A policy dimension required for technology roadmapping: learning from the emergence of Chinese wind turbine industry

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Abstract: Innovation policies play an important role throughout the development process of emerging industries in China. Existing policy and industry studies view the emergence process as a black-box, and fail to understand the impacts of policy to the process along which it varies. This paper aims to develop a multi-dimensional roadmapping tool to better analyse the dynamics between policy and industrial growth for new industries in China. Through reviewing the emergence process of Chinese wind turbine industry, this paper elaborates how policy and other factors influence the emergence of this industry along this path. Further, this paper generalises some Chinese specifics for the policy-industry dynamics. As a practical output, this study proposes a roadmapping framework that generalises some patterns of policy-industry interactions for the emergence process of new industries in China. This paper will be of interest to policy makers, strategists, investors and industrial experts.

Keywords: technology roadmapping; TRM; innovation policy; wind turbine; emerging industry; China.

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1 Introduction and a brief review

Emerging industries have received greater attention in recent years (Ashford et al., 1985), especially in emerging countries who are attempting to transform their economies from labour-intensive to knowledge-driven (Bozeman, 2000). In line with Schumpeter, existing research views emerging industries as decentralised and energised,[1] populated by entrepreneurial firms that compete on technological innovation, new business models, and creative value chain positioning (National Technology Outlook Team, 2008) rather than price or efficiency.[2]

The development of emerging industries is closely associated with the innovative endeavours of several key new technology-based firms, who own the platform technologies and who help form industrial standards (Daim and Oliver, 2008; Eisenhardt, 1989). The growth of these key firms and the industry may be influenced by many factors, such as economic factors, market structure, management systems, key individuals, as well as public policies (Fontes and Novais, 1989; Forbes and Kirsch, 2011).

Since the 1970s, governments have become closely involved in new industrial development for the competitiveness of nations and regions (Torres-Fuchslocher, 2010; Walsh, 2004). Scholars from different perspectives (e.g., neoclassical economics, evolutionary economics and sociology theories), have recognised the impacts of governments' efforts (e.g., through investment and other policy tools) on industrial development, especially during the transitional phases of industrial lifecycles. In some cases, the emergence and development of some emerging industries has been shown to be greatly dependent on public policies (Genus and Coles, 2005; Groenveld, 2007; Johansson et al., 2007; Johne, 1982; Inoue and Miyazaki, 2008; Porter, 1990). For example, innovation policy[3] as a fundamental approach for government agencies has been empirically validated as an effective tool to affect, regulate and motivate the industrial emergence process (National Technology Outlook Team, 2008; Nelson, 2002).

However, innovation policies involve multiple aspects, including technology, education, business, finance, taxation, regulation, market stimulation and procurement (Rothwell and Zegveld, 1984). This makes the industry-policy interactions very complex. Many existing policy studies have viewed the technological advancement and industry growth as a black box, and then focused on the aggregate impacts of innovation policies on them. There is, as yet limited research that attempts to explicate the policy-industry interactions throughout the development process. Therefore, there is a strong need for an analytic tool to systematically elaborate the process-oriented dynamic interactions.

Although there are many tools to study industries, technology roadmapping (TRM) is recognised as an effective and comprehensive tool for mapping the industrial emergence when studying the complex behaviours of industrial development process (Pan, 2005; Phaal et al., 2001, 2010b). The TRM approach is widely applied at both firm and sector levels to support innovation, strategy, and policy development and deployment (Phaal et al., 2010a).[4] It provides a structured approach for mapping the evolution and development of complex systems. For example, Phaal et al. (2009) have developed more than 25 'emergence maps' that examined the industrial evolution process to support the development and testing of the TRM framework as a tool for historical analysis. According to them, the existing applications of TRM "have demonstrated the flexibility of the approach, leading to a generalized framework for strategic appraisal" [Phaal et al., (2009), p.5].

However, according to our literature review, existing TRM tools have failed to pay sufficient attention on the policy-industry dynamics. Phaal et al. (2010a), as one of the few attempts to examine policy-industry dynamics, assumed that the public policy may significantly influence the emergence of some industries when interacting with other dimensional factors such as market/product strategy. However, they did not elaborate the policy-industry linkages other than assuming these links are indirect and implicit.

Therefore, in order to better understand the process, the authors believe it is necessary to develop the TRM tool through explicating the policy-industry linkages, so that it can provide better support to policy makers in China when developing long-term innovation and industry strategies.[5] The authors recognise that there are different patterns of the industrial emergence, thus the dynamics of policy-industry would appear to be disparate. This study, however, will focus on the emergence and development of the wind energy manufacturing sector in China, which has become strategically important to China's energy strategy. Wind energy as a highly regulated sector, has been significantly influenced by government specifically in China, where it is common to have explicit national strategies towards specific technologies.

This paper has three major objectives:

1 to develop an integrated TRM tool which can specifically study the policy-industry dynamics for emerging industries in China

2 to have a better understanding of the dynamics in wind turbine sector for policy making

3 to better understand Chinese-specific aspects of the policy-industry interactions, especially in wind energy manufacturing sector.

As a practical output, this paper integrates the policy dimension into TRM framework which can provide guidance to support the mapping and planning of the industrial development of new industries in China.

As an exploratory study, this paper will use the single case study method (Robinson and Propp, 2008; Rothwell and Zegveld, 1985) to explore the idiosyncrasies of the growth of Chinese wind energy manufacturing industry. Our approach consists of two main steps:

1 based on a literature review, we analyse the policy-industry dynamics through the growth process of the industry

2 we then use case study evidence to contrast against the *a priori* knowledge, in order to identify the patterns of policy-industry interaction through the development process.

The remainder of this paper is structured as follows. First, we draw upon relevant theories from the literature to develop an *a priori* TRM framework with the policy dimension (referred to as P-TRM). Next, this conceptual framework is refined through an empirical case study and discussion. Finally, this paper concludes with a short summary of the research output, theoretical contributions, relevant implications and suggestions for further work.

2 Methodology

2.1 Research design

The research adopts a single case study methodology, following Yin (2003) and Eisenhardt (1989) when trying to bring a new policy dimension to the existing TRM framework. In addition, this paper selects a theoretical case (i.e., the emergence of wind turbine industry in China) for detailed analysis to refine the conceptual TRM framework. A series of workshops for roadmapping the industrial emergence and policy heterogeneity can ensure the construct and internal validity of the data analysis for the refined framework.

2.2 Data collection and analysis: TRM workshops

This paper develops the TRM framework through a series of workshops for data collection and analysis. This fast-start workshop approach is based on existing practices (Bozeman, 2000; Eisenhardt, 1989).

Data collections are two-fold. Firstly, documentary data is significant throughout the roadmapping process. Before every workshop, documentary data and pilot interviews have been conducted to prepare for the discussions. Second, three workshops have been conducted in order to frame the vertical axis for this framework, identify the strategic landscape, and analysing the scenarios for DME.

Experts are invited to contribute valuable comments in these workshops. The invited experts are leading professors in wind turbine, energy and technology policy domains from key government agencies and leading universities in China, including Prof. Ni

Weidou, Prof. SHAO Liqin, Prof. XUE Lan, Prof. Yuan Xiaoming, Prof. Wang Ningbo, and representatives from firms.

Table 1 TRM workshops

WS	*Objectives*	*Experts*
I	Key dimensions of this TRM framework and key policies are identified.	Senior executives and professors from the Ministry of Science and Technology (MOST) and Tsinghua University (THU);
II	Landscape of this TRM framework	Professors/researchers from the Chinese Academy of Engineering (CAE), key firms (wind turbine companies, including Huiteng, Goldwind, etc.), State Grid Company and THU
III	Policy-industry dynamics and charting the roadmap	Academics from THU

In Workshop I, a short presentation was given before the discussions, briefing the existing literature about the dimensions for roadmapping an emerging technology. Experts' inputs have been collated, and the key dimensions for vertical axis and key policies are identified, and the *a priori* framework has been developed, with some unknowns remained for further analysis.

In Workshop II, the landscape of this roadmap has been sketched, and three topics have been discussed:

1 key actors, scope of innovation events, definitions of drivers and barriers

2 key innovation events of wind turbine industry in China through the emergence process

3 risks and key challenging problems (obstacles).

In Workshop III, the dynamics between policy and industrial emergence have been further discussed with documentary data and experts' inputs.

This study was strengthened by the data protocol in data collection, and the adoption of the analytical framework through expert discussion in data analysis. The possible bias of experts' opinion has also been alleviated by the triangulations through multiple workshops/contrasting results by using secondary data.

3 Developing the *a priori* framework of policy-technology roadmapping

Traditional TRM framework has four vertical dimensions: market, product, technology, and required resources (Rothwell and Zegveld, 1984). Through the systematic study of these perspectives, TRM can describe the technology trajectories when concerned with key drivers and barriers to innovation. Based on the trajectory analysis, TRM helps to identify the market needs, leading products, key technologies, and the dynamic interactions between them. This analysis gives suggestions on technology selection, timing and development path (Su et al., 2007; Taylor et al., 2005).

Based on Workshop I, this study adds a new policy dimension to traditional TRM framework, in view of innovation policy's significant impact on the evolution of technology. This additional dimension helps to open the 'black box' of innovation policy's action mechanisms and explore both the direct and indirect influences of policies in technology progress.

3.1 Innovation policy's effect on industrial emergence and evolution

In industrial emergence process, innovation policy tools play important roles through the development of market, product and technology. In addition, policy may vary along the emergence process, and the impacts could be different (Torres-Fuchslocher, 2010; Zhou et al., 2011).

Supply policies can enhance firm's R&D investment and guide technology selection through providing human resources, information, technology and capital. Supply policies' effects on technology may be mainly represented through support for the development of platform or generic technologies that can be applied for product development by individual firms (Eisenhardt, 1989). Additionally, supply instruments can also allocate scarce science and technology (S&T) resources. For example, S&T databases constructed and made available by the government can help reduce unnecessary private sector R&D activity that may result from information asymmetry.

Environmental policies can assist in setting up market regulations and changing market environment (Torres-Fuchslocher, 2010). These policies may affect industrial evolution in different ways. For example, the policies like non-tariff barriers and technical standards can affect the product functional design and technology selection directly and then lead to the changes of the market preference. Environment policies can also make impacts on the user market directly through target planning, tax preferences and regulations.

Demand policies can facilitate the expansion of new market and then pull technology innovation and product development. These policies may provide a certain market expect, reduce uncertainties of new market entrance, stimulate the confidence and determination of innovators, and eventually advance R&D through government procurement of new product or price subsidies.

3.2 The a priori framework for policy-technology roadmapping

There are many innovation policy tools to stimulate technological innovation and industrial growth. According to literature, we grouped the policy tools into three main categories:

1 supply

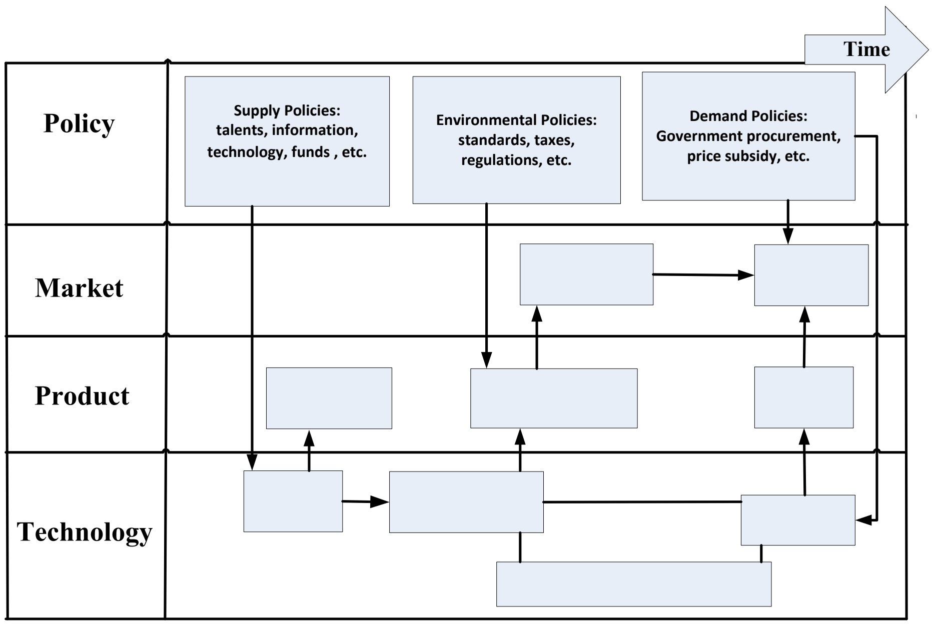
2 environmental

3 demand (Eisenhardt, 1989).

Through the emergence of a new industry, the foci of innovation transfer from R&D to applied technology, from prototyping to mass diffusion. In view of these innovation characteristics, experts argue that innovation policies concerned about industrial emergence should also follow this sequence, along the growth process. Therefore, *Supply, Environment and Demand policies* can be framed in series along the innovation process.

Figure 1 shows the analytical framework for policy-technology roadmapping (P-TRM) that has been developed through Workshop I. With time as horizontal axis and policy-market-product-technology dimensions as vertical axis, the P-TRM framework may be able to count in multi-disciplinary key factors in industrial emergence and evolution, and examines the interactions between these perspectives. This can help to better analyse the complex emergence process, and form the theoretical basis for the analysis on industrial emergence.

Figure 1 The preliminary framework of P-TRM



How to select, combine and implement certain innovation policy tools is still a major concern for policy makers. These policies can be different through the industrial growth process, and are regional and sector-specific. In the following parts, we will try to compare and contrast the empirical data to theory, in order to refine our framework of P-TRM through a case study of the emerging wind energy industry in China.

4 Case study: wind turbine industry in China

In recent years, environmental pollution, global warming and similar phenomena have surfaced major economic and societal issues. This has resulted in a change of public awareness, and the rising interest on environmental concerns, such as renewable energies. However, renewable energies still have relatively low energy densities when compared to non-renewable sources. This means that renewable energy technologies still face major challenges (e.g., economic efficiency and scale-up production) for deployment and diffusion (Inoue and Miyazaki, 2008). To stimulate the emergence of these new energy industries, government can play an important role, especially at the embryonic, nurture and growth phases of industrial lifecycles.[6]

As an example, the wind energy industry has developed rapidly in China and this has been accredited to the intervention of the government. In the following sections, we will examine China's wind turbine industry and examine the interaction among policy, market, product and technology using the *a priori* framework.

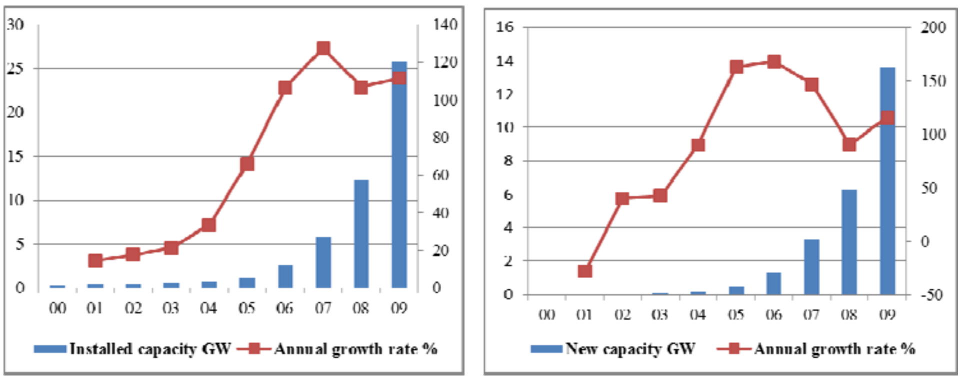
4.1 Industrial emergence and growth: market, product and technology

4.1.1 Market

Chinese domestic wind energy market started relatively late compared with many overseas markets. As shown in Figure 2, before 1995, Chinese wind energy market was very small. Most wind energy equipment demand was met by imports and the domestic manufacturing was very underdeveloped. From 2003, the wind energy market really began to take-off and grew dramatically. After 2006, the accumulative total installed capacity kept an annual growth rate of 100% for three years. In 2009, Chinese wind energy ranked second in the world and only after the USA, with its accumulative capacity reaching 25.8 GW.

Figure 2 Growth of installed capacity in China (see online version for colours)

Accumulative installed capacity in China **Annually increased installed capacity in China**



Until 2005, China had only a few small-scale and low-technology wind energy manufacturers and most of its wind plant construction had relied on imports. However, after 2005, Chinese wind energy manufacturing developed very rapidly with the number of wind energy manufacturers growing tenfold between 2004 and 2009.

Meanwhile, the market share of domestic firms and joint ventures (JVs) has been continuously increasing. In 2008, their market share accounts for 75.6% out of all newly installed capacity in China, and is 61.8% in accumulative total account.

4.1.2 Product

As the domestic market grew, the performance of Chinese core wind energy products has also been improved. In 2006, the average single capacity for wind turbines in China was only 931 KW. However, by 2008, the average capacity had risen to 1.21 MW. Before

2005, the new installed MW-level wind energy systems took 21.5% of new installed wind energy system in China. However, the proportion had grown to 51% by 2007. By the end of 2009, MW wind energy system has become the mainstream products in Chinese wind energy industry. By 2010, Chinese firms had begun to produce 3 MW products and the MW off-shore systems had also entered the stage of component design.

Up until the early 2000s, most components of Chinese-manufactured systems were imported. However, the wind energy system and its components have gradually been localised. In 2009, the production of high-voltage inverters, which accounts for 10% of the MW wind energy cost, was also localised. As a result of this localisation of key parts and components, the average price of single wind energy system declined 15% and thus drove the price of wind energy down.[7]

4.1.3 Technology

The product advancement was largely the result of technology progress. China is a relative latecomer in wind energy industry and, as described earlier, from late 1990s to early 2000s, its initial technologies are mainly imported or developed by reverse engineering. Such an approach can be very effective in helping enterprises to get an initial entry in market in a short time. For example, Hui Teng, the largest blade manufacturer in China gained its first 600 KW technology through reverse engineering.

As the wind energy systems become larger and more complex, safety, economy and efficiency become increasingly important in wind energy systems. Blade variable paddle technology and generator speed constant frequency technology in MW wind generators are now widely used. Following the desire for manufacturing localisation and under the fierce market competition after 2005, most Chinese manufacturers largely imported MW technology, especially through technology licences, in order to better satisfy the market demand and gain the technology advantage.

As of 2011, the trend of wind energy technology in China is towards more capacity, more efficiency, more operational reliability and higher quality of grid power technology. Additionally, the multi-MW wind technology has been gradually maturing. As on-shore wind resources are gradually saturated, off-shore wind energy system technology has become the next direction of wind energy.[8]

4.2 Policy's impacts on industrial emergence

As an emerging renewable energy industry, the cost of wind energy is higher than traditional power at the initial stage and faces more fierce market competition. As such, wind energy's development deeply depends on the good policy environment. There has been significant number of public policy instruments implemented by the Chinese Government favouring wind energy. Examples include the Renewable Energy Law, the Plan for Long Term Development of Renewable Energy, and the 11th Five-year Plan for Renewable Energy Development. The innovation-related policy instruments supporting the development of wind energy in China can be grouped into the four types described earlier.

4.2.1 Supply policy

The Chinese Government gave strong incentives to the R&D of generic technologies. These R&D subsidies include the Ride Wind Program, National 863 Program, special fund for renewable energy development and New Energy Program. Many incentives are given through firm-level projects such as Ride Wind Programme Scheme.[9]

4.2.2 Environment policy

Tax policies have been frequently used by Chinese Government to stimulate the wind energy market. From 1997 to 2005, the import tax on wind turbine systems was waived to encourage equipment and technology import. In 2001, government cut 50% off the value added tax (VAT) for wind energy generation equipment to promote wind energy. In 2006, government waived import tax on production materials relating to wind turbines. In 2008, the government adjusted import tax policy of MW wind energy systems. Domestic enterprises can claim back the import tariff and import VAT when importing key parts, raw materials for the wind system products larger than 1.2 MW. The cost to the public budget can be treated as national investment and of use for R&D of new products and the capacity building of indigenous innovation. Another important measure is that import tax-waiver policy is suspended for wind energy system with a capacity less than 2.5 MW.

Regarding market regulation policies, China has implemented interventions to change the industrial structure of wind turbine. In 2003, the Chinese Government published a requirement of a localisation rate that dictated that at least 50% of wind energy equipment should be provided by Chinese manufacturers. In 2005, the rate was increased to 70%. However, in early 2010, China repealed the regulation on localisation rate, since the Chinese wind turbine providers are now regarded as being capable of competing with overseas companies.

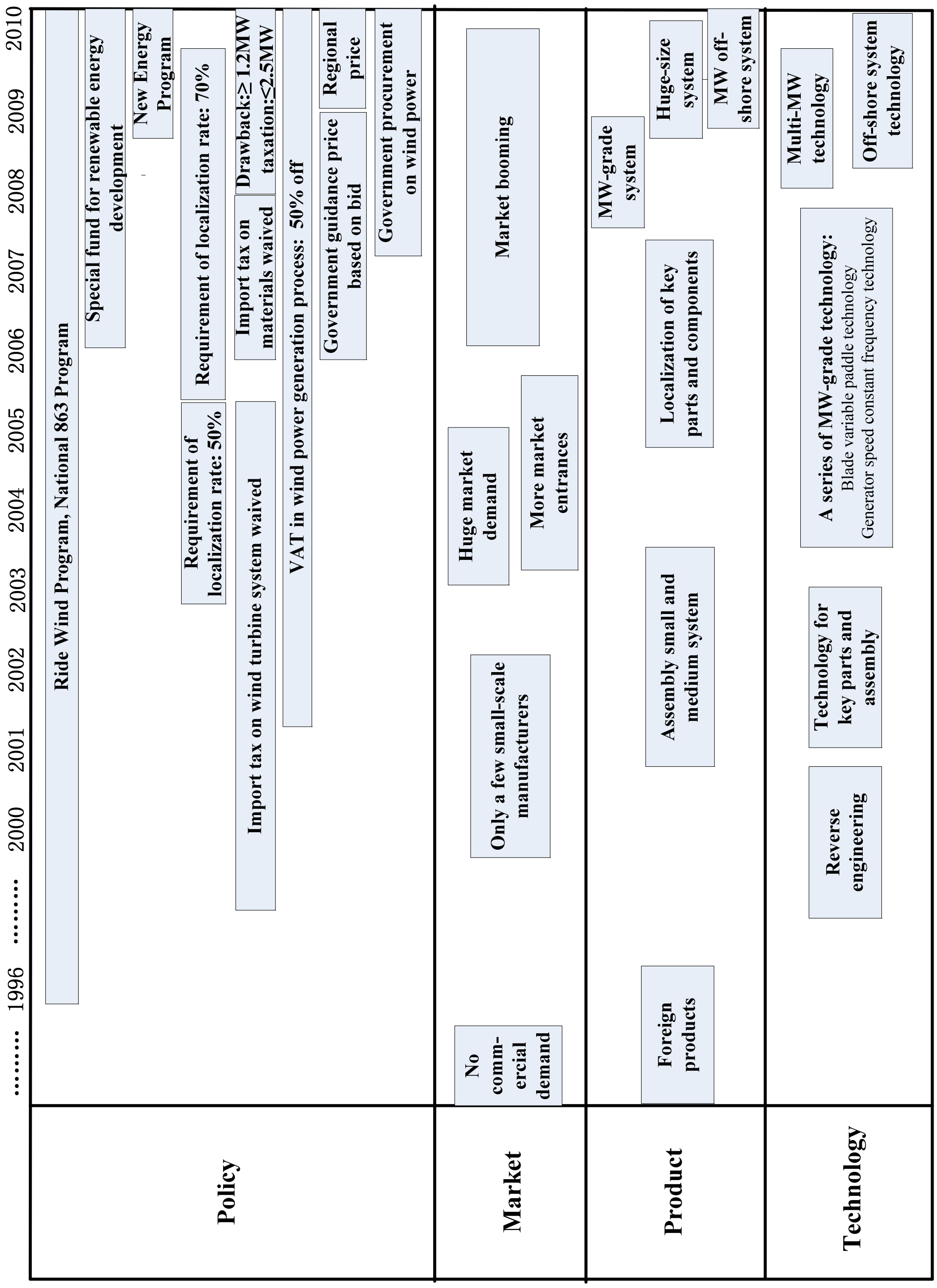
4.2.3 Demand policy

In 2006, the government regulated price based on bid was implemented to regulate the price system. In 2007, the government committed to fully take over all power generated by renewable energy projects including wind energy. In 2009, Chinese Government further set up the standard of wind energy price with regional diversity, and gave price subsidies to wind energy.

4.3 A snapshot of China wind energy industry's development

Based on the above descriptions and analyses, a snapshot of China wind turbine industry's development is drafted as Figure 3.

Figure 3 Key innovation events through the emergence of China wind turbine industry



5 Discussion

5.1 Industry evolution and innovation policies

According to the characteristics of policy, market, product and technology in different time periods, the development of the wind turbine industry in China can be divided into four phases: precursor phase, embryonic phase, nurture phase and growth phase.

- *Precursor phase (up to 1995).* Before 1996, China's wind energy equipment was nearly all imported from oversea manufacturers. There was almost no commercial demand for wind energy in China, and thus there were very few Chinese domestic producers. At that time, China's national grid was in the pilot and demonstration phase, which were mainly supported by international bilateral aid projects.
- *Embryonic phase (1996–2002).* From 1996, the Chinese Government began to pay attention to the wind energy industry. In this period, China passed the 'Ride Wind Program', National Research 863 Program and various wind energy concession projects to encourage technology import and technological innovation of wind energy equipment. Stimulated by these policies, a few small and medium scale Chinese local firms entered the market. Through reverse engineering, these Chinese manufacturers mastered some technology for key parts and assembly and could made small and medium-capacity systems.
- *Nurture phase (2003–2005).* At this phase, the booming Chinese economy (and therefore the soaring demand of electrical power) led to a huge growth in market for wind energy in China, and more and more wind powder equipment-related manufacturers emerged in China market. Gradually Chinese manufacturers mastered a series of MW-grade technologies, such as blade variable paddle technology and generator speed constant frequency technology. The production of key parts and components of wind energy equipment started to be localised in China.
- *Growth phase (2006–2010).* In this period, there is a sharp growth in the size of Chinese wind energy equipment industry. From 2006 to 2009, the accumulative total installed capacity of China kept a growth rate over 100% for three successive years. Chinese firms gradually caught-up with manufacturers from developed countries and mastered some of the core technologies. MW-grade productions were launched by Chinese local firms, and large-scale systems and MW-capacity off-shore systems are in the process of development.

5.2 Impacts of supply policies

The Chinese Government has continuously carried out supply policies for wind energy industry since 1996. Supply policy plays an important role in encouraging technology development in the embryonic phase, nurture phase and growth phase of the industry.

Through supply policy tools, the Chinese Government gives strong support to the development of key general technologies. In the past years, the national R&D subsidy programmes, such as the Ride Wind Program, National 863 Program, consistently provided major R&D investment to key and competitive enterprises to stimulate the import of wind energy technologies and endogenous innovation. For example, the development of blade variable paddle technologies and generator speed constant frequency technologies needed very large R&D investment but also presented firms with high levels of technological and market uncertainties As a result, the development of such technologies were de-risked for firms by support from national investment programmes. These programmes also supported the deployment and demonstration of wind energy systems, which is very important for technology and product development. Chinese wind energy manufacturers were able to leverage the advantage provided by these national programmes, achieved several technological breakthroughs, and gradually caught up with their international competitors.

5.3 Impacts of environment policies

The Chinese Government's environment policies also supported the development of wind energy industry from mid-embryonic phase to growth phase.

On the one hand, Chinese Government implemented tax policies to strategically intervene in the development of wind turbine industry. At the beginning of the industry development, the exemption of import tax on wind turbine systems stimulated technology imports and provided the opportunity to learn from reverse engineering. At the growth phase, the exemption of import tax on production materials promoted the localisation of wind turbine production from 2006 to 2008, while the adjustment of import tax policies in 2008 encouraged the R&D of large-scale systems and off-shore systems. In addition to these, since 2001, the 50% VAT discount in wind energy generation processes has attracted many market entrances and promoted the production localisation process.

On the other hand, government accelerates the development of wind turbine by requiring a lowest localisation rate of wind energy equipment at nurture and growth phase. These policies directly contributed to the procurement requirements of domestic equipment for wind farm construction. Thus, tower, nacelle, blades and motors achieved production localisation in turn; and spindle bearings, gear boxes and inverters also realised localisation in part. Therefore, a large number of local suppliers emerge and grow up, and gradually they catch up and can compete with oversea firms while the localisation rate requirement is terminated. The market regulation of localisation rate led to huge market demand, created a protective market competition environment and accelerated the development of Chinese local firms.

5.4 Impacts of demand policies

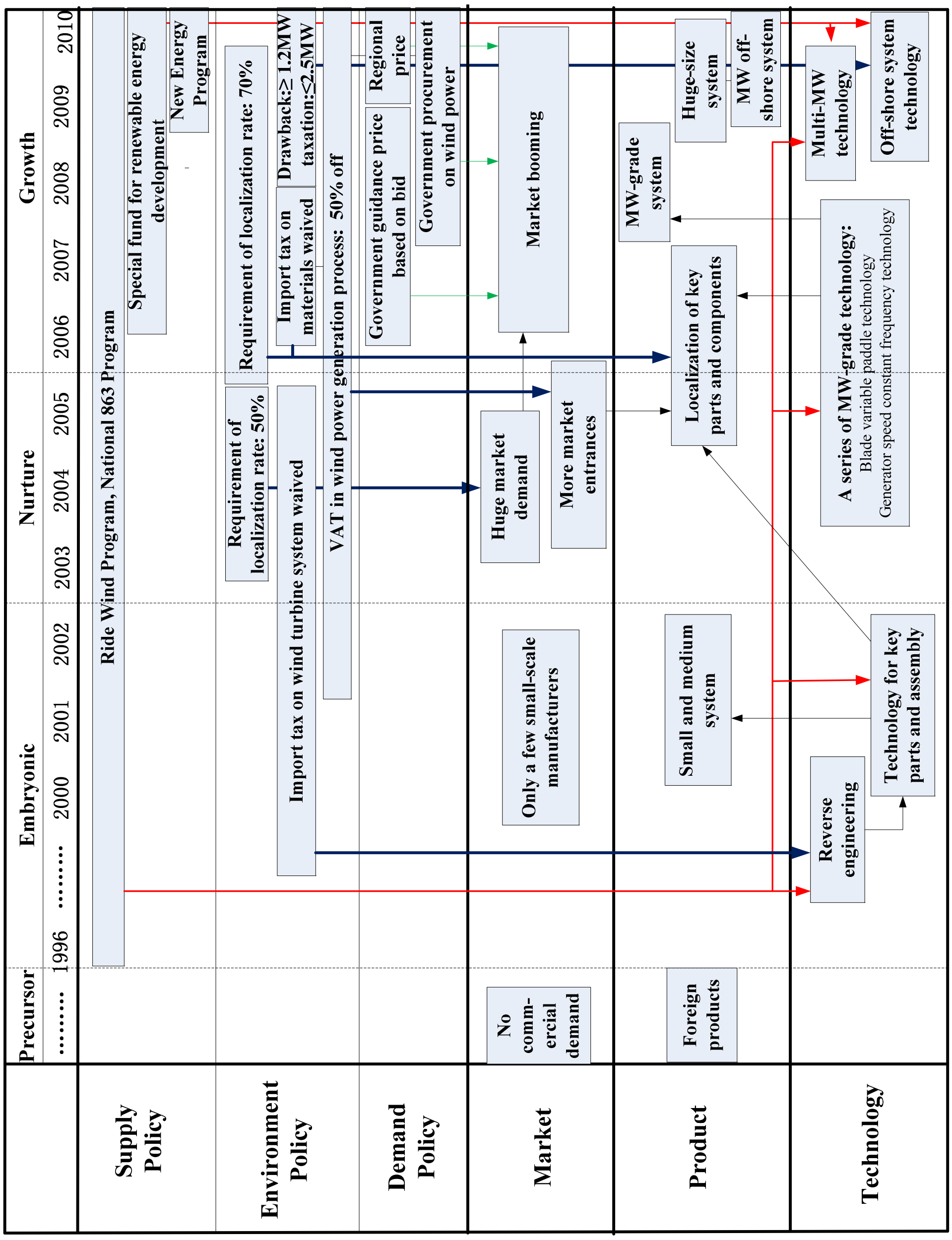
At the growth phase of wind energy industry, Chinese Government applies a lot of price policies and government procurement policies from the perspective of demand.

Compared with traditional energies, wind energy is clean and renewable. However, due to the immaturity of technology and market, the cost of wind energy is still higher than traditional power, which can be a huge obstacle for the promotion of wind energy. In order to solve this problem, Chinese Government has implemented guidance price policies and given according price subsidy to wind energy. What's more, the government committed to fully take over all power generated by wind in 2007. These policies help with the market booming of wind energy in China in recent years.

5.5 P-TRM analysis of China's wind turbine industry

The P-TRM for wind turbine industry is traced out in Figure 4. We can see that the three types of policies, market, product and technology interact with each other, and they all contribute to the rapid development of wind turbine in China.

Figure 4 P-TRM analysis for wind turbine industry in China (see online version for colours)

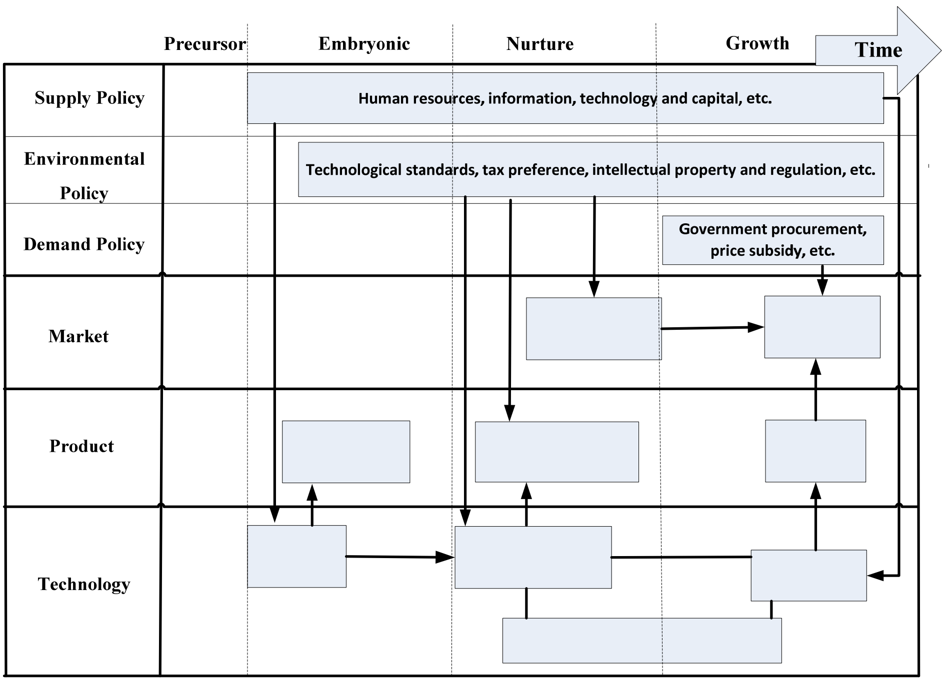


As shown in Figure 4, there are hardly policies at the precursor phase. Supply policies are carried out at embryonic, nurture and growth phases, which have direct impacts on technology enhancement. Environment policies also play an important role from embryonic phase to growth phase, acting on market, product and technology. Demand policies are mainly published at growth phase, leading to the expansion of market capacity.

6 Conclusions and prospects

Many policy makers view industrial emergence process as a black box, which makes it difficult to decide what policies are required to promote and regulate the industrial emergence, especially when policies may vary at different industrial growth stages. This paper proposes a P-TRM framework (see Figure 5) that can provide with a holistic analysis on the development process of emerging industries when examining the interactions between policy and other key influential factors (e.g., market, product, business model, etc.), which can explicate specifically the policies and their impacts on the emergence of highly-regulated sectors (i.e., new energy industries) at different stages. In particular, this paper analysed the emergence process of Chinese wind turbine industry as an exploratory study to understand what policy tools are required at different stages when influencing the emergence of new energy industries in China.

Figure 5 Refined framework of P-TRM



This paper finds that the emergence of Chinese wind turbine industry was significantly pulled by a government-led market, and this process was not a traditional research-to-product process like in developed economies. At the embryonic stage, government strategies stimulate the emergence of local industries through imports and reverse-engineering with low-tech products, which help to create a government-pushed market. Followed by a nurturing stage, given an existing market, government policies provide R&D grants on platform wind turbine technologies, and also provides with tax incentives/regulations/standards to foster the innovation capacity of domestic wind turbine firms, in order to catch up with main stream technologies in developed countries. Subsequently, at the growth stage, the local firms can develop more competitive wind turbine products based on specific technologies (better for Chinese markets) that have been developed in the nurture stage. The industrial emergence process was not a traditional process that starts from research towards the commercialisation of technology; on the contrary, it starts with low-tech products based on acquired technologies, then the industry forms its own technology trajectory based on Chinese specific contextual settings.

Through the study on this emergence process, the authors find that demand/environment/supply policies have different impacts on the development of wind turbine manufacturing industry in China. Demand-oriented policies help reducing market uncertainties in later stage. Environment-oriented policies are active in nurturing and growth stage, mainly shape industrial structure, forming standards, and eliminating externalities. Supply-oriented policies have great impact from the very beginning, specifically on technological advancement by providing grants reallocating resources, and reducing information asymmetries. The authors argue that these policies' impact on industrial emergence may also manifest in other emerging new energy sectors in China.

This paper contributes to theory in three ways:

1. develop the integrated P-TRM tool which can specifically study the policy-industry dynamics through the development process
2. have a better understanding of the dynamics in wind energy sector for policy making
3. better understand Chinese specifics of the policy-industry interactions, especially in wind energy manufacturing sector.

Practically, this study integrates the policy dimension into TRM framework as a guide book, in response to the requirement for mapping and planning the industrial development of new industries in emerging economies (e.g., China).

Limitations of this paper do exist. First, this is a pilot single case research, so further work on other emerging sectors (e.g., photo-votalic, wind farm, clean coal, etc.) will be carried out in order to ensure the generalisability of the P-TRM tool. Second, this explanatory framework is designed for analysing the past trajectory. Further study to integrate other technology management tools (e.g., energy lifecycle analytical tool) would be useful for forecasting or planning the growth. The paper could be the basis for further work to convert analysis into guidance for practitioners to address 'innovation policy gap' and to support policy making and evaluation.

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Notes

1 In the early phase of industrial lifecycles, emerging technologies are viewed as the sources of dynamic and innovative activities in firms, markets, and social institutions through which they operate (Daim and Oliver, 2008; Edquist and Chaminade, 2006; Eisenhardt and Tabrizi, 1995).

2 Schumpeter Mark I industry: for this industry, the innovation and technological change of a nation comes from the entrepreneurs, or wild spirits.

3 According to the literature, innovation policy consists of science, technology and industrial policy (National Technology Outlook Team, 2008).

4 TRM tools have been widely used to study and plan the development of industries, e.g., foresight vehicle TRM in the UK (http://www.foresightvehicle.org.uk/tech_roadmap.asp), computer science roadmap (http://research.microsoft.com/en-us/um/cambridge/projects/towards2020science/), UK Ministry of Defence roadmapping (http://www.aof.mod.uk/aofcontent/tactical/techman/content/rm_intro.htm), etc.

5 TRM is becoming more and more popular as a policy and strategy planning tool in China. For example, in 2010 and 2011, TRM tool is widely used by the Ministry of Science and Technology and Ministry of Industry and Information Science when making the 12th five-year national strategic plan.

6 Phaal et al. (2009) classified the development process of emerging industries into five stages: precursor, embryonic, growth, mature and decline.

7 Interviews with government officers in Chinese Ministry of Science and Technology (MOST).

8 Interviews with government officers in Chinese Ministry of Science and Technology (MOST).

9 http://www.crein.org.cn/forum/windpower/CFJHJJ.HTM.