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# The decomposition of innovation in Europe and China's catch-up in wind power technology: the role of KIBS

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Abstract:

Innovation is increasingly decentralised, traded, and transferred internationally. Specialised suppliers of knowledge-intensive business services have emerged, enhancing the international transfer of knowledge and technology. This has important implications for the global geography of technological and innovative capabilities. This paper focuses on the role of European KIBS providers for the catch-up process in the Chinese wind turbine industry. Drawing on in-depth studies of three central technology domains in wind turbine research and development, it shows how the recent catch-up in the Chinese wind turbine industry was closely connected to organisational changes taking place in the incumbent wind turbine lead markets in Europe. The paper suggests that access to knowledge through KIBS can unlock rapid but bounded latecomer development in emerging markets.

Keywords: decomposition of innovation, KIBS, globalisation, catch-up, China, Europe, technology transfer, wind turbines; R&D

# The decomposition of innovation in Europe and China's catch-up in wind power technology: the role of KIBS

## 1 Introduction

The organisation of innovation has changed dramatically since the 1980s, from centralised innovation set-ups within corporations, to increasingly disintegrated set-ups in distributed networks within and between firms (Chesbrough, 2003; Langlois, 2003; Lazonick, 2010). This is referred to as the organisational decomposition of the innovation process (ODIP) (Schmitz & Strambach, 2009) and it has important ramifications for the changing balance of innovation capacity across advanced economies and emerging markets (Lema, Quadros, & Schmitz, 2015; Manning, Larsen, & Kannothra, 2018).

It is well established that the outsourcing and offshoring strategies of lead firms have expanded from the relocation of production activities to the gradual relocation of innovation activities to subsidiaries and suppliers in emerging markets. The international business literature has greatly enhanced our understanding of the globalisation of innovation driven by large multinational enterprises (MNEs) (Archibugi & Michie, 1995; Cantwell & Mudambi, 2005). Much less is known about the role of specialised firms providing knowledge-intensive business services (KIBS). However, these firms play a crucial role in decentralising, subdividing, and trading innovation (Freel, 2006; Landry, Amara, & Doloreux, 2012; Miles, 2006) and hence in the prospects for transferring knowledge and innovation activities internationally (Schmitz & Strambach, 2009; Shearmur & Doloreux, 2009).

To explore this, we address the following questions in this paper: Does the decomposition of innovation and the emergence of KIBS in advanced economies affect the prospects for deepening capabilities of emerging market firms? What are the potential transmission mechanisms, how effective are they, and what are their limits? We address these questions in the context of knowledge linkages between the European and the Chinese wind turbine industries, the latter of which has emerged as one of the largest in the world in less than two decades. Specifically, the empirical focus of the paper is on the role of European KIBS providers in the process of latecomer development in the Chinese wind turbine industry.

The paper brings together the innovation studies literature on KIBS with the literature on latecomer development rooted in evolutionary economics, thus providing an original avenue to explore the role of innovation decomposition and KIBS in the process of catching up at the firm and sector levels. By doing so, it makes three contributions to the literature. Firstly, it highlights key mechanisms and dynamics involved in the long-distance transmission of technological knowledge in this sector. Secondly, it discusses the implications of innovation decomposition for the sectoral co-evolution of advanced economies and emerging markets. Thirdly, it identifies the limits to a latecomer model founded largely on external innovation linkages to specialised technology providers in advanced economies.

The paper is structured as follows: Section 2 provides a review of the relevant literature and conceptual framing, while Section 3 explains the methodological approach. Section 4 provides the empirical background, giving an account of innovation decomposition in Europe and catch-up in the Chinese wind turbine industry. In Section 5, analyses of innovation decomposition and transmission are provided for three technology domains central to product innovation: wind turbine design, simulation tools, and control systems. Section 6 discusses the effectiveness of knowledge transmission through KIBS and the role of absorptive capacity in recipient firms and the system in which they are embedded. In Section 7, we draw conclusions based on our findings and provide policy recommendations.

## 2 Decomposition of innovation, KIBS, and catching up

### *2.1 Decomposition and the role of external knowledge in catching up*

The evolutionary economics literature on latecomer development refers to catch-up as a substantial closing of the gap in capabilities between firms in ‘incumbent countries’ and firms in ‘follower countries’ (Lee, 2019; Mathews, 2002; Perez & Soete, 1988). In the latter, it requires upgrading of production into innovation capabilities (Altenburg, Schmitz, & Stamm, 2008). This upgrading depends on internal investments in knowledge, but it can be greatly facilitated by absorption of knowledge from the international knowledge pool into open innovation systems (Fu, 2015). Various mechanisms for knowledge transfer and technological learning can be utilised depending on the stage of development (Hansen & Lema, 2019), but the conditions for doing so are highly sector specific (Malerba & Nelson, 2011). Even within the specific domain of green technology industries there is great variability in the conditions for global mobility of knowledge (Binz & Truffer, 2017; Huenteler, Schmidt, Ossenbrink, & Hoffmann, 2016).

The general theory behind this paper is that the prospects for absorbing technological knowledge for latecomer development in a given industry depend on the extent to which and how innovation is decomposed: sectors characterised by decomposed innovation processes may provide openings for latecomers since they provide opportunities to tap into open and dynamic knowledge pools (Schmitz & Strambach, 2009).

Innovation decomposition refers to the process by which innovation moves from firm headquarters to decentralised departments, subsidiaries, research organisations, and suppliers of products or knowledge-intensive services (Lema et al., 2015). Thus, innovation activities are both increasingly subdivided into specialised segments and decentralised within and between firms. Modern firms often innovate with the external sourcing of ideas, knowledge, and resources, combining and leveraging them with internal assets and research and development (R&D) resources. New modes of innovation are bidirectional: outflows of knowledge occur as firms commercialise knowledge in the market place (e.g. licensing out), while inflow refers to use of knowledge from the external knowledge pool (e.g. licensing in) (Chesbrough, 2003, 2017). However, outflows are not always the result of deliberate choice, but may occur with firm spin-offs, labour rotation, or diffusion of knowledge to suppliers or partners.

We focus on the particular mechanism of innovation decomposition involving mediation by KIBS. MNEs in emerging markets often engage in a three-stage 'linkage–leverage–learning' strategy (Mathews, 2002). By linking with KIBS providers, the MNE can leverage knowledge and lay the groundwork for leapfrogging, catching up, and learning, sparing itself the cumbersome steps of learning 'from scratch'.

## *2.2 KIBS providers and transmission of knowledge*

KIBS are defined as organisations providing services that involve economic activities intended to result in the creation, accumulation, or dissemination of knowledge (Miles, 2006, 2007). They are typically expert companies providing services to other companies and organisations, thereby functioning as facilitators of innovation (Strambach, 2008).. KIBS providers often cluster in specialised lead markets or regions characterised by accumulated domain knowledge. Hence, they reinforce sectoral dynamics within local innovation systems. But these firms are also increasingly internationalising (Huggins, 2011), and there are indications that KIBS providers have played a critical role in the formation of industries in developing countries, not least China (Bao & Toivonen, 2014).

A type of KIBS particularly relevant to this study is T-KIBS ('T' for Technology) – firms that provide R&D services and engineering services – as opposed to P-KIBS ('P' for Professional) which provide, for example, financial or marketing services (Miles, Belousova, & Chichkanov, 2018). In this paper we apply a simple distinction between three different types of transmission mechanisms for the provision of knowledge from T-KIBS to clients:

- *Parcelled transmission – unidirectional flow of codified knowledge*: a one-way knowledge transaction involving the provision of access to proprietary knowledge embodied in blueprints, manual designs, software, or plug-and-play hardware, typically made available on a licence or fee basis.
- *Co-located transmission – unidirectional transmission of tacit knowledge*: also one-way but involves a degree of 'socialisation' (Nonaka, 1994), or face-to-face engagement, such as in general training activities or tailored instruction sessions organised by the KIBS provider.
- *Interactive transmission – bidirectional transfer and creation of tacit knowledge:* as a more advanced R&D service, this involves the reciprocal back-and-forth definition of specification for tailored services or solutions provided by the KIBS. It may involve co-created knowledge produced by KIBS and client in intensive collaboration.

These transmission mechanisms are not discrete and may be blended together. A certain degree of progression is implied, with an increasing degree of complexity of knowledge from parcelled to interactive transmission.

### *2.3 The role of KIBS in global knowledge transmission*

In the innovation systems literature, innovation is typically understood to be dispersed mainly across actors within the national system of innovation contained within the regional or national territory, because knowledge involved in innovation is often tacit, sticky, and cumulative in nature (Cooke, 2001; Lundvall, 1992). In contrast, the literature on open innovation has begun to address innovation decomposition spanning national boundaries (Chesbrough, 2003). However, it has mainly concentrated on 'openness' within and across OECD countries.

By contrast, research on global innovation networks (GINs) aims to understand the processes and consequences of MNEs from OECD countries engaging in knowledge exploration, not simply knowledge exploitation, as they move activities to developing countries (Chaminade & De Fuentes, 2012; Kruss & Gastrow, 2012). Part of this literature on innovation dynamics in transnational contexts argues that such innovation networks are now embedded in 'global systems' of actors and institutions and that these systems vary according to sectors and their characteristics (Binz & Truffer, 2017).

Thus we focus on the existence of KIBS as a key enabler of global (or transnational) knowledge networks within sectors. Some general trends have enhanced the global mobility of knowledge, such as an increasing ability to codify – for instance through use of ICT tools (Narula & Zanfei, 2006; Sturgeon, 2002) – as well as the enhanced flow and exchange of tacit knowledge enabled, for example, by cheaper air travel and improved video conferencing. But the existence of KIBS may alter knowledge mobility by packaging knowledge in new ways, making it more tradable and distributable, and pushing knowledge combination across different geographical and national/institutional spaces (Strambach, 2008).

KIBS providers may function as 'intermediaries of knowledge' at a global scale (Schmitz & Strambach, 2009; Shearmur & Doloreux, 2009), potentially playing an important role in the transfer of technology and knowledge from advanced economies to emerging markets, and providing opportunities for latecomer firms to purchase knowledge assets to strengthen their capacity to innovate.

This capacity may vary, however, according to the depth of innovation-aiding knowledge provided by the KIBS. We draw on the modularity and system integration literature and distinguish between problem solving and problem framing (Brusoni, 2005):

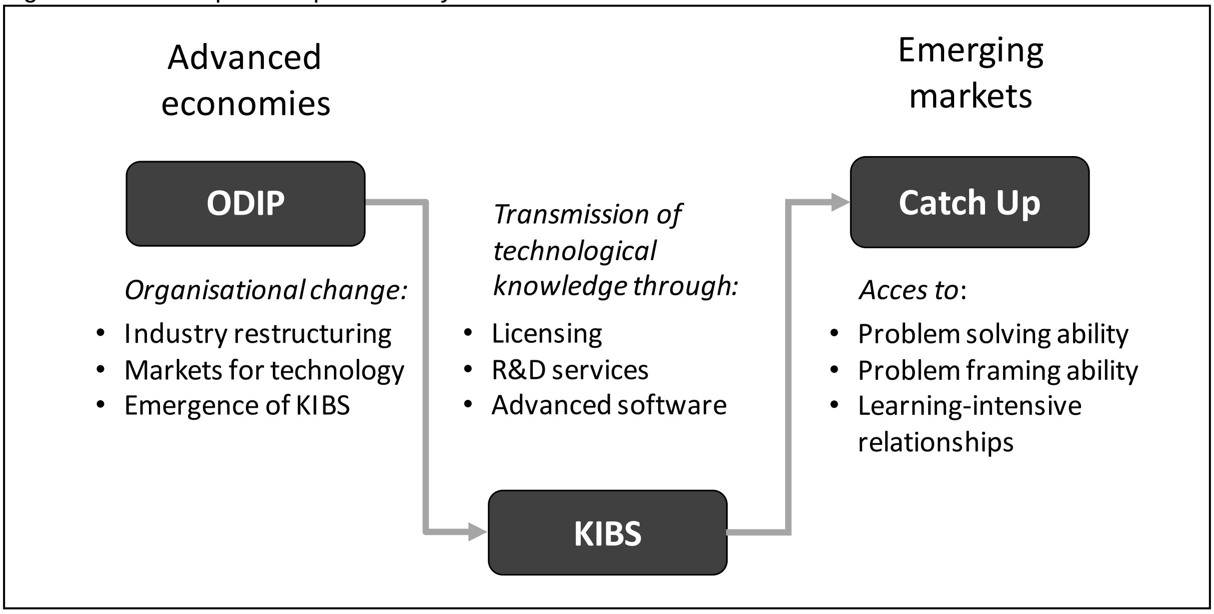
- *Problem-solving ability* involves the commission of services related to individual components of technologies or incremental adjustments of overall technologies to specific needs or contexts. It involves the transmission of 'know-how' types of technological knowledge.
- *Problem-framing ability* involves the acquisition of services related to the design of complete solutions. It builds on a profound understanding of the underlying knowledge base and complete architectures and involves transmission of 'know-why' types of knowledge.

It may be hypothesised that problem solving in latecomer firms facilitated by KIBS-mediated knowledge may be acquired thorough parcelled and co-located transmission mechanisms. By contrast, problem framing is likely to depend significantly on co-located and interactive mechanisms. This will be explored in the empirical sections of the paper.

### *2.4 Summary and roadmap*

Figure 1 provides a roadmap for the empirical analysis. It brings together three 'motions' in the process we seek to explore in the wind sector. (1) The first, addressed in Section 4, is the emergence of KIBS and the origins of this term for industrial dynamics and the associated ODIP in advanced economies. The emergence of KIBS is a prerequisite for the following steps, because they may be willing and able to transmit knowledge from first-mover markets and (indirectly) from lead firms, which tend to be much more protective of their knowledge. (2) The second is the various transmission processes devised by KIBS for long-distance transfer of technological knowledge, which are identified in Section 5.

Figure 1: Roadmap for empirical analysis




(3) In Section 6 we discuss emerging market firms' differing degrees of access to new types of knowledge that are critical to the development of problem-solving and problem-framing ability. Making productive use of this knowledge for capability development and eventual innovation ability depends on the firms' effort and absorptive capacity. The next section introduces the sectoral setting, the choice of this sector for the present study, and the process of data collection.

# 3 Case selection and data collection

## *3.1 The wind energy industry and its technology domains*

The wind energy industry was chosen to explore the role of KIBS in the decomposition process and the sector's changing global geography – specifically whether and through what processes the deepening of capabilities in China, as an emerging market, was influenced by ODIP in advanced economies.

The wind industry constitutes an interesting case to explore organisational decomposition and spatial reconfiguration. In terms of production, there is limited globalisation, in part because of high equipment transportation costs, technological characteristics, and protectionist public procurement policies. Hence, there is a high degree of localisation and close connection between production and deployment. In terms of innovation, the patterns resemble those typical of complex product systems (CoPS) rather than those of mass-produced goods (Huenteler et al., 2016). While the size of turbines is increasing and products are becoming more sophisticated with advanced IT-enabled monitoring and control systems, the core technology is relatively mature (Haakonsson & Kirkegaard, 2016). This allows for an increasing degree of bundling and commercialisation of technology which, in turn, allows for global redistribution of technology and knowledge through KIBS.

The broad KIBS landscape in the wind industry and its contribution to China's catch-up has been emphasised and described in prior literature (Lewis, 2007; Schmitz & Lema, 2015). This paper explores decomposition and its implications for the global geography of innovation by examining specific technology knowledge domains in wind energy and knowledge transmission within those domains. Specifically, we include KIBS in the following (interconnected) technology domains:

A. *Turbine architecture and design services*: the provision of a simulated/calculated, tested, and certified turbine design. It provides the buyer with detailed descriptions and engineering know-how of an accredited turbine design in which the interaction between all turbine components (e.g. control system, generator, gear, blades, brake, and tower) has been analysed and their joint functioning is optimised.

B. *Simulation and testing services*: services integral to the certification of modern wind turbines in accordance with international standards. A new turbine design must be operated under various loading conditions in a simulated environment using a software-based simulation tool before a physical prototype can be erected and tested. Thus, the turbine has an accredited certification of compliance with international standards.

C. *Control system software services*: the integrated supervisory control system (the 'main control') containing both hardware and software that controls how the turbine regulates its everyday operations (e.g. blade angle, generator speed, yaw angle) under different weather conditions.

According to industry experts, these three technology domains are the most critical in the continuous development of wind turbine technology. Numerous European KIBS providers have supplied knowledge and solutions to Chinese firms in development. Examples of these KIBS providers are provided in Table 1.

Table 1: Examples of European KIBS providers across three technology domains

| **Technology Domain** | **Examples of European KIBS** |
|---|---|
| Turbine design | • Aerodyn (Germany)<br>• Avantis (Germany)<br>• Darwind (Netherlands)*<br>• Harosakan (Japan – formerly Zephyros, Netherlands)<br>• Norwin (Denmark)<br>• Vensys (Germany)*<br>• Senvion (Germany)<br>• Windar Photonics (Denmark) |
| Simulation and testing | • DNV GL (Norway – formerly Garrad Hassan, UK)<br>• Mecal (Netherlands)<br>• DTU Wind Energy (Denmark)<br>• Simis (Norway)<br>• W2E (Germany)<br>• QBblade (Germany) |
| Control systems | • AMSC (US – formerly Windtec, Austria)<br>• DEIF (Denmark)<br>• DotX (Netherlands)<br>• FREQCON (Germany)<br>• Mita Teknik (Denmark)<br>• KK Electronics (Denmark)<br>• Spica (Denmark) |

Source: Authors' interviews
* = Has been acquired by a Chinese firm

### 3.2 Focal firms and interviews across domains

Our particular focus is on the types of technology being transmitted between knowledge producers and knowledge users, and the mechanisms involved. The paper is based on qualitative methods, as it would be difficult to unravel such mechanisms and processes across vast geographical space quantitatively. We draw on prior research on the role of European KIBS in wind technology transfer to China and on the technology supply base (Haakonsson & Kirkegaard, 2016; Haakonsson & Slepniov, 2018; Schmitz & Lema, 2015). Our aim is to provide insight on European KIBS providers and their engagement with Chinese wind turbine firms across technology domains.

The analysis is based on case studies of European KIBS providers in three different but strategically important technology domains: turbine design, simulation software, and control systems. It is difficult to assess the degree to which these firms are representative of KIBS, but each is among the leaders in their technology domains. In each domain we draw on interviews with several European T-KIBS as well as technology users in Europe. A total of 16 interviews were conducted among KIBS providers in Europe (see Table 1 for examples), inquiring into decomposed elements of the innovation process which may facilitate catch-up, learning, and innovation by Chinese firms.

In addition, interviews were conducted in China to understand the contribution of these technology and innovation services to firm-level catching up in newcomer firms. The data collection involved more than 50 semi-structured interviews with actors in the global wind turbine industry as well as a range of research institutions and industry associations, collected over a three-year period (2016–2018) in Denmark, Germany, and China. The interviews focused on how KIBS contributed to Chinese firms' learning and innovation processes, the limits to such contributions, and whether Chinese firms internalised technological knowledge to build advanced (problem-framing) innovation capabilities.

# 4 China's wind energy industry in a global context

## *4.1 ODIP and the emergence of KIBS*

In the 1980s the nascent global wind industry was driven by experimental Western (primarily Danish and German) firms engaged in experience-based learning, resourceful improvisation, and dense interactions within their national innovation systems. During the 1990s and 2000s, the industry was rapidly transformed into a big business. The innovation processes and spatial distribution of manufacturing activities resembled those of more mature industries such as the automobile industry (Kirkegaard, Weischer, & Hanemann, 2009; Pedersen, 2009). In wind, innovation processes initially were highly tacit and localised but gradually became more systemic and moved beyond the borders of national and regional innovation systems (Gebauer & Binz, 2019; Karnøe & Garud, 2012).

This industrial transformation signifies the increased maturity of the technology (Hendry & Harborne, 2011), but also a shift in innovation strategy from an 'open source strategy' towards patenting and other forms of knowledge protection where innovation is traded rather than shared (Gregersen & Johnson, 2010). In the wind industry this enhanced the importance of design, drawings, and component specifications for turbines, as they were increasingly used in technology transfer from licensee to licensor along with the right to produce and sell them. Industry consolidation, reducing turbine manufacturers from more than 20 in Denmark alone to only two in a span of 20 years, combined with the codification of designs and component specifications, constituted the initial preconditions for decomposition.

With the simultaneous processes of industry consolidation and decomposition of innovation, three types of firms became critical actors in the new industry value chain (Haakonsson & Kirkegaard, 2016): incumbent turbine manufacturers, specialised component suppliers, and KIBS as providers of various technology services (Gebauer & Binz, 2019; Haakonsson & Slepniov, 2018). KIBS providers became intermediary firms with no manufacturing capacity in-house, adopting a business model focused on licensing out of, for example, turbine design, R&D capacity, and consultancy services. Most of the KIBS providers that played a role in transferring technology to China emerged from the European lead firm base or as spin-offs from nearby research institutions (Lema, Nordensvärd, Urban, & Lütkenhorst, 2014).

As ODIP took place, KIBS providers moved into emerging markets. New-entrant manufacturers in Asia benefited from the availability of licensing technologies while having no proprietary technology themselves. The KIBS segment thus represents an interesting entry point for tracing flows of knowledge and capabilities to emerging market actors in China, India, and South Korea since the turn of the millennium.

## *4.2 Catching up in China*

In China's wind turbine industry in particular, ODIP and the subsequent emergence of KIBS providers contributed to compressed development with a very steep learning curve: it took China just 10 years to move 'from having no wind turbine manufacturing experience to having the ability to manufacture complete wind turbine systems that are state-of-the-art and either already available or soon to be available on the global market' (Lewis, 2012, p. 301). Boasting a total cumulative installed wind production capacity of 188 GW and an astounding 35 per cent of the world's cumulative total of 540 GW installed wind power by the end of 2017 (GWEC 2018), China is now poised to become the world's global 'green leader' (Tan & Mathews, 2015).

The scale and pace of this development is remarkable. While China had experimented since the late 1980s with wind turbine technology in development projects, there was almost no wind power in China before 2006, when growth took off with the enactment of the Renewable Energy Law (Haakonsson & Kirkegaard, 2016). Table 2 shows the catch-up of Chinese wind turbine manufacturers in global market share.

Table 2: Wind turbine lead firms – global markets shares

| **2000** | | **2018** | |
|---|---|---|---|
| **Top 10 companies** | **Market share (%)** | **Top 10 companies** | **Market share (%)** |
| Vestas | 17.9 | Vestas | 20.3 |
| Gamesa | 13.9 | Goldwind | 13.8 |
| Enercon | 13.7 | Siemens Gamesa | 12.3 |
| Neg Micon | 13.4 | GE Renewable Energy | 10 |
| Bonus | 11.5 | Envision | 8.4 |
| Nordex | 8.3 | Enercon | 5.5 |
| Enron | 6 | MingYang | 5.2 |
| Ecotecnica | 3.9 | Nordex Acciona | 5 |
| Suzlon | 2.3 | United Power | 2.5 |
| Dewind | 2.1 | SEWind | 2.3 |

Market share: Top 10 wind turbine manufacturers in 2000 and 2018 (installed capacity). Chinese firms marked with grey shading (CWEA, 2018).

Chinese manufacturers began with no specific know-how on wind turbine technologies, engaging in reverse engineering and backward design based on foreign design licences, including from the Danish manufacturers Vestas and Bonus in the 1980s. In 1997 and 2001, the German firm Repower's predecessor, Jacobs Energie, licensed its design to the then insignificant Chinese manufacturer Goldwind, and further agreements were made with Chinese manufacturers such as Windey during the 2000s (Haakonsson & Kirkegaard, 2016).

European manufacturers have since become more cautious in their licensing strategy. Nevertheless, Goldwind, today the largest wind turbine manufacturer in China, caught up through an apparently extensive ODIP process: in 2003, Goldwind engaged in a new design licensing agreement with the German design company Vensys Energiesystems for a Vensys (direct-drive) 1.2 MW turbine. After this collaboration, Goldwind in 2008 internalised Vensys Energy's design capabilities by acquiring a 70 per cent stake. Goldwind has begun to jointly develop several new designs in partnership with Vensys. As a result of this investment, Goldwind has R&D facilities in China and Germany and has built external R&D capacities through collaborations with certification bodies, design houses, and universities in China and Europe. Another Chinese manufacturer, Envision, also hired Western experts on wind power technology and software and established a Global Innovation Centre in Denmark in 2010.

A broad array of other factors also enabled the rapid rise of Chinese firms. These included proactive Chinese demand- and supply-side policies, significant financial power, and pre-existing capabilities in China's heavy industry. Together, these created a demand for foreign technology as well as a foundation for Chinese catch-up in wind power (Lema, Berger, & Schmitz, 2013).

# 5 Decomposition and the role of KIBS in technology supply for catching up

The following section looks at three central KIBS-related technologies that are essential for the manufacturing, operation, and performance of wind turbines. In these cases, ODIP has occurred through three mechanisms: (1) externalisation of technology from the home national innovation system and its lead firms; (2) establishment of independent and specialised KIBS providers capable of extending the technology beyond the home market; and (3) transfer of technology to Chinese manufacturers.

### *5.1 Wind turbine design*

Design is at the core of the first stage of the process of producing a new turbine model and includes engineering drawings of the turbine and its sub-systems, along with specification of its components, their ratings and performance, and so on. Design processes are highly specialised, and newcomers to the industry often buy their first few full designs from established design companies. After that, manufacturers tend to make incremental changes and optimisations as they develop some knowledge of design in-house. Still, even large manufacturers use design companies to work on incremental innovation for parts of their designs. This ongoing co-creation keeps the design companies at the forefront of technological development as they have experience with many different manufacturers, as described by one of the KIBS providers in design:

> *We are always a step ahead in the technology and we are quicker. We have strong expertise in designing wind turbines. And we do a lot of designs. This is also our strength. For example, companies, if you compare to the big lead firms, they make 1 or 2 turbine designs but we do between 3 and 8 turbine designs a year. Furthermore, we have a big database. So when we start a new design, we already have data available. Because we have more than 80 turbines we have good reasons to figure out what will be a reasonable way, so we start at the good point, we don't need so many development loops.*

Design companies originally emerged in Northern Europe in the 1980s, when design specialisation was decomposed from universities and Europe-based manufacturers into specialised design houses. For new entrants, buying a completed design shortens the development and project processes, as it often comes with a supplier list for the core components. Turbine-design KIBS providers license their finished designs for certain geographical areas – for example, Latin America or China – so manufacturers have exclusive rights to sell turbines based on the specific design in a given location. According to one of the design houses, 70 per cent of the wind turbines in China are based on designs from Northern European design houses.

One turbine-design KIBS provider explained that Asian customers often require a complete design:

*When we were first involved in China in the mid-1990s, it was an upcoming Chinese wind turbine manufacturer who obtained a grant from the government to build their first megawatt turbine. At that time the company had many engineers, but no one had an overview of the technology – they were specialised here and there … but someone who could make decisions for the whole project was lacking.*

The same KIBS provider still develops designs for Chinese manufacturers such as Goldwind and DongFang. More recently, Chinese manufacturers have introduced new requirements related to the Chinese market, for example, specialised designs for low wind speeds, typhoons, high humidity, cold mountain climate, and earthquakes.

Buying a design from abroad provides access to the know-how of interaction dynamics between the different components. However, it is also costly, as one KIBS provider explained: 'You can buy all the know-how on the market, but you must pay for it.' Often Chinese manufacturers are stuck with the design as they bought it, because the certification is only valid for the specific fixed combination of components: 'When components are changed, the certification is gone.' Further, to get access to the international market, new designs must be certified in accordance with the International Electrotechnical Commission (IEC). To overcome this barrier to catch-up, some Chinese manufacturers have bought foreign design companies  or established innovation centres in Northern Europe. Meanwhile, there is still no indigenously designed Chinese wind turbine on the market, which shows the limits to catching up.

### *5.2 Simulation tools*

Simulation tools are specialised software packages used to simulate the working of the turbine before a prototype is built and erected, and are used to certify new and/or optimised designs' compliance with IEC standards. Simulation tools are used for research purposes, but also constitute highly specialised KIBS technologies. They are only available from a few specialised KIBS software providers, which are sometimes part of larger certification bodies. The software is essential for calculating the safe functioning, the optimal efficiency, and the forecasted energy output of a turbine. Simulation tools enable manufacturers to build a numerical model of the turbine and its planned environment, and to run simulations covering all the different conditions it will experience during its lifetime.

For Chinese manufacturers, simulation tools are increasingly important due to the increased focus on meeting international standards. The competitiveness of a design is largely determined by its aerodynamics, which ensures the optimal relation between the aerodynamic forces on the turbine, the loads on blades and tower, and its performance. KIBS providers of simulation software emerged out of the consolidation of the European industry when it became crucial to compare and certify different turbines. Today, the few internationally recognised simulation tools provided by European KIBS providers are good examples of how ODIP has given independent service providers the status of standard-setters of technology in an internationalised industry. Both Chinese manufacturers and the China General Certification Authority have developed standards based on and according to international software systems. Chinese actors adapted quickly, and the interaction with KIBS providers has primarily taken place as learning through technical support and training courses offered by KIBS providers.

There are barriers to further upgrading, however. According to the providers of simulation tools, Chinese actors access each tool as 'kind of a standard package' as it largely constitutes a 'black box, meaning that nobody actually knows how it calculates'. The core algorithms of the aeroelastic code that contains the turbine's control and optimised aerodynamic design are protected through encryptions, trade secrets legislation, technical locks, and/or non-disclosure agreements. Still, with the development of the market and the industry looking for foreign markets, standards are increasingly important, and certification KIBS are key for this, as noted by a Chinese manufacturer:

> *Yes, there are more and more requirements of certifications in China, so we have made the strategic decision that we want the best one, the DNV GL certification, on our blades. Maybe not so much because it is 100% needed in China but it will be needed when we go abroad ... we have an experienced international blade designer to look through all our documents to make sure that we did not make any mistakes. It gives us an extra safety to do the certification.*

Since the capacity to develop these core algorithms and aeroelastic codes has taken decades to build up and refine in European firms and research institutions, the lack of basic research into aerodynamics is a barrier to Chinese upgrading in simulation tools. Research is needed to further develop Chinese designs, rendering leapfrogging impossible.

### 5.3 Control systems

The control system ensures the safe and reliable automatic operation and optimisation of power output by continuously regulating the turbine's components according to changing wind speed conditions. The control system also provides data to the communication system that transmits operational data to project owners, as they control and monitor the overall running of their wind farms. Some of today's control system KIBS providers have worked in the business since the early 1980s and offer specialised technology within R&D services and know-how, turbine control, wind farm control, and grid integration. European manufacturers such as Vestas and Siemens have, over time, developed their own control systems.

With the upgrading of manufacturers, larger turbines, and high demand for lowering energy costs in China, having the right control system has become critical. Most Chinese firms buy from foreign KIBS providers, and control systems are an area where Chinese manufacturers are still lagging. Control systems are often specified by name as part of the turbine design. When a specific control system software is written into a licence, the supplier of the system is formally protected by patents, copyright, trademarks, and/or trade secrets and will receive a share of the royalties according to the number of turbines sold. Thus, when licensed, the software is proprietary and bound by non-disclosure agreements. With the upgrading of Chinese manufacturers, the control system package comes with training and assistance in the use and integration of the system.

Some co-creation is involved in the adaptation of the control systems technology to Chinese environmental conditions. Interaction between Chinese manufacturers and control system KIBS providers has escalated over time. According to a KIBS provider, some of their Chinese customers have now:

> *reached the limit, we are into the source code ... the only thing we lack is to give them access to the central nervous system. What they are getting access to, that's all the different sub-control systems, which are specific for the individual products, but the main control, the core algorithm is protected.*

However, the software cannot be installed on other systems or platforms, and the 'most core' and 'cutting-edge' technology is protected. This is still an arena for disputes, as there have been issues around copying of control systems:

*If customers pay for the source code, they get it. But if the customer re-sells our controller with the source code, we have a problem. There are many companies in China running with our control system in their turbine, and they know more with their further development. But if they don't pay, they don't get it.*

As Chinese lead firms have acquired more capabilities, they have also aimed to adjust the control system by upgrading their capabilities. While limiting the sharing of algorithms is critical to the survival of European suppliers, access to control system source codes is central to the upgrading of Chinese firms. Chinese customers increasingly demand room for manoeuvre to learn and experiment and to make adaptions to the systems, and KIBS providers risk losing market share if they do not engage in co-development with Chinese manufacturers. Foreign control system KIBS providers started out delivering the entire control system – including both hardware and software, in effect a 'plug and play' module system – but increasingly they deliver specific smaller modules, as Chinese firms have established capabilities to build, for instance, control cabinets (hardware) themselves. Furthermore, a number of indigenous Chinese control system suppliers have emerged, and Chinese as well as European manufacturers and control system suppliers are generally convinced that the Chinese will catch up in control system technologies.

Chinese manufacturers have accessed the three technology domains at different levels over time through different transmission mechanisms. For the control systems, accessing this technology from specialised KIBS allowed for a shift from parcelled transmission – buying package solutions – to building capabilities to adjust, and later, in the catch-up process, to interact with the technology as they were able to buy source codes. As a result, Chinese manufacturers have started to develop domestic standards and hence catch up on capabilities through co-location transmission. Very little in terms of turbine architecture and design has been co-located, as all designs still come from foreign design houses.

# 6 The role of KIBS for catch-up in the Chinese wind turbine industry

Through externalisation and global distribution via ODIP, KIBS providers made otherwise inaccessible but critical technology services available in the Chinese market, allowing Chinese manufacturers to catch up very quickly. Over time, more advanced KIBS components containing higher degrees of tacit knowledge not easily copied have been introduced into

China. Although all of this technology is now available in China, none of the specialised KIBS functions are performed independently by Chinese companies.

## 6.1 Transmission mechanisms and their limits

The analysis has shown how KIBS providers have functioned as intermediaries of knowledge (Strambach, 2008). Transfers to Chinese manufacturers occurred mainly through licensing agreements combined with service packages for practical training, supervision, and assistance in supply chain development. Licensing acted as a key vehicle for rapid organisational decomposition. With the upgrading of Chinese capabilities, licence contents have changed, and designs now include more disclosure of components and modules, allowing Chinese actors to develop smaller parts of the systems themselves.

The analysis also reveals that technology catch-up from ODIP has had clear limits. Chinese manufacturers have not reached a point where they no longer need foreign technology to develop new models. These limits are linked not only to the pre-existing knowledge base in China, but also to the extent and nature of the codifiability of the licensed technology. In general, the more codifiable a technology, the easier the transfer.

In the global wind turbine industry, components have become more standardised with the increased international demands for certification. In this way a process of knowledge decontextualisation (Strambach, 2008) has occurred in some areas of wind turbine innovation, making it more tradable. Certification involves documentation that relies on the KIBS providers' simulation tools, control system software, and certain standard requirements that are essentially coded in thousands of lines of algorithmic calculations. The competitive advantage of these KIBS providers depends on the protection of these codes. Therefore, the most essential software codes and algorithms in the simulation tool and control system are protected, either by black-boxing them or by intellectual property rights protection. Moreover, the standards set by the IEC do not reveal the underlying principles. Chinese certification bodies are struggling with translating the standards to Chinese conditions. This tacit knowledge is not codified anywhere and requires long-term investment in basic research.

Comparatively speaking, the more advanced and 'core' the technology is, the less likely it is that KIBS providers will reveal the codes. In the three cases, the highest degree of technological upgrading was in the case of control system software. Although it is still relatively complicated, improved capabilities among Chinese players have led to demands for access to more of the codes. Chinese companies have gained access to the use of proven technologies and international certification, but only to a limit set by KIBS providers, and negotiations on those limits are ongoing.

## *6.2 Access to knowledge and absorptive capacity*

Both technological problem-solving and problem-framing abilities have been utilised in China, but whereas the former has to some extent been acquired, the latter has been much more difficult to internalise. The engagement with KIBS has been an effective way of linking, leveraging, and learning. Although the relationships have proven to be very learning intensive, there are limits to the learning process when it comes to technological problem framing. European firms began with individual entrepreneurs experimenting to develop and refine indigenous turbine designs and components. Chinese firms began by acquiring foreign technologies and full turbine design licences, engaging in a trial-and-error strategy, and putting together components without the underlying system and design knowledge. As such our analysis shows that there are limits to the depth of knowledge which can be acquired through KIBS. A summary of access to problem-framing and problem-solving ability across the three domains is provided in Table 3.

Table 3: Access to problem-solving and problem-framing ability in China through European KIBS

| **Technology domain** | **Problem-solving ability** | **Problem-framing abilities** |
|---|---|---|
| Certified design | Build turbines in accordance with foreign design licence | Ability to get designs optimised to Chinese environmental conditions<br>Ability to experiment with development of Chinese standards |
| Simulation | Access to software used for testing and simulation<br>Ability to simulate/calculate the functioning of the turbine | Ability to simulate the optimisation of the turbine's performance in accordance with different conditions |
| Control systems | Building control systems hardware | Experimenting with development of indigenous Chinese control systems<br>Experimenting with optimisation of control systems software algorithms |

These limits to technological catch-up from ODIP and KIBS providers illustrate that Chinese catch-up requires not only access to KIBS, but the gradual build-up of an indigenous knowledge base. While the Chinese government officially pursues a strategy of building indigenous innovation capabilities in core technologies and developing its own standards, its wind turbine industry was built on reverse engineering, a politically planned and controlled research system, and a focus on fast industrial development through prioritising applied science over more long-term fundamental research. This may constitute the main barrier to moving from manufacturing catch-up to technological leadership.

Chinese firms have increased absorptive capacities and built indigenous capabilities in the development of specific components (e.g. towers, brakes, blades). However, only recently have they have started to look into more specialised and advanced tools, such as overall design as well as certification and standardisation supported by public and private investments in sizable R&D departments. Such investments are necessary to overcome the limits associated with the ‘stage skipping’ process in China and to gain the knowledge pertaining to the underlying aerodynamic principles of turbine design.

If and when Chinese manufacturers are to move from rapid catch-up to the development of advanced turbine technologies, reliance on technology transfer must be complemented by investments in basic research. Internalisation of externally acquired technology is necessary to build dynamic capabilities needed for technological leadership.

# 7 Conclusions

We started by asking whether and how the deepening of capabilities in the wind turbine industry in China was influenced by the decomposition of innovation and the emergence of KIBS in Europe. Our analysis suggests that decomposition contributed to Chinese firms’ catch-up in important ways, as KIBS providers within important knowledge-intensive business services made their know-how available to Chinese manufacturers. We also showed that this catch-up is limited in certain instances and that the prospects for a real technology takeover are far more complicated. This concluding section seeks to summarise the findings, discuss their implications, and pose new questions.

The rapid upgrading and catch-up of the Chinese wind turbine industry is widely recognised, and key factors and circumstances involved have been identified in a growing body of literature (Tan & Mathews, 2015; Haakonsson & Kirkegaard; Lema, Berger, & Schmitz, 2013). This paper adds to this literature by pointing to the crucial role of innovation decomposition and the resulting emergence of KIBS providers as key root cause which facilitated rapid catch-up. The three cases showed how decomposition was a precondition for catching up, and how it contributed to the catch-up process in various ways. The emergence of Chinese wind turbine manufacturers depended on business model changes among firms in OECD countries seeking to commercialise their technologies in the external market. KIBS providers were either dedicated design houses without manufacturing capacity or smaller turbine firms that did not compete head to head with domestic firms in China. Overall, the acquisition of foreign technologies, know-how, and technology have been integral to China's strategy for gradually building up its own wind turbine industry. By utilising mature technology through licensing and thus avoiding high R&D expenditures, Chinese manufacturers were able to produce turbines at much lower costs than their foreign counterparts, which together with the market structure in China led to their commodification.

For Chinese firms it became increasingly easy to obtain knowledge from external sources, and over time opportunities for acquiring tacit knowledge, know-how, and softer skills deepened (Haakonsson & Slepniov, 2018; Tan & Mathews, 2015). The interaction between Chinese firms and European KIBS changed over time, becoming co-design relationships involving significant flows of people between firms. Other important external mechanisms included hiring of personnel from Europe and the US in the cases of Goldwind and Envision. Decomposition influenced the internal learning set-up of Chinese firms: while orientation towards external knowledge remained central, over time Chinese firms increased their internal knowledge development.

A key question is whether decomposition and the emergence of KIBS providers is fundamentally affecting opportunities for catch-up across a range of industrial segments in emerging markets (Schmitz & Strambach, 2009), or whether wind power in China is a unique case with no significance for other industries and locations. The answer probably lies somewhere in between. There is no doubt that government support has been particularly important in the rapid development of the Chinese wind industry. The government has created domestic demand, which has in turn created a space for learning within firms (Tan & Mathews, 2015). Furthermore, most wind turbine technology is – in relative terms – standardised, and Chinese firms have been able to move directly to systems design very quickly (Haakonsson & Slepniov, 2018).

Our findings in the wind industry suggest that the circumstances for catching up may be changing in important ways. Catching up in technology and specialised knowledge has been difficult because incumbent firms create technological entry barriers to latecomer countries and firms. The decomposition of innovation processes contributes to altering the balance between the opposing forces, which enhances or blocks catching up by latecomers. However, it is relevant to focus on two key issues. Firstly, the key policy question in emerging markets is how to make the most of the opportunities provided by the decomposition of innovation. Future research should seek to identify and map out policy instruments that facilitate different types of decomposition and their exploitation for the purpose of technological learning. Secondly, as this development allows emerging market firms to catch up, they may be locked into a technology regime that belongs to the past while incumbent lead firms move on to new technologies.

Our findings have important policy implications at different levels. Emerging market governments need to identify and integrate industrial and innovation policies to facilitate development beyond catching up and building problem-solving capacities at the firm level. Policies should balance the high-impact mechanism of government-driven demand and market formation as an outlet for the production of strategic industries with the creation of innovation capabilities across the national innovation system. Although decomposition of innovation and technology makes technology and knowledge accessible through parcelled and co-located transmission mechanisms, it comes with clear limitations. It does not automatically build the capacity for interactive transmission and problem-framing abilities in the receiving country. Emerging market governments need to prioritise domestic innovation capacity so that firms can forge ahead and take on problem-framing activities.

From the global perspective of grand challenges, climate change is on the agenda of most international organisations. KIBS providers are crucial actors in the dissemination of climate-friendly technology, as in the case of wind energy. International organisations, such as the UNFCCC, could seek to integrate KIBS providers into their focus in order to enhance technology transfer to emerging markets and developing economies. Currently, the large integrated lead firms take up most of this focus.

# 8 References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