth. Thus, the study grounds and illustrates the co-creation concept by case study and finally drawing the framework and further discusses the importance of policies favouring co-creation with some pointers.

4.3.3 Focus of the analysis

Since the prime objective of this paper is to analyse catalytic role of government R&D inducing hybrid management of technology, focus of the analysis can be identified as the interactions of the following institutional factors as a system as demonstrated in Figure 4. 8:

(i) Management of government policy encompassing resource allocation of the nation,

(ii) Government's market inducing policy tools,

(iii) Government inducement of manufacturing industry's strength,

(iv) Enhancement factors of industry's learning ability and mutual interaction between indigenous strength and learning effects.

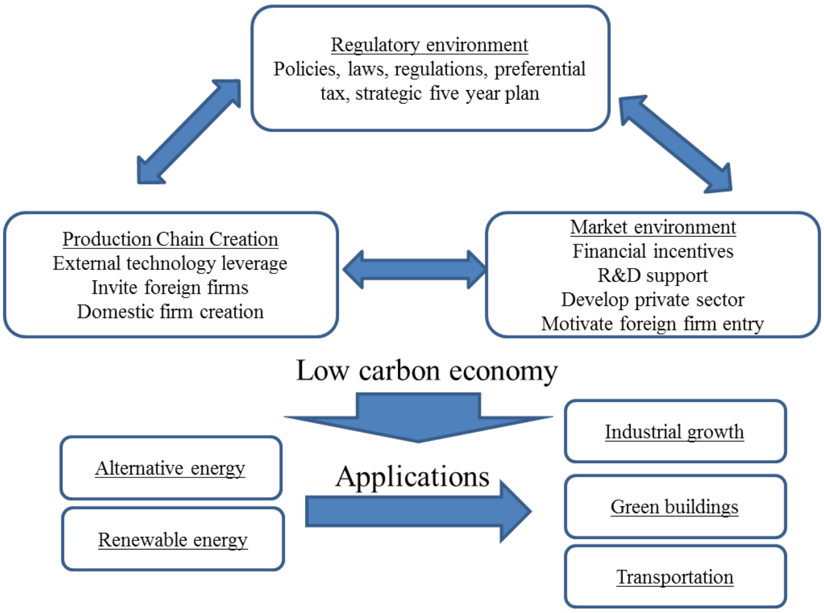


Figure 4.8 Systems interaction framework to relate the policy tools to co-create the production chain and domestic market to support a low carbon economy.

4.3.4 Analytical model formulation

Aiming at demonstrating the causal relation between foregoing institutional factors, the following investigations are attempted:

(i) Effects of government's catalytic stimulation,

(ii) Effects of technology stock on functionality development,

(iii) Spillover effect from foreign invested firms to private firms, and

(iv) Effect of technological progress of clusters growth.

(i) Effects of government's catalytic stimulation

The gross production value of the wind and solar industries in China can be depicted as a function of the government investment with a time lag that captures the incubation period to materialize implementation as follows:

$$Y_W = F\left(R_{gW(t-i)}\right) \quad (1)$$

$$Y_S = F\left(R_{gS(t-j)}\right) \quad (2)$$

where

Y_W: yield of China's wind turbine installations in mega watts,

Y_S: yield of China's solar PV installation, in mega watts,

$R_{gW(t-i)}$: indicates government funding to wind with a time lag (t-i),

$R_{gS(t-j)}$: indicates government funding to solar PV with a time lag (t-j),

i and j: denotes number of years for wind and solar, respectively, that varies from 0 to 5.

Taking logarithm, and varying 'i' and 'j' from 0 to 5 the best fit can be identified by taking statistically most significant:

$$ln(Y_W)_i = a + bln(R_{gW(t-i)}) \quad (3)$$

$$ln(Y_S)_j = a + bln(R_{gS(t-j)}) \quad (4)$$

where *a* and *b*: coefficients.

(ii) Effects of technology stock on functionality development

The technology stock (*T*) at time *t*, can be depicted by the following equation:

$$T_t = R_{t-m} + (1-\rho)T_{t-1} \quad (5)$$

where T_t: technology stock at time *t*,

R_{t-m}: R&D investment (fixed prices) at time *t-m*,

m: time-lag between R&D and commercialization; and

ρ : rate of obsolescence of technology.

Under the competitive circumstances where nation aims at maximizing the productivity of its technology stock, marginal productivity of technology $\partial V/\partial T$ corresponds to the relative price of technology P_T as follows:

$$\partial V/\partial T = P_T \quad (6)$$

Following Zhao and Watanabe (2006), using price of technology P_T, and nations technology stock *T*, market learning in fusing global best practice can be depicted by the following function with dynamic learning coefficient as a function of time 't':

$$P_T = AT^{-\lambda(t)} \quad (7)$$

$$\lambda(t) = \sum_{i=0}^{n} a_i t^i \quad (8)$$

Having established an increase in the cumulative production of renewable energy sources that includes solar PV and wind technology, the learning coefficient can be determined. The learning coefficient depicted by $P_T = A\sum Y^{-\lambda(t)}$, where P_T is the fixed price of the product, Y is the cumulative production, A is coefficient and $\lambda(t)$ is dynamic learning coefficient as a function of time 't'.

Emergence of the new renewable energy functionality development in China was triggered by the government's catalytic inducement initiated by its industrial cluster policy. It stimulates to assimilate the spillover technology from related foreign invested firms into renewable industries to develop indigenous products such as wind and solar energy equipment production and installation. It also induces fusing technologies that are licensed from international firms and by accessing global open access knowledge such as patent database and design standard. Thus, the strategy has helped maximize the marginal productivity of technology (*MPT*) ($= \partial RE_T/\partial T$), where RE_T is the renewable energy and its technology stock T is created by accumulating the R&D investment (R). An increase in the technology stock enhances renewable energy's functionality development, as demonstrated by the epidemic function depicted in equation (9).

$$(\partial RE_T/\partial T) = aRE_T\left(1 - \frac{RE_T}{N}\right) \quad (9)$$

where a: velocity of diffusion, and *N*: carrying capacity, this is raised by the new generation invention and diffusion (Meyer and Ausbel, 1999). From equation (9), diffusion trend in the renewable energy uptake can be depicted by the following logistic growth function:

$$RE_T = \frac{N}{1-exp(-aT-b)} \quad (10)$$

where b: the initial state of diffusion.

(iii) Spillover effect from foreign invested firms to private firms

The inter-dependency of private firms on the foreign firms' technology stock can be studied by composing the production function of a set of private firms specific to machinery and accounting the spillover of the technology stock from foreign firms at national level. One method is to compute the independent technology productivity function of the foreign firm as follows:

$$Y_F = A_F L_{F,j}^{\alpha_F} K_{F,j}^{\beta_F} \quad (11)$$

where

Y_F: foreign firms' production,

A_F: scale factor,

α_F, β_F: coefficients,

j: specific sector of industries,

L_F: foreign firms' labour stock, and

L_F: foreign firms' capital stock

Taking logarithmic form and computing the total factor productivity (TFP) for different industries, as follows:

$$ln(TFP_{F,j}) = ln(Y_{F,j}) - \alpha_F \, ln(L_{F,j}) - \beta_F ln(K_{F,j}) \quad (12)$$

where $TFP_{F,j}$: total factor productivity of j th sector of industries.

Given that the domestic private firms utilize TFP spillover from foreign firms by assimilating it, the productivity function of the domestic private firms can be computed by accounting the foreign firms' technology stock of same type of industrial sector as follows:

$$Y_P = A_P L_{P,j}^{\alpha_P} K_{P,j}^{\beta_P} TFP_{F,j}^{\gamma_P} \tag{13}$$

where,

Y_P: domestic private firms' production,

A_P: scale factor, and

$\alpha_P, \beta_P, \gamma_P$: coefficients,

Expressing in logarithmic form as follows:

$$ln(Y_P) = ln(A_F) + \alpha_P\ ln(L_{P,j}) + \beta_P\ ln(K_{P,j}) + \gamma_P\ ln(TFP_{F,j}) \tag{14}$$

(iv) Effect of technological progress of clusters growth

The gross production value of the heavy industries of different region in China can be depicted as a function of the employees and total capital assets as follows:

$$Y_i = F(L_i, K_i) \tag{15}$$

where subscript 'i': indicates region.

Expressing in Cobb-Douglas type production function and taking logarithm, total factor productivity (TFP) can be predicted as follows:

$$ln(TFP_i) = ln(Y_i) - \alpha\ ln(L_i) - \beta ln(K_i) \tag{16}$$

where α, β: coefficients.

4.3.5 Data construction

The present study utilized data such as gross domestic product (GDP), national R&D investment, patent and journal paper statistics, industrial statistics from World Bank data. Since China (OECD Science and Technology statistics) does not belong to OECD members countries, it was difficult to get data on multi-factor productivity. Therefore, China statistical database[7] was referred to obtain the time series at the national level and the regional level for the year 2010.

In modeling the technology spillover from foreign firms to domestic firms the machinery sector was chosen and 41 sector responsible for the wind and solar PV industry's supply chain was chosen and their labour, capital stock of domestic and foreign invested firms were analysed.

In modeling the quality, the China's regional manufacturing competitiveness was used as a measure for different region. The FDI data related to investment in assets, employment and industrial output were obtained from China's official FDI website[8]. Patent information, exports and overall country level data was also referred from OECD and World Bank data.

4.4 Results of the analysis

In the following section the empirical findings at national, regional and cluster level will be discussed.

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[7] http://www.stats.gov.cn/tjsj/ndsj/2011,

[8] http://www.fdi.gov.cn/pub/FDI_EN/Statistics/FDIStatistics/default.htm

4.4.1 Empirical findings

4.4.1.1 Effects of the stimulation

(i) Inducing effects of government R&D support

The production dependence on government support for wind industry was found to be:

$$ln(Y_i) = 6.650 + 0.796\, ln\left(R_{g\_W(t-2)}\right) \qquad adj.\ R^2 = 0.988$$

$$(9.97)^{***}\ (3.22)^{***}$$

*** Significance at the 1% level.

The production dependence on government support for solar PV industry was found to be:

$$ln(Y_i) = 5.804 + 0.809\, ln\left(R_{g\_PV(t-2)}\right) \qquad adj.\ R^2 = 0.893$$

$$(7.58)^{***}\ (10.49)^{***}$$

*** Significance at the 1% level.

(ii) Effect of technology stock on functionality development

The technology stock was computed and plotted against the patent stock which shows the increase of domestic patents applications and granted publications as shown in Figure 4.9.

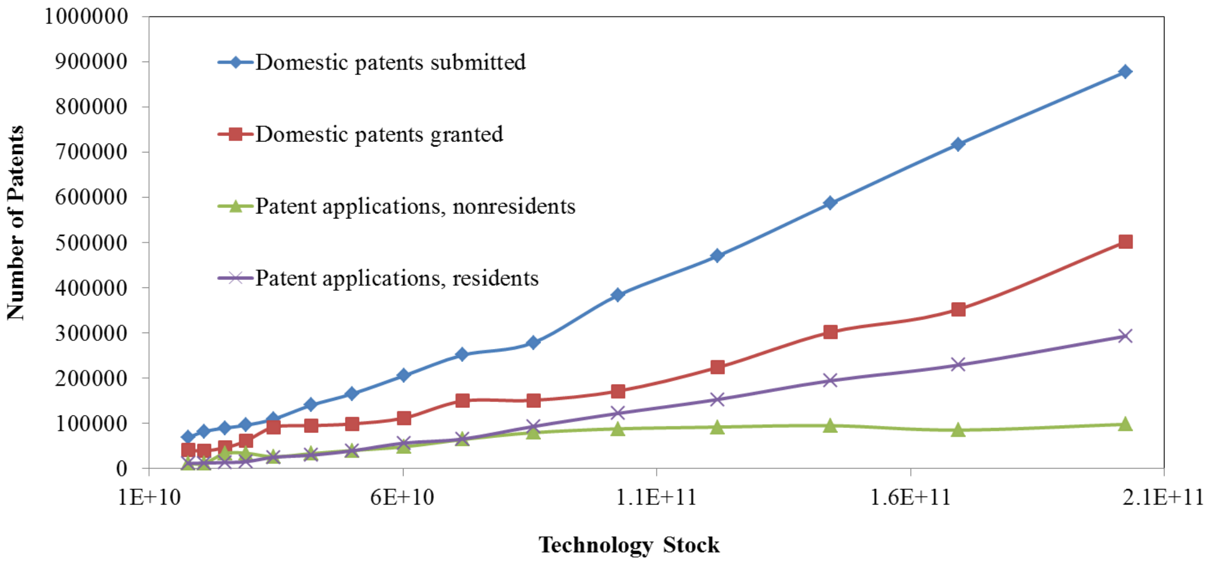

Figure 4.9 Industry patent stock trend with technology stock in China (*1993-2006*).

The learning coefficient of China's overall renewable energy adoption as shown in Figure 4.10 was empirically found using backward elimination method (BEM) with 1% significance criteria as follows:

$$ln(P_n) = 162.474 - (4.122 - 0.310\, t + 0.028\, t^2 - 5.076\, (10)^{-6} t^4)\, ln(\sum RE\,)$$

$(0.66)^{***}$ $(-4.44)^{***}$ $(-2.58)^{***}$ $(4.23)^{***}$ $(-4.26)^{***}$

*** Significance at the 1% level. *adj*. $R^2 = 0.979$

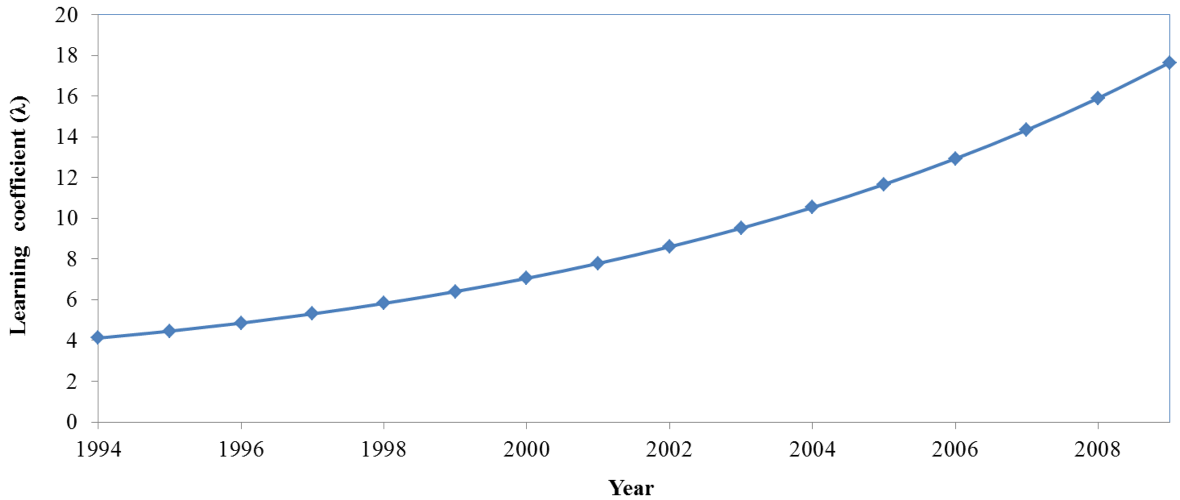

Figure 4.10 Trend in learning coefficient with respect to renewable energy (*1994-2009*).

The uptake of the renewable energy in China which includes the solar and wind energy can be modelled as equation (10) as follows:

$$RE_T = \frac{6E12}{1-exp(-(6.145E-22)T-6.579E-11)}$$

The above evidences confirm the increase in technology stock with the learning and assimilation efforts.

(ii) Spillover effect from foreign direct investment

The increasing productivity of hi-technology products from domestic firms as shown in Figure 4. 11 with world class features are evidences of the assimilation capability derived from the foreign firms' know-how and mobility of labor stock from foreign firms to domestic firms. In earlier study on solar industry (Srikanth and Watanabe, 2012) patents analysis results showed the assimilation capability of wisely fusing the external know-how with domestic know-how of similar technology class to the new industry need, which demonstrates the searching, absorbing, assimilating and transforming skills of the domestic work force.

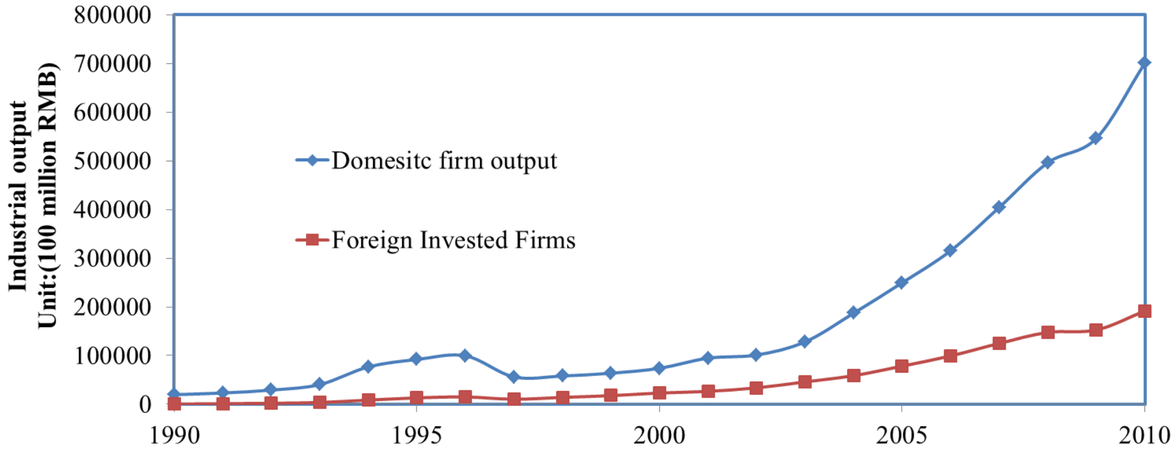

Figure 4.11 Industrial output trend in domestic firms versus foreign invested firms (*1990-2010*).

The present empirical analysis showed the production function of the private firms with respect to 100 heavy industrial products shows interdependency of the foreign firms' technology effects based on equation (13) is found to be:

$$ln(Y_P) = 3.837 + 0.686\ ln(L_{P,j}) + 0.332\ ln(K_{P,j}) + 0.479\ ln(TFP_{F,j})$$

(4.99)*** (5.91)*** (2.79)*** (3.60)*** *adj.* R^2=0.990

*** Significance at the 1% level.

From the above empirical finding, it is clear that the elasticity of productivity with foreign firms TFP which is identified as 0.479 clearly indicates the foreign firm's technology stock contributes to the domestic firm's productivity, through spillover and labour mobility.

(iii) Effect of clusters' technological progress

The production function for different region's industrial sector, illustrated in Figure 4. 12, is given by:

$$ln(Y_i) = 6.041 + 0.584\, ln(L_i) + 0.586 ln(K_i) \qquad adj.\ R^2 = 0.978$$

$$(28.41)^{***} (4.10)^{***} \qquad (5.14)^{***}$$

*** Significance at the 1% level.

The TFP was computed based on equation (16) and is demonstrated in Figure 4. 13.

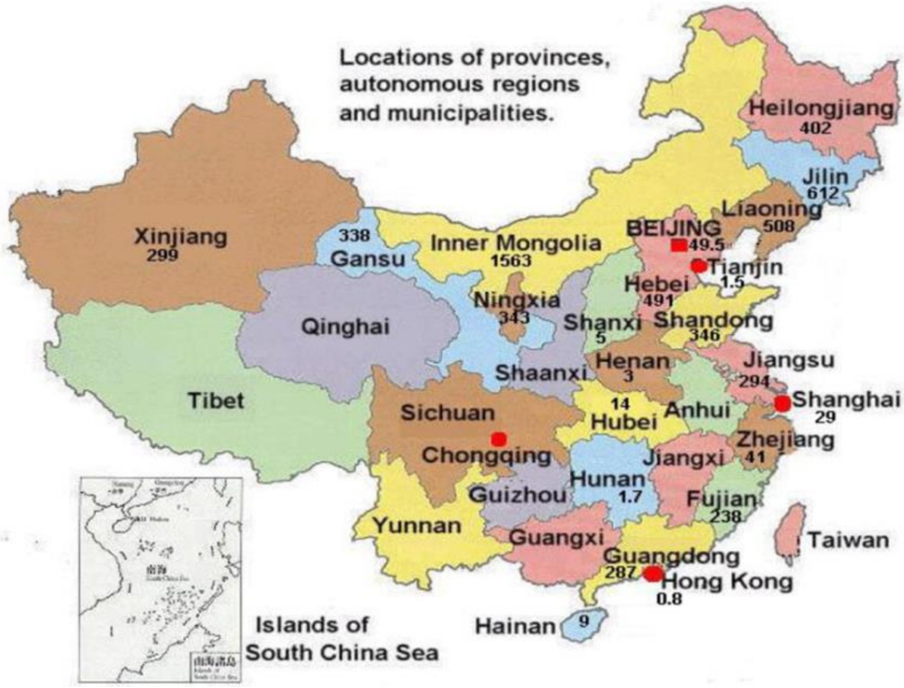

Figure 4.12. Different regions of China taken for analysis.

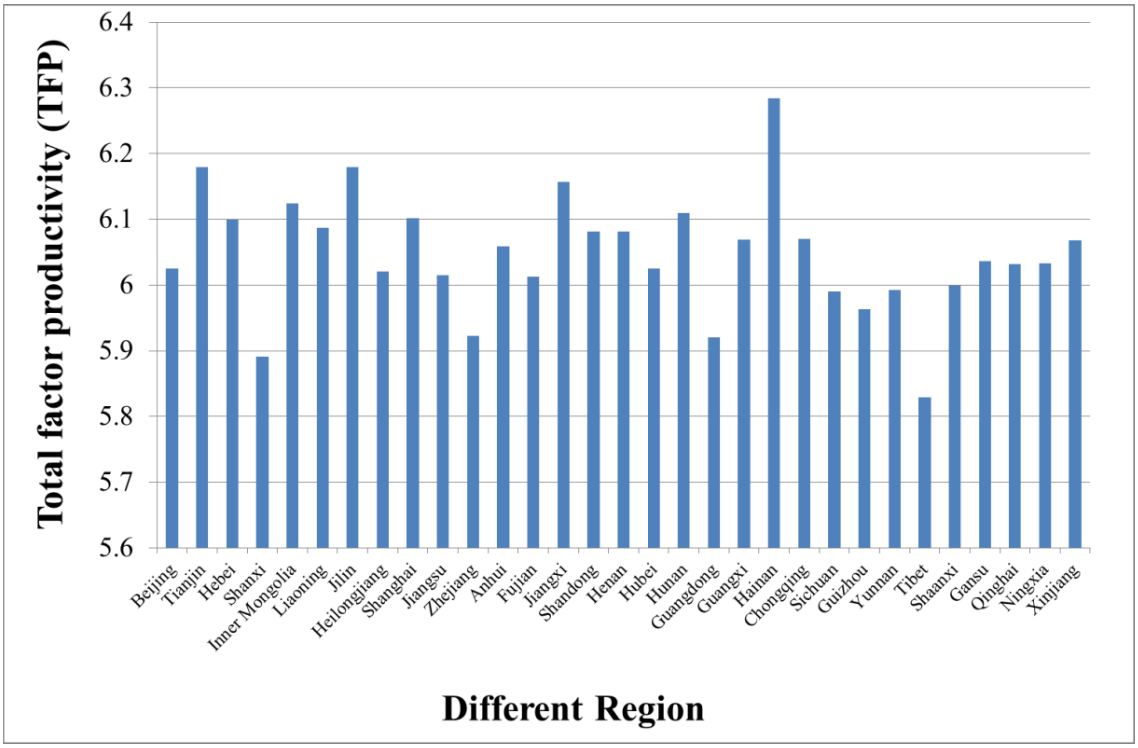

Figure 4.13 Technological progress of different region of China in heavy industry (*2010*).

The above regional performance of clusters in heavy industry matches well with the actual observation of wind industry manufacturing in Hebei, Inner Mongolia and Tianjin. For example, the Tianjin industrial cluster is from the development of state owned enterprises as foundation to cooperate with foreign companies, together to lower costs and improve market reaction to become worldwide competitive, large number of existent trained skilled industrial technical workers to suit heavy industry and has more than 850 wind power manufacturers and suppliers, including domestic and foreign firms. Total investment of 12.645 billion Yuan and a total workforce of 24,760, have formed the most complete system in China's wind power industry. Its annual capacity is 5600 MW of turbines that encompasses generator, blade and gearbox skills.

Such success lured a foreign firm such as Vestas to establish itself in Tianjin cluster during 2005, to setup a factory with a 363 million USD making it an important manufacturing base in China. Choice of selection of this cluster was due to its location and infrastructure (Renewable energy today, 2006). As of now, it has developed a strong value chain with 80 odd local suppliers. Spain-based Gamesa Corporation and India-based Suzlon Energy has follow suit of such investment in Tianjin. In 2009, Vestas started core technology components (control systems, and precision components) and introduced new product that was designed for the China's terrain and was locally produced and for the region V60-800KW model to meet China's domestic content policy requirement.

4.5 Discussion

4.5.1 Theoretical Implication

4.5.1.1 Systems Interpretation

Diffusion process of innovative goods can be depicted by the following epidemic function with its carrying capacity *N*.

$$\frac{d}{dt}V(t) = aV(t)(1-\frac{V(t)}{N}) \qquad (17)$$

$$V(t) = \frac{N}{1+e^{-at-b}} \qquad (18)$$

where $V(t)$: cumulative number of innovative goods; N: carrying capacity; a: velocity of diffusion; b: initial stage of diffusion; and t: time trend.

Under the presence of a catalytic role of the government with clear expectations such as the Renewable Energy Law in 2005 and domestication expectation, technology seeking and market identification support, the various actors in the value chain are ready to support the national expectation. This induces the assimilation capacity of the manufacturing clusters that has the right know-how such as heavy industry technologies in terms of labor stock, patents and intellectual property (IP), to suit the identified industry of the government such as wind or solar industry. This increases the velocity of production (V) and enhances the functionality development. Such functionality development (FD) emerges in the various segments of the value chain such as design transformation to meet regional need with the support of customer, production and adoption to meet the nation’s target, etc. The increase in the functionality development further increases the marginal productivity of technology which is the partial derivative of the change in production to the technology stock. The technology stock can be further shown that it accrues with the increase in the assimilated knowledge such that it increases with assimilation as shown in the following equation:

$$T(t) = T_i(t) + z(t)T_s(t) \tag{19}$$

where z(t): the assimilation capacity which depends on the firm’s skilled labourers, absorption capacity and prior knowledge stock.

$T_s(t)$: spillover technology of the other related industry from local industries, and

$T_s(t)$: total technology stock at time t.

Thus, increase in technology stock with assimilation will induce more assimilation capacity and thereby will induce more functionality development and further encourage more assimilation of spillover technologies and thus form a viscious cycle between assimilation, functionality development and agglomeration of technology stock in industrial clusters as illustrated in Figure 4. 14.

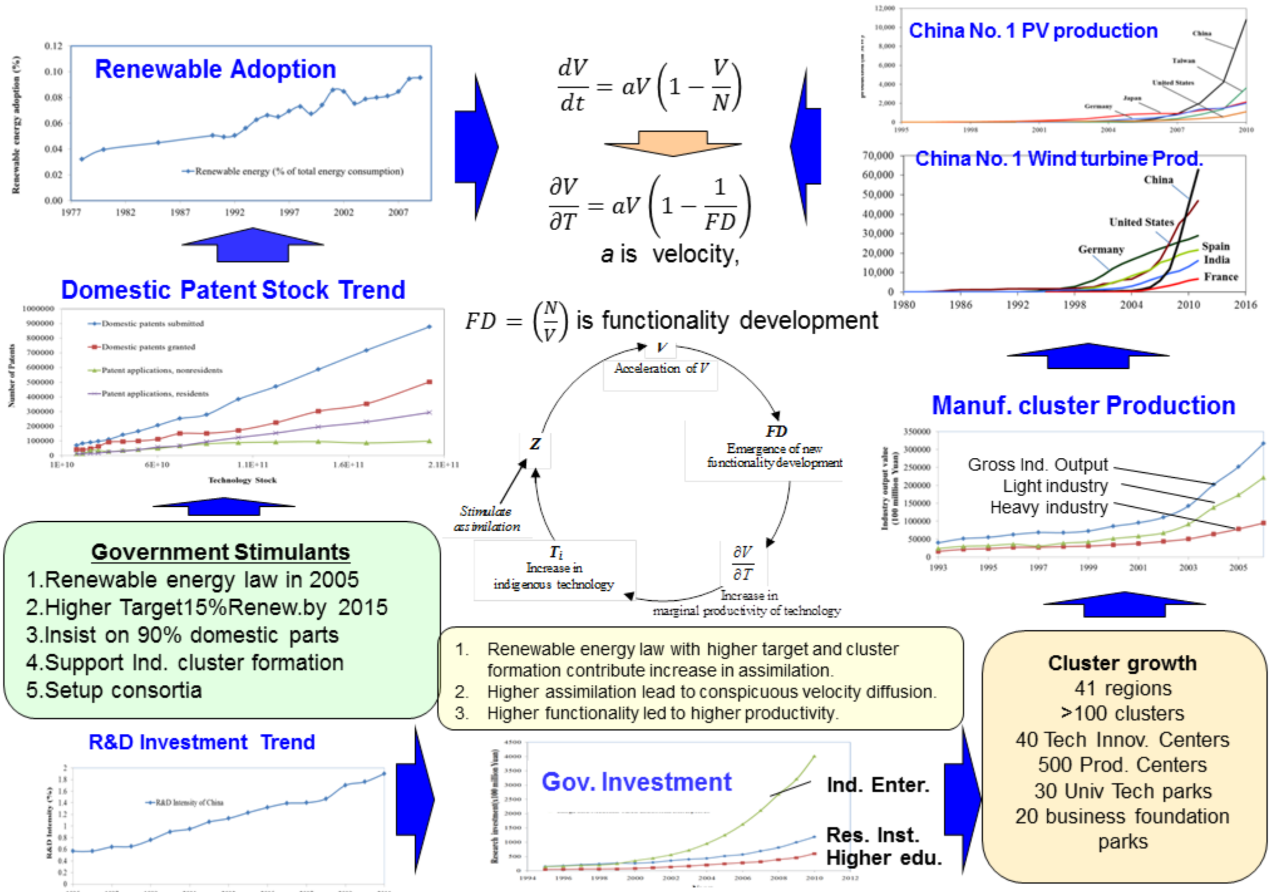

Figure 4.14 Government catalytic role inducing virtuous cycle between assimilation capacity increase and acceleration of the emergence of functionality development.

The above mechanism could be accomplished with proper national institutional system which China that is capable to assess the core-capabilities of its resources such as industrial clusters, academia and research institutes to support in a symbiotic way to support the assimilation process. Tables A1, A2 and A3 in Appendix show the statistics of institutional increase in academia, research institution and industrial clusters that were responsible in the learning and assimilation process. On the demand side the national innovation system should be capable to evaluate the internal and external market demand and coevolve a market with the expectations in terms of technology, product features against the existing choices. Figure 4. 15 shows the various elements of the input and output components of the overall National Innovation System (NIS). Such a system under the catalytic stimulation of the government, initiates the assimilation, transformation and acclimatization by following the process flow of the acclimatization process shown in Figure 4. 16 to support the functionality development.

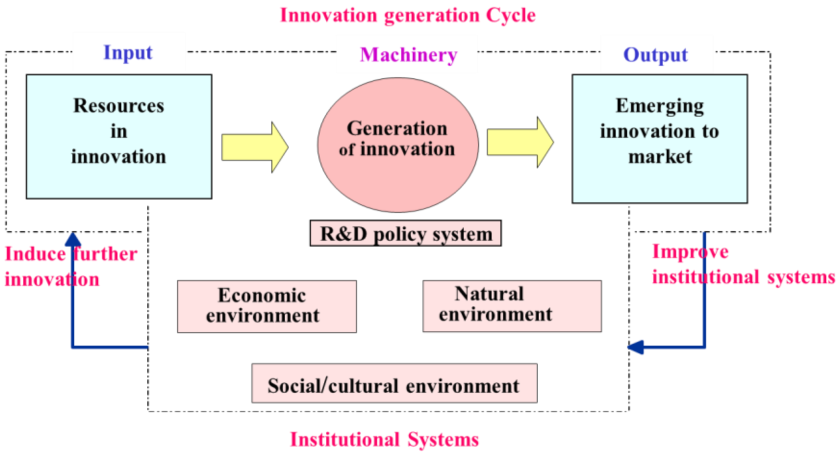

Figure 4.15 China’s NIS and indigenous innovation generation scheme.

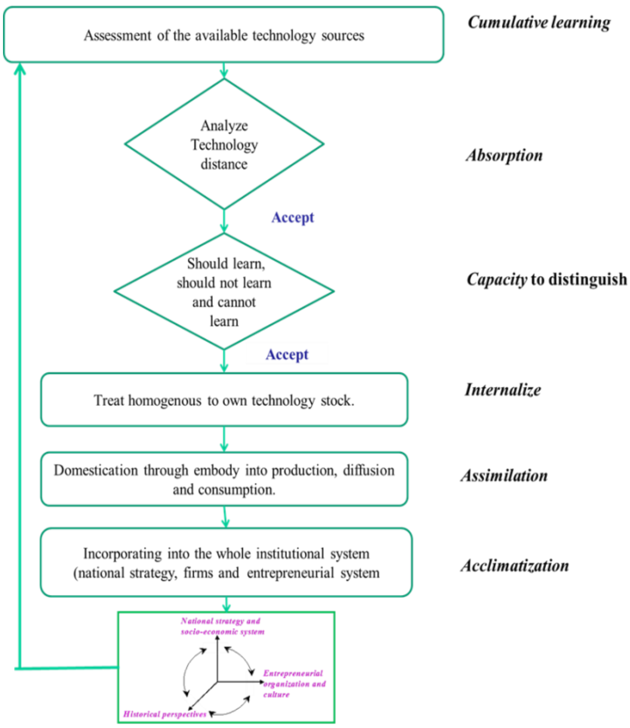

Figure 4.16 Process to acclimatize the assimilated knowledge to support the functionality development.

4.5.1.2 Catalytic role technology acquisition path differences observed between Chinese solar PV and wind manufacturing firms

Comparing the two industries solar PV and mega wind turbines we find that both industries have demonstrated conspicuous development strength in production. However, detailed analysis showed solar PV industry resides the first generation technology (crystalline silicon technology), while the foreign firms are working in second and third generation technologies (viz., thin film PV and organic solar industry). Thus, we see that the economic growth model of this industry is purely dependent on the gross output '*V*' as shown in Figure 4. 17

$$\frac{\Delta V}{V} = \sum_{X=L,K}\left(\frac{\partial V}{\partial X}\cdot\frac{X}{V}\right)\frac{\Delta X}{X} + \frac{\partial V}{\partial T}\cdot\frac{R}{V}$$

$$\frac{\partial V}{\partial T} = aV\left(1-\frac{1}{FD}\right)$$

Figure 4.17 Production focus of China's solar PV industry.

where *V*: production output,

X: traditional resources as labour (L) and capital (K),

R: R&D investment,

FD: functionality development,

a: diffusion coefficient, and

$\partial V/\partial T$: Marginal productivity of technology (MPT).

However, in the case of wind turbines, the functionality development measured in terms of capacity of the turbines has been increasing steadily with the indigenous technology and have reached the performance of the foreign firms. Thus, the MPT grows with functionality increase and thereby increases the production output of the firms. This is more preferred as it motivates new innovation than purely investing into the production resources. Thus, the case of stimulating FD is a preferred choice to enhance MPT and thereby the growth. Comparison of Figure 4. 17 and 18 shows the effect of investment in functionality development as a better choice in increasing the value of the investment towards increase in production.

Comparing the two cases' technology acquisition path, solar PV industry shows the least evidence of direct technology transfer and internal increase in new technology platform such as lack of moving into second and third generation technology such as thin film technology or organic solar technology from the present first generation technology such as crystalline silicon technology. However, the evidence of the solar industry rise and their world leading production capability of indigenous products of global standard along with the domestic semiconductor industry shows the technology spillover evidence through utilization of global best practises of foreign solar multinational companies (MNCs) and fusing with local domestic semiconductor know-how. The present finding showed China supply chain has high dependency on foreign imports for raw materials and foreign markets for deploying the solar panels. Thus, the dynamics of the foreign players greatly affect the China's supply chain and thereby the functionality development. This trend may extend to future technologies too, since China's production has been purely focusing on the first generation technology compared to USA and Europe that have been focusing on second and third generation technologies.

$$\frac{\Delta V}{V} = \sum_{X=L,K}\left(\frac{\partial V}{\partial X}\cdot\frac{X}{V}\right)\frac{\Delta X}{X} + \frac{\partial V}{\partial T}\cdot\frac{R}{V}$$

$$\frac{\partial V}{\partial T} = aV\left(1 - \frac{1}{FD}\right)$$

Figure 4.18. Functional development focus of China’s wind industry.

On the contrary, the technology acquisition path of China for wind industry has been robust that has transformed from a state of technology scarcity condition to total indigenisation. The results can be seen in terms of increasing functionality (such as large geometric size and capacity). This resulted in increasing market share to become world leading domestic producers and adopters. The present study results showed that the wind industry does import some of the key technologies such as control systems and precision bearings; however, their fraction has been reducing with growing indigenization such that domestic firms with indigenous products support China’s wind turbine installation up to 90% as of 2011. The success to such world dominance is in setting up the symbiotic institutions of production and adoption which can be attributed to the government catalyst role to assimilate and transform into indigenous products in the early stage of the solar PV and wind industry.

4.5.2 Significance of catalytic role of government policies

4.5.2.1 Co-evolution of a domestic production chain with adoption

In the wind industry, while wind policies began since the late 1990s they did not generate impact both on the production side and on the market creation side to cater to the energy needs due to lack of incentives. Hence by 2003, only a meagre installation of 0.56

GW was achieved which catered for 0.15 percent of the country's energy needs. The concessional projects in 2003 dictated 70 percent of domestically manufactured components which encouraged domestic firms to evolve and assembly of the turbines within China. These policy tools helped support the domestic firms. These requirements greatly reinforced the market and production chain to become stable, with foreign direct investments into Chinese facilities to a level of US$ 34.6 billion and resulting in local wind turbine brand names such as Gold wind and Sinovel and exhibited the advanced stage of maturity of the renewable energy segment in China.

4.5.2.2 Importance of local content requirement for indigenization

China on a course of rapid adoption of wind turbine, its technology and manufacturing capacity was not capable to match its demand in 1995. China had to rely on the foreign turbine manufacturers. Economies of scale in production helps reduce the cost of electricity and price of wind turbines due to learning curve concept. The monopoly behaviour of these foreign turbine manufactures keep the prices of turbines rising as China's order size is growing. China initially subsidized foreign turbine imports. However, it realized the monopoly behaviour of the foreign turbine manufacturers resulting in steady increase in prices. Hence the china's policy focused in prompting the importance of domestication and included the role of local parts of atleast 70 percent and insisted in assembling within the Chinese territory so as to encourage the technology spillover and domestication of manufacturing technologies and co-evolve a production chain to support wind energy adoption in China. This was originally proposed for the concession projects and later extended to normal projects. Thus, with initial bidding mechanism along with the domestic requirement speeded up the localization of the wind turbine manufacturing. By the year 2007, the installed capacity of domestically made turbines exceeded that of foreign ones. By the year 2009, with consistent domination of the domestic players with increasing shares, china abolished the local content requirement practice in November 2009 (Zhang, 2010). By the end of 2011, China had 62.4 GW wind turbines installed but only 45 GW of this was connected to the grid. As of 2012, China has achieved grid connected wind power to 52 GW[9] (Wu (2011)). The state grid said China's annual connection rate for wind turbine had grown at an average rate of 87 % in the six years from 2006 to 2011. In China's five-year economic plan for 2011 to 2015, the government has already set out its intention of prioritising the development of 3MW to 5MW onshore and 5MW to 10MW offshore wind turbines[10]. During the same period, the National Energy Bureau has said it will complete five 10GW-wind projects. It will also begin to construct the 2 GW wind farms in Hami of Xinjiang, 2GW wind farms in Kailu of Inner Mongolia, and 1.5 GW wind farms in Tongyu of Liaoning Province. China will start to construct the 1GW offshore wind farms in Jiangsu, and push ahead with the development of offshore wind farms in Hebei, Shandong, Zhejiang and Fujian provinces. It will also complete the second phase of Shanghai East Sea Bridge Offshore Wind Farm. This means, industry officials said, China will gradually move away from relying solely on onshore wind farms.

In 2011, China dominated the Ernst and Young index of the most attractive country for wind power development. China lead on 78 points with a 12 point over the next best country Germany and followed by USA and UK[11].

[9] http://www.windpowermonthly.com/channel/powersystemissues/news/1142602/China-takes-grid-connected-wind-power-52GW/
[10] http://www.windpowermonthly.com/news/1056010/China-back-wind-industry-new-policies/?DCMP=ILC-SEARCH
[11] http://www.windpowermonthly.com/news/1072238/China-continues-lead-wind-attractiveness-index/?DCMP=ILC-SEARCH

4.5.2.3 Importance of domestic market to indigenization

Comparing solar PV industry with wind industry of China, the government had taken a slow start in creating domestic market for its PV products compared to the production chain formation. Secondly, even such program is observed to have focused more on a demand based policy wherein the drive to create large scale PV (LSPV) systems was aimed at achieving from independent village supportive PV deployment. This is good but yet has not helped to reduce the cost of energy to the necessary extent compared to the fossil fuels.

A closer look of China's production chain of PV industry will show that the industry is poor in technology at the raw material such as pure-silicon sourcing. Its internal demand has not met the overall demand. Secondly, the industry is still in its first generation PV technology and not invested much in the upcoming thin film PV technology and organic solar technology, in which countries such as USA and Germany are leading. This lack of foot print on those disruptive technologies will affect the further competitiveness of China's solar PV industry in further years.

4.5.2.4 Additional barriers from China's lack of complimentary technologies' maturity to support renewables

First, successful renewable energy transfer requires robust grid infrastructure. In countries such as China, the wind and solar energy rich sites are at significant distances apart from the power demand locations where manufacturing industries and domestic urban environments are located. These demands for a unified national electricity grid. China has six regional grid clusters, which spans both at partially within the 26 provinces and thus trading takes places both in-between regional grid cluster and in-between grid cluster level. For example, in 2009, the inter-regional electricity trade was only 532 TWh (Cheung, 2011). Hence new technologies such as high voltage lines to support AC and DC grids are needed to be laid similar to road infrastructure for transport. Twelfth five year plan has outlined efforts for large scale smart grid system that would demand 40 billion US dollars.

Secondly, renewables such as wind and solar are variable in their power supply. Thus, connecting these variable distributed energy sources need to credible as a steady energy supply to nation's needs (Chandler, 2009). Failing which the penetration of the wind or solar energy into the regular energy stream becomes minimal. Even, successful countries such as Denmark have shown a maximum wind energy penetration of only 20 percentage. This is one reason for non-variable power generation sources from fossil fuels will continue dominate the country's energy mix in the near future due to high certainty. Hence long distance, cross regional power transmission infrastructure needs to be a part of the country's strategy.

Thirdly, good forecasting tools to predict wind and solar energy should be developed by academic circle for the country to minimize uncertainty from the natural causes.

Thus, regional electricity transmission, flexible generation and demand side management and energy storage technologies become important.

4.6 Conclusion

4.6.1 General summary

For a decarbonized state of a nation, sustained efforts of private and government actors are important to bring changes. Country and industry specific development challenges are being studied to form working recipes that payoff in quick and large way. China's demonstration of a conspicuous strength in wind power adoption diffusion in year 2007 interests the world community, especially the emerging countries.

Present successes shows China did not wait to achieve perfect business conditions to stimulate growth; rather it coevolved the institutional changes by having the government as the catalyst in these reforms. It identified its weakness and leveraged the global strength in technologies along with the local accumulated technology stock of both people and explicit knowledge with present prevailing situations that are second best in condition. One such evidence is that its pro-growth government policies have been good and helped to draw private investment and innovation to fulfil the shortage in the investment gaps. Still now World Bank ranks China to have been successful in certain industrial sectors to nurture international firms based on its industrial clusters and R&D investment.

4.6.2 Noteworthy findings

China's conspicuous accomplishment in PV and wind production has been possible due to the government's catalytic role to initiate assimilation of technologies in order to increase functionality development which exhibits as increased marginal productivity of technology and results in increased technology stock thereby resulting in increased assimilation and operates as a viscous cycle between assimilation and functionality development. Such a phenomenon was possible due to the government's establishment of institutions such as industrial clusters, academia and research institutes and create an apt climate to assimilate the spillover knowledge towards functionality development.

The momentum gained by the manufacturing industry since 2000 in China contributed to the sustaining of competitive factors to new industries like wind and solar industry.

Contrast between wind and PV on adaption shows China co-evolved a wind market in tune with country's energy goals, with proper demand side policies that supported the production stability. While solar industry targeted export market since the domestic market policies were lacking and failed in not supporting the country's energy goals even with enough solar resources.

4.6.3 General Suggestion Renewable Energy Policy Recommendations

The Chinese government issued the 12th FYP at the end of 2010, which aimed to consolidate and improve established sectors where inefficiencies still reside as well as promote the fast development of seven new strategic sectors including energy and technology areas. The strategic sectors, if sustained successfully, will serve as platforms to supply the domestic market and global markets. These are sectors where China plans to use its resources and current strong competitive positioning to become indigenous and dominant manufacturer.

Demand and supply for science and technology development are considered important driving forces and government's policy instruments such as direct funding and tax incentives is well documented, but implementation should be clearly lined up through an integrated policy system whereby, the science and technology institutions should be interlinked with the industrial R&D institutions as in the case of Singapore and Japan.

(i) The economic potential of a renewable energy source to choose depends on two major factors: the yearly production capability and the cost-effectiveness for the electricity produced. The success of these new technologies to a new region depends on the capability of the cost-decreasing path of learning and economies of scale and thereby the market size of the region. Today both wind power and solar power costs are still a few cents/kWh higher than the traditional fossil fuel based power costs in China. Hence effective policy tools are required to promote the adoption and diffusion of wind and solar power in new region. The 12^{th} Five-Year Plan will usher in the next development stage for wind and solar energy, both of which will be vital to optimizing China's energy structure and reducing greenhouse gas emissions (Leggett (2011). This cannot be achieved without the support of even more detailed and active policy systems, as well as solutions to the issues of high production cost and grid connection difficulties.

(ii) Recommendations to China's wind energy policy

China's wind energy policy has more favoured in the past to the onshore wind turbine deployment. Taking countries such as UK, it is clear that in order to support "increasing returns to geometric scaling" such as development of large rotor or tall towers, China needs to venture into offshore wind industry where the space requirement is minimized. In this market too, the West leads over the East and hence China should continue the knowledge spillover mechanisms from developed global firms.

(iii) Solar PV Policy recommendations for China

Still China’s PV industry production chain lacks key raw materials such as silicon material and key technology needs (such as circuit topology and Maximum power parity tracking control method and grid-connect) for new generation solar PV. In terms of technology, still China’s production chain lies in the first generation solar PV industry and has to catch up with USA and Japan in terms of thin-film and organic solar PV technologies. The reason being, these disruptive technologies are promising to provide lower cost of energy and will out-weight the crystalline solar PV industry. Hence the government should step in to provoke technology transfer and motivate domestic players to assimilate the useful knowledge with domestic know-how to internalize and improve its existing practices towards new generation of solar technologies.

(iv) Recommendations to China’s domestic solar industry

China has exhibited its conspicuous strength in solar cell and module manufacturing but suffers from the silicon material required for its ingot preparation. Secondly at the final end of the supply chain it heavily depends on the export market. Today with USA and Europe blaming China for dumping in their soil below manufacturing price and claiming that it violating the WTO rules, it becomes clear that China should ramp up its internal domestic market and support its internal production chain.

(v) Recommendations to China’s domestic wind industry

The wind industry must look beyond the look beyond the local environment and must go for a global market. Presently the China’s wind industry lacks complimentary technologies such as high power fault tolerant grids. This is a barrier to renewable adoption. Similar to countries like UK, China should plan to extend its domestic market towards offshore conditions. Demand and supply for science and technology development are considered important driving forces and government's policy instruments such as direct funding and tax incentives is well documented, but implementation should be clearly lined up through an integrated policy system whereby, the science and technology institutions should be interlinked with the industrial R&D institutions as in the case of Economic Development Board (EDB) in Singapore and Ministry of International Trade and Industry (MITI) in Japan.

4.6.4 Future works

While this research study, focused on China's solar and wind industry, it can be extended to other industries that are playing similar roles for innovation and indigenization. Therefore comparative studies on similarities and disparities across different industries and products and technologies can be another focus of future studies.

As service innovation, becomes important in emerging economies the present framework's applicability can be investigated in the context of moving from an industrial to an information society.

Tacit knowledge quantification through survey methods can be pursued to quantify the assimilation capacity more accurately.

The present framework study can be extended to developing and developed nations to contrast and understand the effect of government policies, firm level technology strategies, market, industries and domestic know-how on the new industry growth.

Appendices

Table A1 Number of high technology firms and their gross output, total income and exports

	Number of High-tech firms	**Number of Persons Engaged in High-tech firms**	**Gross Output Value of High-tech firms**	**Total Income of High-tech firms**	**Exports of High-tech firms**
		Person	10,000 Yuan	10,000 Yuan	10,000 US$
1999	17498	2210487	59435684	67747892	1190818
2000	20796	2350679	79419851	92092630	1858175
2001	24293	2761433	119284135	101167793	2266439
2002	28338	3486686	129371015	153263685	3292207
2003	32857	3953621	172574344	209387307	5101690
2004	38565	4484387	226389344	274663091	8238168
2005	41990	5211960	289575838	344156082	11164537
2006	45828	5737003	358989390	433199030	13608826
2007	48472	6502370	443769460	549251627	17281217
2008	52632	7165307	526846717	659856923	20152382
2009	53692	8153213	611513927	787069413	20072181
2010	51764	8590060	757502707	971809299	24763404

Source: China statistical data (2012).

Table A2 Scientific research institution and enterprises growth

Year	**Scientific Research and Development Institutions**[a]	**Higher Education institutions**[b]	**Large and Medium-sized Industrial Enterprises**[c]
1995	146.4	42.3	141.7
1996	172.9	47.8	160.5
1997	206.4	57.7	188.3
1998	234.3	57.3	197.1
1999	260.5	63.5	249.9

2000	258	76.7	353.4
2001	288.5	102.4	442.3
2002	351.3	130.5	560.2
2003	399	162.3	720.8
2004	431.7	200.9	954.5
2005	513.1	242.3	1250.3
2006	567.3	276.8	1630.2
2007	687.9	314.7	2112.5
2008	811.2	390.1	2681.3
2009	996	456.2	3211.6
2010	1186.4	597.3	4015.4

Source: China statistical data (2012).
[a,b,c] the number indicate in units of 10,000 person.

Table A3 Health pipeline of raw material to finished products (*1998*-*2012*)

Year	Total Production of Energy	Coal	Crude Iron Ore	Rolled Steel	Aluminum Oxide	Aluminum Products	Electricity	Thermal Power	Hydro power	Power Generation Equipment
98	122390	123555	20554	10508	334	147	11388	9290	1949	1930
99	104139	97781	20934	11957	384	174	11978	9854	1969	1469
00	98834	88010	22395	13146	432	217	13256	10867	2212	1249
01	106185	96418	21701	15745	475	229	14333	11768	2380	1339
02	118317	111293	23143	19218	548	276	16024	13288	2465	2121
03	134992	132670	26108	23582	619	363	18462	15421	2593	3701
04	158618	160611	31010	29739	702	448	21302	17702	3065	7138
05	178640	182424	42049	37117	861	594	24146	19857	3644	9640
06	198187	206599	58817	46685	1324	834	27557	23189	3783	11882
07	218698	229468	70707	56461	1951	1240	32087	27013	4343	13180
08	248000	262183	82401	58177	2279	1477	34047	27857	5277	13343
09		296477	88017	69244	2383	1770	29814	5545		4394
10		20301	6807	3153	1067	336382	6622			12993
11		20365	8122	3424	1111	413329	6108			14739

Source: world bank (2013).

Appendix B1

B.1 China's renewable energy policies – laws, instruments and programmes

China energy policy challenges are largely framed by national socio-economic policy goals; climate policy competes economic development policy particularly climate and environment measures[12] (Speed (2009)). Renewable energy was recognized as a good solution worldwide to global warming and emission reduction but there is no reference to climate change or GHG emissions in the "Renewable Energy Law of People Republic of China" that became effective from 1st January 2006 (Wang and Watson, 2009). Kan (2009) lists the prominent renewable laws and regulations of China such as prominent laws, regulations and plans related to wind and solar PV renewable energy in China.

B.2 China 12th five year plan

The national five year plan for Economic and Social Development (FYP) is a key strategic document of the Chinese government and is seen as a crucial document that have directed policy since the establishment of People's Republic in 1949. It sets the development priorities and basic governmental objectives of the country in the upcoming five year period. In 1980s, the FYP focused on growing attentiveness to energy concerns (Yao et al. (2005)). In 6th FYP (1981 to 1985) it focused on 10% of energy supply investment into energy conservation projects and was continued to 7th FYP and the percentage reduced to 8%. From 2001 to 2005, the Agenda 21 was implemented to the 9th FYP for sustainable development and a plan for Renewable Energy Development was introduced, to offer recommendations for

[12] Reuters, China may cap 2015 energy use at 4.1 bln TCE, 21 April 2011.
China daily, Energy policy to fuel economic objectives, 21 March 2011.
Xinhua, Energy sector goals for China's 12th five year program by province, 31 dec 2010.
Xinhua, five power groups to benefit from RMB11.1 trin investment in power in next 10 years, 23 dec 2010.

adoption of renewable energy. In the 11th five year plan (2006-2010) directed by the scientific development perspective, China set a target to produce 15% primary energy from renewable sources (including hydropower) by 2020, and up from 7.5% in 2005 (NDRC (2007b), NDRC (2010)). For the electricity sector, the target is 20% by year 2020 which includes 20GW from wind power, 30 GW from biomass, particularly in wind and solar power and 300 GW from hydropower. This set an ambitious path to adopt renewables.

China's national people congress approved a new national development strategy for the next five years (2011 to 2015) in March 2011[13] [14] (KPMG (2011)). The 12th FYP designates seven strategic emerging industries (SEI) as the drivers for China's future economic development from low-end manufacturing to higher-value industries and creating sustainable growth. Clean energy technology; high-end equipment manufacturing; alternative energy; new materials; and clean energy vehicles are some of the key focus and aligns with sustainable growth. However, the 12th FYP does not specify any preferred financing, tax breaks, subsidized electricity and utility fees, free or subsidized land, etc.

Chinese government support for at least one of these industries has been successful in the past. During the 11th FYP, China designated clean energy technology (solar, wind, bio, and nuclear energy) for government support, spending approximately 2 trillion RMB (US$ 309 billion) on energy efficiency and environmental protection measures. In the 12th FYP the key focus was on clean energy, energy conservation, and clean energy cars as three key investment areas (among seven special sectors) identified in china's. Among the various renewable energy, China bets on hydro power and not much on nuclear power after the Japan nuclear accident in 2011. It motivates expansion of wind, solar and biomass particularly wind and solar as core in its environmental efforts as follows.

[13] http://www.kpmg.com/cn/en/IssuesAndInsights/ArticlesPublications/Documents/China-12th-Five-Year-Plan-Energy-201104.pdf

[14] http://www.uscc.gov/researchpapers/2011/12th-FiveYearPlan_062811.pdf

(i) Wind power generation: with the continuation of strong policies supporting the development of wind power, the sector needs to move from rapid expansion to a stage of healthy development. By 2015, annual generation of wind power will reach 190 TWh, which is more than the energy produced by 60 million tons of standard coal.

(ii) Solar energy generation: the sector needs to achieve fast development and expand installed capacity. Development goals are 5 to 10 GW by 2015.

The China's big five power generation groups (China Huaneng, China Guodian, China Datang, China Huadian, and China power investment) are actively looking for foreign direct investments and are engaged in adopting new technologies such as smart grid development which is an effort to improve energy efficiency through the support of foreign players (example, Siemens and ABB) and thus can co-evolve new equipment industries in smart meter supply.

B.3 Policy development for wind and solar

China's renewable energy policies have not been seen significant inducement to a renewable energy, but it clearly played a catalytic role in the production capability development in wind and solar industry and favoured domestic market development in the wind energy and export market in the solar industry as described in the following section.

B.3.1 China's wind energy policy

In the 1980s, efforts by Wang Wenqi to create China's wind power capital in Dabacheng putting 300 wind turbines to support irrigation works. Today, it generates 500 MW and not the largest capacity it had the pioneering effort that comprised of domestic and foreign turbines.[15] In 2003, to increase wind power sources the China government shifted to a market oriented policy to address commercial wind farms. The generated wind power was supplied to the state grid through bidding process. With this a stable domestic market evolved.

Some of the supply side policies include heavy investment for leveraging external know-how through technology leasing and joint ventures. Applied regional feed in tariffs to take the variation in the grid availability and transmission loses between the generated location and demand location. Promotions loans and subsidies to domestic firms in the production chain and insistence of up to 90% domestic parts requirement in all domestic installed turbines (Lewis and Wiser, 2007).

Demand side policies include China's public tendering for concession wind power projects. To increase the wind turbine installations, the government adopted a market oriented policy for wind power concession projects in 2003 to motivate power saleable wind farms to sell wind electricity that was traded by a bidding process with the provincial grid companies and were managed by National Development and Reform Commission which resulted in a stable domestic market evolution. For example, China's promotional feed in tariffs in 2006 as shown in Table B1 compared to fossil fuels and to address the disparity between regions it introduced varying feed in tariff as shown in table B2 which helped the adoption of wind energy optimally in different regions based on their wind resource, grid availability, local demand, transmission loss to the point of usage, etc.

Table B1 Feed in tariff of wind energy generated power into state grids

Province	Fossil based cost of energy	Feed in tariff	Percentage difference (%)

[15] http://bw.china-embassy.org/eng/xwdt/t755048.htm

	(Euro-cent/kWh)	(Euro-cent/kWh)	
Hebei	2.81	9.59	241
Inner Mongolia	1.94	6.01	210
Xinjiang	1.74	5.23	200
Shandong	3.29	7.75	135
Liaoning	2.91	8.82	203
Jilin	2.91	8.72	200
Guangdong	4.94	6.59	33
Zhejiang	4.07	11.72	188
Fujian	3.97	4.46	12

China had clear feed in tariff variation with region as listed in Table B2, which promoted the growth of larger wind farms in remote places with wind rich conditions.

Table B2 Feed in tariff for different wind farms in different region

Province	Name of the wind farm	capacity (MW)	Tariff (RMB/KWh)	Year
Jiang Su	Ru Dong	100	0.4365	2003
Guang Dong	Hui Lai	100	0.5013	
Inner Mongolia (Western)	Huitengxile	100	0.382	2004
Inner Mongolia (Western)	Huitengxile	100	0.382	
Jilin	Tongyu	200	0.509	
Jilin	Tongyu	200	0.509	
Jiang Su	Ru Dong	100	0.519	
Jiang Su	Ru Dong	200	0.4877	2005
Jiang Su	Dafeng	200	0.4877	
Gansu	Anxi	100	0.4616	

Inner Mongolia (Western)	Ximeng Huitengliang	300	0.42	2006
Inner Mongolia (Western)	Ximeng Huitengliang	300	0.42	
Inner Mongolia (Western)	Bayin	200	0.4656	
Hebei	Zhangbei Danjing	200	0.5006	
Inner Mongolia (Weastern)	Wulan Yili	300	0.468	2007
Inner Mongolia (Eestern)	tongliao beiqing	300	0.5216	

Source: GWEC China wind tariffs (2011).

2.5.2 China's solar energy policy

The five year plan (2011-2015) for solar industry developed by Ministry of Industry and Information Technology was released in Feb 2012 chiefly focusing on supply and demand side (Semi, 2012). Following are some key aspects:

(i) Reduce the cost of domestic solar power to 0.8 Yuan (about US $0.13) per kwh by 2015 and 0.6 Yuan (about US $0.10) by 2020,

(ii) The cost of solar panels in China will drop to 7000 Yuan (about US$ 1100) per kw by 2015 and 5000 Yuan (about US$ 800) per kw by 2020,

(iii) The plan requires China's leading polysilicon manufacturers to reach a 50000 ton annual production capacity (per firm) and leading solar panel makers to reach 5 GW (annually per firm) by 2015,

(iv) China will further help solar companies increase their annual sales, with atleast one firm reaching 100 billion Yuan (about US$ 16 billion) in sales and 3 to 5 firms reaching 50 billion Yuan (about US$ 8 billion) in sales by 2015.

(v) Increase the conversion efficiency of monocrystalline silicon solar cell to 21 percent, polysilicon cell to 19 percent and amorphous silicon cell to 12 percent by 2015.

(vi) Eighty percent of solar equipment and auxiliary materials will be produced domestically,

(vii) Thereby it aims at and having a minimum installed capacity target of 5 GW by 2015 and 20-30 GW by 2020 such that these large scale capacities is being planned to be placed in deserts.

China's central government has launched a number of demand side policies to promote PV power installation (Zhang et al. (2012)):

(i) Before 2009: PV installation depended on government financed projects "Tibet Non-electricity countries electrification project", "China Brightness Project", "Tibet Ali PV Plan", "China Rural Township Electrification Program" and "Non-electricity Areas Electrification Program", and the cumulative installation is small.

(ii) 2009: subsidies for "Golden Sun demonstration Program".

(iii) 2009 and 2010: Two series of concession projects.

(iv) As per 2010, the total installation is only 800 MW, which equates to 10% of annual production of PV cells (Semi, 2011).

(v) 2009 to 2011: "Solar PV for building program" for greater than 50 KW.

Concession project has been recognized as an efficient and effective approach to figure out the real cost of new power generation technology and bring down the cost through demonstration borrowing the successful experience of wind power development. Therefore, two series of concession projects with total capacity of 290 MW were taken off in 2009 and 2010.

"Golden Sun Demonstration Program" is also a good example in shedding light on LSPV. In 2009, China's Ministry of Finance, Ministry of Science and Technology and the National Energy Administration of the National Development and Reform Commission jointly announced the program which provides upfront subsidies for qualified demonstrative PV projects from year 2009 to 2011. The subsidy will cover 50% of total cost for on-grid systems and 70% of total cost for offgrid systems. Compared to the first national subsidy program - “Solar PV for Buildings Program” with minimum system size of 50 kW, the required system size increased to 300 kW.

Chapter 5

Conclusion

5.1 General summary

China has embarked into its decarbonized path of adopting clean energy sources such as wind, solar and hydro for its economic growth. This study focused on China's adoption of solar PV and wind turbine and identified its co-evolution framework of, supply chain formation and markets. Through this path, China has exhibited conspicuous strength in indigenous product creation, means to produce and setup robust supply chain to support the technology adoption for its energy sources. Thereby it co-evolved between innovation and institution, not only at R&D stage but also on marketing, manufacturing and consuming stages.

In chapter 2, results shows China's solar PV industry has reached world No.1 in production capacity of cost-effective solar cells and modules and the top few firms at world level are from China's domestic firms. Investigation of its technology sources showed lack of technology transfer modes, but the engagement of early domestic firms have helped to evolve the conspicuous strength in manufacturing cells and modules that are able to serve the global market and upcoming domestic market. This success can be attributed to the fusion of the domestic industry's intensive effort in learning global best practices for exploring new business and government's catalytic role for attainment of decarbonisation society.

In Chapter 3, it was concluded that China has reached world leading wind turbine production through its indigenous firms' technology assimilation capacity to produce indigenous wind turbine that have scaled in sizes and capacity comparable to the foreign firms and helped sweeping the domestic market share. Thereby the utilization of domestic firm helped to indigenize world class products, world level production volume and secure profits and job market within the soils of China.

Chapter 4 illustrated the roles of government as a catalyst in the technology transfer and assimilation process by evolving the domestic firms through evolving spin-offs from the academic and research which enhanced the assimilation of technology transfer and foreign direct investments and support inter-industry spillovers. Similarities between wind and solar PV industry showed the common benefits of government role in supporting the firm growth through labour and regional support and proper subsidies. Dissimilarity studies between wind and solar PV industry showed that Solar industry did not enjoy the necessary technology transfer support that the wind industry enjoyed and thereby the lag in technology dominance within the solar cell and module industry and the asymmetry in the overall supply chain.

5.2 Noteworthy findings

Empirical analysis shows the interaction between indigenous domestic firms, such as semiconductor, marine and automotive industry, and newly emerging solar PV and Wind industry in absorption of global best practices and technical know-how, thereby fusion between them was demonstrated. Success of this fusion can be attributed to a joint work between industry's intensive effort in learning global best practices for exploring new business and government's catalytic role for the attainment of decarbonisation society for nation's sustainability. This suggests a new insight for growing economy for its development of global competitive industry.

5.2.1 Conspicuous strength in solar industry

(i) Success of the fusion can be attributed to a joint work between industry's intensive effort in learning global best practices and existing know-how for exploring new business,

(ii) Technology contributes significantly to production increase in solar industry and thus an increase in technology stock by assimilation capability,

(iii) A set of 74 leading domestic solar PV manufacturing firms shows the evidence of positive knowledge spillage from the existing semiconductor industry,

(iv) The top 23 leading domestic solar PV manufacturing firms exhibits an assimilation capacity of 0.24 in learning the global best practices from global MNE solar firms,

(v) Improvement of assimilation capacity is essential for effective utilization of spillover technology, and this depends on the level of technology stock and skilled labour in the host,

(vi) A new way of identifying the technology spillover and competence growth using patent technology class has been demonstrated.

(vii) Government's catalytic role in supporting the solar manufacturing industry has aided the attainment of decarbonisation society for nation's sustainability,

5.2.2 Leap into wind turbines

(i) The industry evolution and useful supply chain can be attributed to a joint work between industry's technology transfer partnership and exploiting existing know-how of related industry to explore new business,

(ii) Internal market demand contributes significantly to indigienization and thus an increase in technology stock by assimilation capability,

(iii) The set of leading domestic wind turbine manufacturing firms shows the evidence of positive knowledge spillage from the existing manufacturing industry,

(iv) A new way of identifying the technology spillover to evolve a new product from existing sources using patent technology class was demonstrated.

(v) Existing industry's exploitation of know-how minimizes the barriers to technology adoption.

(vi) Government's catalytic role in supporting local manufacturing industry through evolving new industries and supporting through domestic market has been successful in evolving the conspicuous strength.

(vii) The evidence demonstrates the possibility that emerging economies can co-develop the internal demand for a product and its supply chain together thereby the benefits to the sustained growth of the country.

(viii) The evidence demonstrates the possibility that developing countries can take an alternative path of development with green technology industries growing by its conspicuous strength and leapfrogging into global low carbon economy.

5.2.3 Government's role in conspicuous strength development

(i) The momentum gained by the manufacturing industry since 2000 in China, contributes to the sustaining of competitive factors to new industries like wind and solar industry.

(ii) SMEs in particular high technology areas, such as clean energy, are playing an increasingly important role in R&D performance and productivity growth.

(iii) High rate of firm evolutions has been originated as spin-offs from academia and high-tech industrial hubs that have transformed as private domestic firms with good assimilation capability

5.3 Implications

5.3.1 Theoretical implications

(i) A patent metrics based empirical method has been demonstrated that utilizes the technology classification as a means to deduce the assimilation capacity. This could be practiced in evaluation of commercial and academic research institutions to understand their assimilation capacity.

(ii) Leveraging foreign technology through various technology transfer modes, viz., licensing, joint ventures and mergers have enhanced the domestic firms' conspicuous strength in performing at the recent technologies and thereby accelerated functionality development in products. For example, the China's indigenous wind turbines have been scaling significantly in tune to market demand and at par to the foreign firms, while solar PV industry has a disproportionate manufacturing competency within supply chain, viz., only solar cells and modules, and dominantly remains in first generation technology due to asymmetry in China's early support towards solar PV industry.

(iii) The study shows presence of modular product architecture can lead to modularity in supply chain, as opposed to a vertically integrated organization, and thereby enables multiple domestic players to enter the new industry with relevant know-how and thereby take part in the indigenization pursuit and accelerated functionality development.

(iv) The present study elucidated the importance of supply chain in terms of its barriers to technology adoption. The case study of wind turbine shows how emerging nations can co-evolve a supply chain by fusing its domestic firms' know-how and keen interests with foreign technology and best practices to form useful supply chain to support further scaling.

(v) Management literature has highlighted the exploration and exploitation in product development. This study adds to the little knowledge seeking research stream, in identifying the importance of local actors in knowledge seeking, identifying, absorbing, assimilation and acclimatization process steps during internalizing external know-how and thus provides new research findings.

(vi) Domestic firms have enabled inter-industry spillovers specifically in manufacturing technologies to support cost-effective and accelerated functionality development and in acclimatization of the external technology and know-how. Foreign firms have been instrumental in providing latest technologies and reduce the knowledge seeking path to domestic firms.

(vii) The present study elucidated the sources of conspicuous strength and highlighted the availability of skilled labour stock from the relevant domestic industry which can be deduced by identifying the industry's technology distance. This results in accelerated technology assimilation by utilizing the right talents for the technology seeking and assimilation processes and further support industry scale up to reach production target.

(viii) Government's catalytic role in technology adoption has been a key focus of this study and contrasting the two case studies clearly shows the importance of government's role in inducing fusing the external technology and the domestic firms' technology seeking and assimilation capacity. The early engagement of domestic firm thus supports technology transfer, c and market evolution.

(ix) The present study has shown the importance of domestic and export markets on the domestic firm growth and government's catalytic role. Domestic market enables indigenization, early functionality development and cost-effective product creation while export markets help domestic firms' learning from the global competitors and global customers the best practices.

5.3.2 Implications for open innovation

(i) Traditional literature on open innovation has described the path to leverage external sources of innovation. The present study elucidates the institutions changes and their roles required to bring the various institutions viz., government, domestic firms, foreign subsidiaries and academic and research institutions, to enhance the technology identification, assimilation and acclimatization and further support production through forming a robust supply chain to support future production capacity, functionality and quality needs.

(ii) The present study has shown the benefits of product modularity in choosing multiple partners for indigenization to effectively utilize their specific know-how and concurrent product development to support early functionality development and further benefit in coevolution of a robust supply chain through an open innovation platform.

5.3.3 Implications for exploitation and knowledge flow

(i) Management literature has discussed the impact of foreign direct investment on domestic firms' productivity. This study has elucidated the technology spillovers and the importance of assimilation capacity of domestic firms from foreign direct investment. The early engagement of domestic firms as an equal knowledge partner helps in better assimilation and supply chain creation and thereby early functionality development.

(ii) Secondly, it is presumed in research literature that the foreign direct investment to a nation is fully exploited. FDI are packages that can compose of explicit and tacit knowledge and best practices. In reality, technology transfer between firms of two different nations experience barriers to transfer technology due to geographic distance, technology mismatch of donor and host, national IP security and receiver's assimilation capacity. Hence early engagement of domestic firms in the technology transfer enables exploitation of domestic know-how and best assimilation capacity of external technologies, know-how and best practices that are shared. The domestic firms' learning by doing raises the required curiosity and enquiry that prompts to ask more in-depth investigation of the external technology and thereby results in robust functionality development.

(iii) From the case of solar energy, it is clear that the availability of global patents, international papers, design standards, internet and other open literature enables a firm to exploit with its knowledge identification and assimilation capacity and evolve new products and support new markets.

5.3.4 Implication for collaboration

The present study has highlighted the role of domestic firms and other local institutions and the government's catalytic role in inducing the fusion between the global firms and domestic players to explore and exploit the foreign know-how and thereby induce early functionality development and ensure project certainty in meeting the national and industry level goals.

5.3.5 Implication for government policies

(i) The government should encourage a local market for the solar industry as in the case of wind industry to support solar PV manufacturing industry due to the volatile global economy and weak overseas market and thereby enhance the nation's renewable energy capacity due to healthy availability of Sunlight energy capacity on their soil.

(ii) Secondly it should induce technology transfer mechanisms with foreign solar players and technology leaders to shift China's solar production firms to move into next generation technologies so as to sustain their world leading position as a cost-effective supplier in delivering products of high energy conversion capacity.

(iii) Having identified the related industries to solar and wind industry, government should encourage their growth to enhance further technology spillovers and possible reverse spillovers from the host industry and produce useful labour stock to support future skilled manpower needs of these industries.

(iv) Demand and supply for science and technology development are considered important driving forces and government's policy instruments such as direct funding and tax incentives is well documented, but implementation should be clearly lined up through an integrated policy system whereby, the Science and technology institutions should be interlinked with the industrial R&D institutions as in the case of Singapore and Japan. This can be run in the form of consortiums where the R&D subsidies can be provided as research scholarship to firms which they utilize as benefits to collaborate with domestic research institutions. Thereby, new innovations can be customized to industry needs along with possible spin-offs to support future supply chain.

(v) To emerging nations, a technology seeking and assimilation frame work has been discussed in this study. Many emerging nations adopt new technologies for their industrial growth but do not succeed equally. The present study elucidates the possible care to be taken in actor selection for assimilation of external and internal technologies to ensure effectiveness of technology transfer.

(vi) Even under no official technology transfer, the present study shows by sheer domestic know-how and available global knowledge such as internet, design standards, global patents, open literature, nations can evolve new industries and thereby enhance their growth, job availability and meet the country's requirements.

5.4 Limitations

The present study has deduced assimilation using measurable parameter such as patent details and product details. Tacit knowledge is difficult to quantify and hence the predicted assimilation factors of a firm may be of lower bound. Further work should focus in taking the ratio of skilled people and survey of these firms to determine their knowledge seeking, assimilation and acclimatization capacity.

5.5 Future Studies

This dissertation focused on China's solar and wind industry; however it can be extended to other industries that are playing similar roles for innovation and indigenization. Therefore comparative studies on similarities and disparities across different industries and products and technologies can be another focus of future studies.

As service innovation, becomes important in emerging economies the present framework's applicability can be investigated in the context of moving from an industrial to an information society.

The patent-metrics can be further enhanced by performing patent mapping using backward and forward linkages and inventor’s firm associations. However present patent database of China do not support with such details.

Tacit knowledge quantification through survey methods can be pursued to quantify the assimilation capacity more accurately.

The present framework study can be extended to developing and developed nations to contrast and understand the effect of government policies, firm level technology strategies, market, industries and domestic know-how on the new industry growth.

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