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Knowledge flow in low-carbon technology transfer: A case of India's wind power industry

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Key words: Technology transfer; technological capabilities; knowledge; innovation; wind power; India

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Abbreviations

- ¥ CDM: Clean development mechanism
- ¥ CEO: Chief executive officer
- ¥ C-WET: Centre for Wind Energy Technology
- ¥ FY: Fiscal year
- ¥ GBI: Generation-based incentive
- ¥ IPP: Independent power producer
- ¥ kW: Kilowatt
- ¥ M&A: Merger and acquisition
- ¥ MW: Megawatt
- ¥ O&M: Operation and maintenance
- ¥ R&D: Research and development
- ¥ WFOE: Wholly foreign-owned enterprise

1. Introduction

Technology transfer is one of the key drivers of leapfrogging in climate change mitigation. In the context of climate change, leapfrogging suggests that developing countries may be able to skip emissions-intensive development stages by incorporating more sustainable, low-carbon technologies that are currently available (Goldemberg, 1998; Watson and Sauter, 2011). Besides the build-up of internal knowledge, the access to external knowledge is crucial for successful leapfrogging (Lee and Lim, 2001; Lewis, 2013).

IPCC (2000, p.3) defines technology transfer as a “broad set of processes covering the flows of know-how, experience and equipment” between various types of actors. As this definition indicates, both technology hardware and the associated knowledge are essential elements of technology transfer. However, a lion's share of low-carbon technology transfer to developing countries involves only a limited flow of technology-related knowledge (Bell, 2012). Thus, many developing countries lack the capability to design and manufacture low-carbon technology and hence depend on the technology developed abroad (Lema and Lema, 2013; Pueyo, 2013). For a sustained impact of low-carbon technology transfer on climate change mitigation, recipient firms need to manage the technology innovation processes and ensure long-term adoption and improvement of low-carbon technology (Ockwell et al., 2008). Because knowledge acquisition is essential to capability development, it is important to accelerate the shift from pure sale of technology hardware to transfer of technological knowledge to developing countries (Bell, 2012; Watson et al., 2015).

The degree of knowledge transfer is partly influenced by the organizational mechanisms of technology transfer (Lema and Lema, 2016; Ockwell et al., 2008; Schneider et al., 2008). For example, technology transfer mechanisms involving substantial cross-border interaction and recipient effort may create more learning opportunities (Lema and Lema, 2016). However, the mechanisms' long-term knowledge dividends are highly situational (Rai and Funkhouser, 2015) and the causal mechanisms and contingent variables involved in technology transfer and technological capability development require further empirical investigation (Lema and Lema, 2013). This study aims to fill this gap by addressing the following questions:

- 1) How do different technology transfer mechanisms foster technological capabilities of recipient firms?

- 2) In what ways do firm- and context-specific factors influence the choice of technology transfer mechanisms?

To this end, India's wind power industry is analyzed using various firm-level statistics and semi-structured interviews conducted in 2013 with 15 wind turbine manufacturers and 12 other organizations working on wind power. A firm-level analysis is useful because firm strategies play a pivotal role in technology transfer and capability development. Wind power is a prominent option for low-cost, low-carbon electricity (IPCC 2014). India ranked fourth in the world in terms of wind power generation capacity in 2015 (GWEC, 2016), and was home to several globally competitive wind turbine manufacturers and a number of smaller turbine manufacturers. These turbine manufacturers pursued a wide range of technology transfer mechanisms to build up their technological capabilities (Hayashi, 2015; Mizuno, 2011, 2007). The large variations in technological capabilities and technology transfer mechanisms make India's wind power industry an appropriate case for empirical analysis.

The remainder of this paper is structured as follows. Section 2 reviews the literature and develops a framework for analyzing the linkages between technology transfer mechanisms and technological capabilities, while section 3 explains the empirical strategy. Section 4 shows how different technology transfer mechanisms result in varying degrees of technological capabilities, and how this is influenced by various firm- and context-specific factors. Finally, section 5 concludes the paper, discussing the main findings and contributions to the literature.

2. Literature review

2.1. Low-carbon technology transfer and technological capabilities

Numerous studies on low-carbon technology transfer examine the factors leading to technology transfers. One major research field on low-carbon technology transfer is the Kyoto Protocol's Clean Development Mechanism (CDM) for climate change mitigation projects in developing countries. Scholars measured the number of CDM projects involving technology transfer and related it to country- or project-level factors such as openness to trade and project size (e.g., Dechezlepretre et al., 2008; Hascic and Johnstone, 2011; Murphy et al., 2015; Schmid, 2012). Studies also identified various factors affecting the access to low-

carbon technology such as intellectual property regime, cost of labor and capital, and education and skill base (Rai and Funkhouser, 2015). While these studies help in explaining whether and why low-carbon technology transfers occur, they fail to clarify how different technological content is transferred and the consequences thereof. By using CDM projects as a unit of analysis, these studies also fall short in understanding how firm characteristics influence technology transfer activities. This is an important omission as firm strategies play a key role in technology transfer and capability development (Lema et al., 2016; Urban et al., 2015).

An emerging literature explains the role of knowledge transfer in fostering technological capabilities, using firms as a unit of analysis (Bell, 2012; Doranova et al., 2011; Watson et al., 2015). Technological capabilities can be defined as “the skills—technical, managerial or organizational—that firms need in order to utilize efficiently the hardware (equipment) and software (information) of technology, and to accomplish any process of technological change” (Morrison et al., 2008, p. 41). Bell (2012) distinguishes between two types of technological capabilities: production and innovation. While production capabilities refer to the resources necessary for producing industrial goods at given efficiency levels and input combinations, innovation capabilities are the resources needed to generate and manage technological change (Bell and Pavitt, 1993, p. 163).

Creation of production capabilities requires the transfer of capital goods and basic operation and maintenance (O&M) knowledge of the transferred technology, while innovation capability accumulation requires the transfer of advanced knowledge for adapting, improving, and further developing the acquired technology (Bell, 2012). Bell and Figueiredo (2012) stress that routine production work does not accumulate innovation capabilities, for which firms need to actively invest in learning to innovate. Accumulating innovation capabilities is particularly important because technological catch-up is not just achieving higher production efficiency levels, but is also about enhancing dynamic efficiency by creating capabilities for innovation (Bell and Figueiredo, 2012).

2.2. Determinants of knowledge flow in technology transfer

The degree of knowledge transfer depends on the organizational arrangements of technology transfer (Easterby-Smith et al., 2008; Lema and Lema, 2016; Ockwell et al., 2008). Mowery et al. (1996) demonstrate that equity-based joint ventures promote greater technological knowledge transfers than contract-based alliances. Schneider et al. (2008) argue that

technology transfer mechanisms involving long-term, repetitive exchanges (e.g., foreign direct investment: FDI) provide a greater incentive for continuous knowledge transfer. According to Lema and Lema (2016, 2012), unconventional transfer mechanisms (acquisitions of foreign firms, overseas research and development (R&D), and joint R&D) require substantial cross-border interaction and recipient effort. Such mechanisms may provide more learning opportunities than conventional transfer mechanisms (trade, FDI, joint ventures, and licensing agreements). Long-term knowledge dividends of technology transfer are highly situational, but their organizational arrangements provide an “early indication” of the degree of knowledge transfer (Rai and Funkhouser, 2015, p. 353). There remains a knowledge gap about the causal mechanisms and contingent variables involved in technology transfer mechanisms and technological capability development (Lema and Lema, 2013).

Knowledge acquisition through technology transfer can be understood with the exploration-exploitation framework, which exhibits a trade-off between exploration of “new possibilities” and exploitation of “old certainties” (March, 1991, p. 71). While exploitation is reflected in terms such as “refinement, choice, production, efficiency, selection, implementation, execution,” exploration is associated with “search, variation, risk taking, experimentation, play, flexibility, discovery, innovation” (March, 1991, p. 71). Exploration and exploitation compete for scarce resources, and so firms need to strategically decide on how to balance the two activities (Lavie et al., 2010; Levinthal and March, 1993; March, 1991; Raisch and Birkinshaw, 2008). While exploration helps firms renew their knowledge base, those engaged exclusively in exploration will not gain the returns on its knowledge. Exploitation may enhance firms’ short-term performance, but those pursuing only exploitation will suffer from obsolescence of knowledge. Scholars argue that both exploration and exploitation are necessary for firms’ survival and prosperity (e.g., Levinthal and March, 1993). Thus, firms need to strike a balance between technology transfer for creating production capabilities (exploitation) and that for accumulating innovation capabilities (exploration).

The determinants of exploration and exploitation can be firm or context specific. Firm-specific factors include absorptive capacity and financial resources. Cohen and Levinthal (1990) argue that external knowledge is often critical to innovation processes, but firms cannot benefit from simply being exposed to it, and instead need to develop the ability (absorptive capacity) to “recognize the value of new, external information, assimilate it, and apply it to commercial ends” (Cohen and Levinthal, 1990, p. 128). Absorptive capacity can be generated in several ways, such as through R&D and as a byproduct of manufacturing

operations (Cohen and Levinthal, 1990). Greater absorptive capacity thus facilitates acquisition of external knowledge and consequently enhances technological capabilities.

Surplus financial resources enable risk taking and innovation by buffering firms from competitive pressure (Greve, 2007). Because acquisition of advanced technological knowledge is often a time-consuming and risky process, some financial resources are necessary to engage in such activities. Conversely, excessive financial resources can discourage knowledge transfer because resource-rich firms may “satisfice” rather than optimize their decision behavior; that is, instead of considering all possible alternatives, the first feasible alternative may be chosen (Bourgeois III, 1981, p. 35). These contradictions suggest an inverted U-shaped relationship between knowledge transfer and financial resources; both excessive and inadequate financial resources can hinder knowledge transfer.

The contextual factors influencing exploration and exploitation include intellectual property regime, competitive intensity, and environmental dynamism. A strong intellectual property protection regime increases economic returns to new knowledge generation and encourages innovation activities and knowledge transfer (Hoekman et al., 2005; Levinthal and March, 1993; Maskus, 2004). However, some argue that a weak intellectual property regime leads to greater knowledge spillovers through replication, imitation, and reverse engineering (Kumar, 2003). A weak intellectual property regime may induce second-tier technology transfers because of its low priority for intellectual property protection (Maskus, 2004; Rai and Funkhouser, 2015).

Competition intensifies as the number of competitors increases, and intensified competition induces exploration because firms need new sources of competitive advantage to withstand competition (Levinthal and March, 1993). In contrast, lack of competition results in a stronger focus on exploitation because firms can gain reasonable returns without the risk of innovation (Lavie et al., 2010).

Environmental dynamism is characterized by the turnover, absence of pattern, and unpredictability of firm environment (Dess and Beard, 1984) rooted in changes in customer preferences, technologies, or market demand (Lavie et al., 2010). Firms focusing on production activities prefer stable environments because they cannot exploit emerging opportunities as quickly as those specialized in innovation (Lavie et al., 2010). In dynamic environments, products and services quickly become obsolete, pressurizing firms to generate and/or acquire new knowledge (Lavie et al., 2010). However, excessively dynamic

environments may discourage innovation activities because knowledge depreciation rates can outweigh knowledge generation rates, for example, through employee turnover (Gallagher et al., 2012). These again suggest an inverted U-shaped relationship between knowledge transfer and environmental dynamism.

The above discussion shows that technology transfer mechanisms carry varying degrees of knowledge flow, resulting in different levels of capability development of recipient firms. Furthermore, the choice of transfer mechanisms is influenced by various firm- and context-specific factors. The analysis of causal mechanisms involved in technology transfer and capability development needs to take into account these contingent variables.

3. Data and methods

A case study method is employed because the linkages between technology transfer mechanisms and technological capabilities are yet to be well established. This method is particularly well-suited to research the causal mechanisms of understudied phenomena (Eisenhardt, 1989; Yin, 2014). The analysis proceeded in two major steps: desk research and semi-structured interviews. The desk research first identified the technology transfer mechanisms pursued by wind turbine manufacturers in India by reviewing academic articles, government documents, media reports, and wind turbine manufacturers' websites. This process was guided by the technology transfer mechanism definitions in Table 1, which were classified along four variables: the location and ownership of manufacturing, as well as the origin and ownership of proprietary technology (adapted from Lema and Lema, 2016, 2013).

The location of manufacturing asks if manufacturing facilities are located inside or outside a recipient country. The ownership of manufacturing evaluates whether the manufacturing facilities are owned by a recipient firm (internal ownership) or supplier firm (external ownership), or shared by them. The origin and ownership of proprietary technology examine if the original technology design comes from a recipient firm or elsewhere, and whether the technology is owned by a recipient firm, supplier firm, or jointly. These variables are closely related to the effort required for recipient firms, which in turn may influence the degree of knowledge transfer. Transfer mechanisms are ordered to roughly indicate increasing recipient effort towards the bottom of Table 1. Note, however, that the degree of recipient effort and knowledge flow is only indicative, hence requires careful empirical investigation.

[Insert Table 1 here]

The desk research also collected statistical data on firm- and context-specific factors. The turbine unit size is a common indicator of technological progress in wind power technology (Lewis, 2016; Ru et al., 2012). The maximum size of newly installed wind turbines was calculated for each manufacturer in India based on the Directory Indian Windpower 2015 (Consolidated Energy Consultants, 2015). However, manufacturing capabilities are different from innovation capabilities. Thus, the turbine size indicator was complemented by a *proxy* measure of innovation capabilities, the number of wind power patents filed by each manufacturer in India. Patent counts are admittedly an imperfect measure of innovation. However, they have been used widely in energy innovation research because patents offer a wealth of information about innovation activities and can be disaggregated into specific technological fields (IPCC, 2014; Johnstone et al., 2010). Thus, wind power patents were extracted from the Derwent Innovations Index, and counted for each of the wind turbine manufacturers (Thomson Reuters, 2016). Furthermore, the geographical location of innovation capabilities was analyzed by examining each patent's assignee and determining whether the patent was assigned to a firm located in India or elsewhere. The turbine size and patent indicators also measure firms' absorptive capacity, which develops through R&D and manufacturing operations.

As the financial data for all the turbine manufacturers studied were not available, the annual turbine installation capacity was used as a proxy measure. Most Indian turbine manufacturers, except for Suzlon, supplied wind turbines almost exclusively to the Indian market. Therefore, their domestic turbine installation figures were collected (Consolidated Energy Consultants, 2015). For Suzlon and five WFOEs, global turbine installation figures were obtained (Navigant Research 2013; IEA Wind TCP 2013). Competitive intensity was measured by the number of wind turbine manufacturers in India, whereas environmental dynamism measured by the annual growth rate of installed wind power generation capacity (Consolidated Energy Consultants, 2015).

The next step was face-to-face interviews with wind turbine manufacturers, government officials, and wind power experts during February and March 2013. The interviews aimed to

gain detailed insights into the technology transfer mechanisms identified in the desk review, and to understand how various firm- and context-specific factors influenced the turbine manufacturers' technology acquisition strategies (for the interview questions, see Table 2). As of March 2013, 19 wind turbine manufacturers had "type approval" for selling wind turbines in India, issued by the Centre for Wind Energy Technology (C-WET), a testing and certification body under the Ministry of New and Renewable Energy. All the 19 manufacturers were contacted for an interview, of which 15 accepted the interview request;¹ their market shares collectively accounted for 1,302 megawatts (MW) or 76% of the total additional turbine capacity in fiscal year (FY) 2012-2013 (see Figure 1).

As the interviews involved strategic and technical questions, firm representatives holding positions in management, business development, and/or engineering or R&D were contacted. The interviewees of eight turbine manufacturers were top management personnel (e.g., managing director, chief executive officer (CEO)) and seven turbine manufacturers were middle-management personnel (e.g., vice president) working in the business development or engineering departments. Besides the turbine manufacturers, interviews were conducted with wind power experts of 12 organizations (e.g., central and state governments, industry associations, research institutes; for the list of expert interviewees, see Table 3). The interviews typically lasted for 45 to 75 minutes, and were recorded when permission was given. Pattern matching of the interview transcripts and/or notes identified the relationships between the empirical patterns in the interview records and theoretical predictions (Yin, 2014). The part of interview records pertaining to analytical constructs (e.g., absorptive capacity) was coded and checked for whether the empirical observations fit the theoretical prediction (e.g., greater absorptive capacity enhances knowledge transfer). Since several interviewees wished to remain anonymous, interview quotes are not attributed to any organization or individual.

[Insert Figure 1 here]

[Inset Table 2 here]

[Insert Table 3 here]

¹ Chiranjeevi Wind Energy, Wind World (India), Sinovel DB India, and Siva Windturbine India did not respond to the interview request.

4. Results

4.1. Evolution of India's wind power industry

This section explains the evolution of India's wind power industry, paying particular attention to the contextual factors: intellectual property regime, competitive intensity, and environmental dynamism. India's wind power market has shown a long-term growth, with some boom and bust periods due to government policy changes (see Figure 2). The first boom was triggered by the economic reform in 1991, which permitted joint ventures with foreign companies and reduced customs duties for imported power equipment from 400% to 25% (Mizuno, 2011). Growth was also driven by various central government tax incentives (e.g., 100% accelerated depreciation on investments in wind power equipment, a five-year tax holiday on wind power sales revenues) and state-level policy support (Hossain, 2006). Market liberalization and various support policies attracted private investments in wind power. Several foreign companies entered the Indian wind power market through joint ventures or technology licensing (Mizuno, 2011, 2007). However, since the focus of these early investments were mainly on tax incentives (accelerated depreciation) rather than power generation, investors did not make sufficient effort to adapt imported wind turbines to the local conditions, and this resulted in sub-optimal performance of wind turbines and distrust in wind power in India (Hayashi, 2015). In order to address the quality problems, the first wind power technology quality standards were introduced in 1995, and C-WET was established in 1998 with Danish development assistance for the testing and certification of wind turbines (IRENA and GWEC, 2013; Kristinsson and Rao, 2008).

The first boom period ended in FY1996-1997 with a large reduction in both central- and state-level tax benefits. For example, the "minimum alternate tax" clause required companies claiming 100% accelerated depreciation to pay a 12.9% corporate tax (Rajsekhar et al., 1999). The market stagnation was due to the increase in the Indian Renewable Energy Development Agency's loan interest rates from 4–5% to 18–20% (Mizuno, 2007, p. 265). Abrupt policy changes shrank the country's wind power market, and, consequently, many foreign companies pulled out from the Indian market (Mizuno, 2011).

The Electricity Act 2003 revived the market, providing a legal framework for promoting renewable energy. Each state was required to set preferential tariffs and purchase renewable power, ensure connectivity of renewable power to the grid, and allow for the sale of

renewable power to any third party (IRENA and GWEC, 2013). The market expansion during this period led to a gradual increase in competitive intensity, and the number of wind turbine manufacturers increased from 9 in FY2003-2004 to 19 in FY2014-2015 (see Figure 3).

In order to create a performance-oriented market for wind power, the central government introduced a generation-based incentive (GBI) in FY2009-2010. By providing a tariff-based incentive, GBI attracted independent power producers (IPPs; non-utility power generators) and foreign investors who lacked tax liabilities in India and hence could not use accelerated depreciation (Hayashi, 2015). Thus, the market shares of foreign turbine manufacturers, who were specialized in larger, more efficient turbines that met the IPPs' needs, increased since 2009. Both accelerated depreciation and GBI were discontinued in FY2012-2013, and the market growth of wind power declined sharply. However, following resistance from the industry, the central government reinstated GBI in FY2013-2014 and accelerated depreciation in FY2014-2015 (Shrimali et al., 2017).

[Insert Figure 2 here]

[Insert Figure 3 here]

The maximum unit size of newly installed wind turbines steadily increased in India (see Figure 4). The technological progress until FY1999-2000 was driven by joint-venture manufacturers. In FY2000-2001, Suzlon installed the first 1-MW turbines in India and since then has been one of the country's leading manufacturers in terms of both turbine size and market share. The Electricity Act 2003 accelerated the progress of technology by providing a long-term policy signal for wind power support (Hayashi, 2015). For instance, major foreign manufacturers such as Vestas, Gamesa, and General Electric established their WFOEs after the Electricity Act 2003 was passed, introducing their advanced wind power technology to the Indian market. The shift toward a performance-oriented market after FY2009-2010 also encouraged Indian manufacturers (e.g., Global Wind Power, Regen Powertech) to introduce larger wind turbines for their IPP customers demanding superior generation performance. Some Indian manufacturers even surpassed foreign manufacturers in terms of size of wind turbine units installed. Foreign manufacturers could have brought in much larger turbines

(e.g., Gamesa, Spain, then had a 4.5-MW turbine model for onshore applications in their product portfolio), but the local supply chain for such advanced turbines was not yet developed in India, and importing necessary turbine components would have increased the manufacturing costs. Thus, foreign manufacturers decided to transfer more proven technology for which local vendors were available.²

[Insert Figure 4 here]

A daunting problem with the intellectual property arose in India in 2007 when Enercon Germany cancelled a licensing agreement with its joint venture partner Enercon India due to difference in business strategy (May and Röder, 2011). Consequently, Enercon India filed a legal dispute against 19 patents held by Enercon Germany (May and Röder, 2011). The Intellectual Property Appellate Board of India decided in favor of Enercon India in 2010, nullifying the patents held by Enercon Germany owing to “lack of novelty” in patent documents (Ewing and Bajaj, 2011; Smith, 2014). The issue escalated to a political level, at least in Germany, when the German Federal Ministry of Economy and Technology called this a “grave circumstance” (May and Röder, 2011, p. 93). The Supreme Court of India decreed in 2014 that the case should go to arbitration under the Indian law, ruling out Enercon Germany’s claim that arbitration should be sought in London under the UK’s stricter intellectual property regime (Smith, 2014). Enercon India then rebranded itself as Wind World (India) and no longer cooperates with Enercon Germany.

4.2. Technology transfer mechanisms and technological capabilities

The wind turbine manufacturers in India have utilized various technology transfer mechanisms to build up their technological capabilities, as summarized in Table 4 for 19 wind turbine manufacturers holding C-WET type approval as of March 2013.

[Insert Table 4 here]

² Lead business analyst, WFOE manufacturer, interviewed on February 21, 2013. CEO, WFOE manufacturer, interviewed on March 6, 2013.

The most prevalent technology transfer mechanisms were licensing, M&A, and WFOEs. Seven manufacturers entered into licensing agreements with foreign companies. They used licensing for market entry to start manufacturing wind turbines in India. Even newly established Indian firms with licensing agreements (e.g., Inox Wind, Regen Powertech) could manufacture wind turbines as large as those supplied by WFOEs. The licensed technology's intellectual property is controlled by the licensor, and the licensee is unlikely to acquire the knowledge behind the licensed technology. In fact, turbine manufacturers relying solely on licensing (Chiranjeevi Wind Energy, Inox Wind, NuPower, and Regen Powertech) held no wind power patents.

Six manufacturers pursued M&A. The new owner gains access to the capital assets and technological knowledge of a merged or acquired company. Access particularly to technological knowledge can offer the basis for accumulating innovation capabilities. Of those who engaged in M&A, however, only Suzlon and Kenersys held wind power patents. Both companies acquired 100% of European firms' shares and conducted major R&D activities in Europe.³ For Suzlon, cutting-edge innovations were generated by its German subsidiary REpower (Walz and Delgado, 2012). Thus, most of their wind power patents were owned by their European operations, with their Indian operations accessing intellectual property through intra-firm technology transfer.

The other four manufacturers (Global Wind Power, Pioneer Wincon, Shriram EPC, and Southern Wind Farms) held no wind power patents despite past M&A. Global Wind Power acquired 33% of Norwin's share to benefit from the Danish firm's R&D activities.⁴ Global Wind Power engaged in no technology development in India, but relied on the intellectual properties held by Norwin. Pioneer Wincon acquired its former joint venture partner Wincon West Wind as the latter closed its wind power business. Pioneer Wincon managed to develop a 750-kilowatt (kW) turbine model with its own R&D and technology design acquired from Wincon West Wind, making a design adjustment to the original power control system.⁵

³ Senior manager (business development), Indian manufacturer, interviewed on March 7, 2013. President (business development), Indian manufacturer, interviewed on March 9, 2013.

⁴ CEO, Indian manufacturer, interviewed on March 15, 2013.

⁵ Senior vice president (design and development), Indian manufacturer, interviewed on February 25, 2013. Wincon West Wind's original turbine model was pitch-regulated, while Pioneer Wincon's was stall-regulated.

Lastly, Shriram EPC took over TTG Industries of India and Southern Wind Farms acquired NEPC India, and both gained full control of the intellectual properties of small wind turbine models. However, they focused on manufacturing these turbine models and never developed their own technology.⁶ Thus, M&A can foster firms' innovation capabilities only through active R&D efforts.

Five foreign manufacturers established WFOEs in India. Sinovel and WinWinD focused on manufacturing without any R&D activities⁷ and thus created production capabilities in their Indian operations; all their wind power patents were held outside India. In contrast, Gamesa, General Electric, and Vestas operated manufacturing factories and also established local R&D centers for wind technology research with a team of Indian and foreign engineers (Gamesa, 2011; General Electric, 2014; Vestas, 2008). The engagement of multinational companies shows that the talent of engineers and lower capital and labor costs in India made the country an attractive destination of FDI for both manufacturing and R&D activities. However, whether the WFOEs' R&D can be considered knowledge "transfer" is debatable because intellectual properties can be tightly controlled by the parent companies. In fact, Gamesa, General Electric, and Vestas assigned none of their wind power patents to their Indian subsidiaries.

Joint ventures became less popular as a market entry strategy for various reasons. As explained above, Pioneer Wincon ended its joint venture with Wincon West Wind because the latter closed their wind power business. Enercon's joint venture also ceased owing to strategic conflicts and patent litigation. RRB Energy had a joint venture with Vestas, but Vestas acquired the Danish wind turbine manufacturer NEG Micon, which then operated a WFOE in India. To avoid conflict of interest between RRB Energy and NEG Micon's subsidiary in India, RRB Energy decided to part ways with Vestas, and then conducted its own R&D and developed its own 1,800-kW turbine model. This represented a significant improvement from the 600-kW model in the joint venture setup.⁸

⁶ Vice president (quality), Indian manufacturer, interviewed on March 1, 2013. CEO, Indian manufacturer, interviewed on March 15, 2013.

⁷ Head (operations), WFOE manufacturer, interviewed on February 21, 2013.

⁸ Deputy managing director and vice president (R&D), Indian manufacturer, interviewed on February 20, 2013. RRB Energy's 1,800-kW turbine model was not approved by C-WET as of March 2013, and is not listed in Table 2.

Only two joint ventures were actively involved with wind power as of March 2013. Leitwind Shriram focused on wind turbine manufacturing using the technology design provided by their joint venture partner Leitwind of Italy. Suzlon formed a joint venture with Elin EBG Motoren of Austria, a leading manufacturer of wind turbine generators. The joint venture agreement stated that the intellectual properties developed by Suzlon “shall vest with the [c]ompany” (Red Herring Prospectus, 2005, p. 94). This arrangement was probably a special case in which Suzlon held a large majority shareholding of the joint venture (75% shares). The details of Suzlon’s R&D activities are not publicly known, but it held a few generator-related patents in its own name. The knowledge dividends of joint ventures may depend on the extent to which local partners engage in R&D activities, which in turn may be influenced by the joint ventures’ ownership structure.

Suzlon was the only Indian turbine manufacturer with international R&D centers for wind power technology. In 2001, Suzlon set up an R&D center for rotor blade design in the Netherlands, building on the acquisition of a Dutch blade manufacturer, AE-Rotor Techniek (Red Herring Prospectus, 2005). In the following year, Suzlon created a wind turbine design center in Germany (Red Herring Prospectus, 2005). In 2004, Suzlon established its international headquarters in Aarhus, Denmark, to benefit from the wind energy expertise and extensive network of the region’s component suppliers (Lewis, 2007). Their R&D centers in Europe were vertically integrated with their wind turbine supply chain to ensure greater control over time, cost, and quality in product delivery (The Smart Manager, 2008).

Table 5 relates technology transfer mechanisms with the maximum turbine size and the cumulative number of wind power patents. Sample A shows the results for all wind turbine manufacturers. The underlined turbine size and patent figures are for firms that pursued a combination of technology transfer mechanisms, while other figures are for those that used only one type of transfer mechanism. Sample B excludes firms that pursued multiple transfer mechanisms, thereby focusing on those that pursued a single transfer mechanism. The sample restriction is applied to make the relationship between transfer mechanisms and technological capabilities more intuitive. Note that samples A and B show the same results when all the firms included in the same transfer mechanism category have pursued only one type of transfer mechanism (e.g., WFOEs). When interpreting Table 5, a comparison should be made among different transfer mechanisms within the same sample.

[Insert Table 5]

Sample A does not show a clear relationship between transfer mechanisms and the maximum turbine size; firms were capable of manufacturing wind turbines of comparable size regardless of the transfer mechanisms pursued. When firms with multiple transfer mechanisms are excluded in sample B, the maximum turbine size for M&A without recipients' R&D engagement (225–250 kW) becomes far smaller than for other transfer mechanism categories. Still, the other categories score similarly in the maximum turbine size. Thus, the relationship between transfer mechanisms and the maximum turbine size is unclear.

On the other hand, technology transfer mechanisms are closely related to the firms' innovation capabilities as measured by wind power patents. This is more obvious in sample B, in which the patent counts for WFOEs with or without local R&D centers (198–1,320 and 13–280, respectively) as well as M&A with R&D by recipient firms (18) are greater than for other categories. Furthermore, joint ventures without recipients' R&D engagement, licensing, and M&A without R&D by recipient firms are clearly associated with zero patents. In sample A, the trend is less obvious because most of the upper-range patent figures are for Suzlon which pursued various transfer mechanisms such as licensing, joint ventures and M&A with own R&D, and international R&D centers. While it is difficult to assess the relationship between Suzlon's specific transfer mechanisms and innovation capabilities, it is important to note that M&A and international R&D centers were the firm's key strategies for acquiring foreign technological knowledge.⁹

To be sure, causality cannot be claimed based only on the relational analysis in Table 5. It is probable that firms with established innovation capabilities chose specific transfer mechanisms, as opposed to certain transfer mechanisms resulting in innovation capabilities. The question is which causal direction is more likely. Most Indian manufacturers did not invest much in R&D and consequently lacked innovation capabilities.¹⁰ For Suzlon and Kenersys, the only Indian firms holding wind power patents, M&A was a major strategy for acquiring innovation capabilities. The patent counts prior to technology transfer in Table 4

⁹ President (business development), Indian manufacturer, interviewed on March 9, 2013.

¹⁰ Secretary general, Industry association, interviewed on February 6, 2013.

demonstrate that both firms started M&A when they had zero or a very few patents. There are also four other manufacturers who pursued M&A when they held no patent. Hence, the more likely causal direction—at least in this case—is that M&A helped foster innovation capabilities of the Indian firms, but not that they established innovation capabilities before engaging in M&A.

Suzlon is the only firm which created a joint venture with own R&D and international R&D centers. When Suzlon utilized these transfer mechanisms between 2001 and 2004, the firm held at most 16 wind power patents. All of the 16 patents were owned by Aerpac and Enron Wind Rotor Production, which Suzlon had acquired in 2001. This indicates that Suzlon was yet to establish its own innovation capabilities, and they used the joint venture and international R&D centers to acquire external sources of innovation capabilities. In fact, Suzlon decided to form a joint venture with Elin EBG Motoren, a wind turbine generator manufacturer, because Suzlon “did not know how to manufacture generators.”¹¹ Again, the causality rather runs from the transfer mechanisms to innovation capability accumulation.

Most WFOEs already had established innovation capabilities in their parent firms when they entered the Indian market. It is plausible that the multinational corporations chose WFOEs—not joint ventures or licensing—because of their high innovation capabilities. For example, two WFOEs explained that they chose this transfer mechanism because they already controlled the entire supply chain and preferred to run their business independently.¹² Thus, it is likely that the causal direction goes from innovation capabilities to the mechanism choice.

The above suggests that there is no clear relationship between technology transfer mechanisms and production capabilities of recipient firms. However, recipients’ innovation capabilities are associated with certain transfer mechanisms including M&A and joint ventures with recipients’ R&D effort, international R&D centers, and WFOEs. For M&A, joint ventures, and international R&D centers, the causal direction appears to run from the transfer mechanisms to innovation capabilities. In contrast, multinational corporations tend to choose WFOEs because they already have high innovation capabilities. Hence, the causal direction seems opposite for this category.

¹¹ President (business development), Indian manufacturer, interviewed on March 9, 2013.

¹² Lead business analyst, WFOE manufacturer, interviewed on February 21, 2013. General manager, WFOE manufacturer, interviewed on March 6, 2013.

4.3. Other determinants of technology transfer mechanisms

The choice of technology transfer mechanisms depends on various firm- and context-specific factors besides technological capabilities (and the closely related concept of absorptive capacity). Most Indian turbine manufacturers did not pursue transfer mechanisms for innovation capabilities partly due to their insufficient financial resources. Some Indian turbine manufacturers' representatives have commented that "R&D makes sense to do from a profit of [the company's] existing operation,"¹³ but they "did not have enough financial strength to start into that [R&D]."¹⁴ Because the payoff to R&D usually occurs in the distant future, only firms confident of long-term survival would consider investing in R&D (Rosenberg, 1990). One Indian manufacturer argued that for a firm exceeding a "sales turnover of close to about USD 100 to 150 million per year [...] this [the knowledge behind technology] would be a logical requirement."¹⁵ This is because turbine manufacturers would otherwise be dependent on external technology suppliers, increasing the vulnerability of their business. The suggested sales turnover range translates into annual sales of 73 to 109 MW, assuming the average turbine cost of USD 1,370 per kW in India in 2013-2014 (IRENA 2015).¹⁶ Most of the Indian and foreign turbine manufacturers holding wind power patents had annual (global) turbine sales of over 300 MW in 2012 (see Table 4). Thus, accumulation of innovation capabilities was not a priority for most Indian turbine manufacturers because their profits were insufficient to start investing in R&D. Since larger sales volumes offer the prospect of a higher payoff to R&D, firms with a larger market share are more likely to engage in R&D (Rosenberg, 1990).

The transfer mechanism choice is also influenced by various contextual factors such as intellectual property regime, competitive intensity, and environmental dynamism. The interview analysis shows mixed results on the effect of intellectual property regime. While the government representatives and wind industry association argued that intellectual

¹³ CEO, Indian manufacturer, interviewed on March 15, 2013.

¹⁴ Senior manager (business development), interviewed on March 7, 2013.

¹⁵ President (business development), Indian manufacturer, interviewed on March 9, 2013.

¹⁶ Cost figures are used because price information was not publicly available.

property regime was not a barrier to technology transfer in India,¹⁷ turbine manufacturers expressed concern about intellectual property infringement, referring to recent patent litigation cases such as Enercon's.¹⁸ Some manufacturers preferred technology transfers through WFOEs or acquisitions of foreign firms, rather than joint ventures or licensing, because the former ensures greater control over intellectual properties.¹⁹ The "weak" intellectual property regime in India, at least from the manufacturers' perspective, seems to have restricted the choice to technology transfer mechanisms that ensure greater control over intellectual properties (e.g., WFOEs, M&A).

The competitive pressure intensified from around FY2009-2010 with the entry of IPPs and introduction of GBI. IPPs strongly valued power generation and demanded larger wind turbines with higher efficiency.²⁰ Thus, the GBI subsidy on each unit of wind power generation attracted IPPs into the Indian market. Performance orientation, as the interviewees argued, encouraged the transfer of advanced wind turbines as well as technology innovation for performance improvement.²¹ The transfer of advanced wind power technology is evident from the increasing size of wind turbine units after FY2009-2010 (see Figure 4). Furthermore, wind power projects supported by GBI resulted in at least a three percentage points higher plant load factor, a generation efficiency measure, than those supported by accelerated depreciation (Shrimali et al., 2017). While its impact on the transfer mechanism choice is unclear, stronger competition seems to induce transfer of advanced wind power technologies.

As regards environmental dynamism, the interviewees argued that predictable market growth was key to technology transfer. The technology strategies of wind turbine manufacturers are

¹⁷ Director, Indian government, interviewed on February 5, 2013. Secretary general, Industry association, interviewed on February 6, 2013.

¹⁸ Managing director, WFOE manufacturer, interviewed on March 2, 2013.

¹⁹ Senior manager (business development), Indian manufacturer, interviewed on March 7, 2013. Lead business analyst, WFOE manufacturer, interviewed on February 21, 2013.

²⁰ President (business development), Indian manufacturer, interviewed on March 9, 2013. Director general, Research institute, interviewed on March 8, 2013.

²¹ Managing director, WFOE manufacturer, interviewed on March 12, 2013. President (business development), Indian manufacturer, interviewed on March 9, 2013.

determined by long-term market trends, and not by temporary market demand fluctuations.²² One WFOE argued, “Our whole product strategy, or even the market strategy in India is based on how we expect the Indian market to evolve in a long-term.”²³ Despite some earlier boom and bust periods, the Indian wind power market has been growing steadily, especially since the enactment of the Electricity Act 2003 (see Figure 2). A predictable market environment encouraged the transfer of advanced wind power technology to India (see Figure 4). This agrees with the previous research suggestion that successful technology transfer requires the creation of a sizable, stable market demand to enable long-term business commitments (Hayashi, 2015; Lewis, 2011; Mizuno, 2011). While this is an important point for technology transfer in general, the analysis did not find any clear relationship between predictable market growth and specific transfer mechanisms.

In summary, greater financial resources of recipient firms appear to support innovation capability accumulation through technology transfer (and in-house R&D). Weak intellectual property regime seems to shift technology transfer mechanisms to those that ensure greater control over proprietary technology (e.g., M&A, WFOEs). While stronger competition and predictable market growth encourages technology transfer, the empirical evidence did not find support for their impact on the mechanism choice.

5. Discussion

5.1. Contributions to the literature

This study contributes to the literature of low-carbon technology transfer in three ways. First, this study offers one of the first firm-level causal analyses of technology transfer mechanisms and technological capability development. The analysis revealed that the dividing line between the technology transfer mechanisms for creating production capabilities and those for accumulating innovation capabilities is whether the organizational arrangement encourages recipient firms’ active R&D effort. Transfer mechanisms amenable to innovation capability accumulation include M&A and joint ventures with recipients’ R&D effort as well

²² Senior manager (business development), Indian manufacturer, interviewed on March 7, 2013. Secretary general, Industry association, interviewed on February 18, 2013.

²³ Lead business analyst, WFOE manufacturer, interviewed on February 21, 2013.

as international R&D centers. Second, this study linked the technology transfer mechanism argument with the exploitation-exploration framework to examine how various firm- and context-specific factors influence the choice of technology transfer mechanisms. The theoretical framework serves as a useful guide to firm-focused analyses of technology transfer mechanisms. Third, the study provided a comprehensive overview of technology transfer mechanisms in India's wind turbine industry as of 2013. While there are several studies analyzing technology strategies of leading Indian turbine manufacturers (e.g., Suzlon), technology transfer studies covering the entire wind turbine industry in India are rather rare, and cover periods only until 2005/2006 (Hossain, 2006; Mizuno, 2011, 2007).

5.2. Limitations and future work

While this study utilized the best available data, the causality analysis has some room for improvement. A future research could use a quantitative analysis with a large-sample firm survey to better disentangle the causality involved in technology transfer mechanisms and capability development. Another limitation of this single-country case study is that some contextual factors such as intellectual property regime show little variation over time. A cross-country comparison may thus show the relative importance of contextual factors in knowledge transfer. Also note that the analysis examined only wind power, a relatively mature clean-energy technology. As technological characteristics play a key role in industry localization (Schmidt and Huenteler, 2016), a future research should conduct a comparative analysis of industries with different technological characteristics.

6. Conclusions and policy implications

This study examined the linkages between technology transfer mechanisms and technological capabilities of recipient firms, taking into account the effects of various firm- and context-specific factors. To this end, taking India's wind power industry for a study, semi-structured interviews were conducted in February and March 2013. Wind turbine manufacturers in India pursued various technology transfer mechanisms including licensing, M&A, WFOEs, joint ventures, and international R&D centers.

Innovation capability accumulation through technology transfer fundamentally requires recipient firms' active engagement in R&D. M&A with recipients' R&D engagement and

international R&D centers are among the most effective examples. Joint ventures could be appropriate if local partners are allowed to engage in technology development or to gain control over intellectual properties. However, such an arrangement could require a local partner to gain a large majority shareholding of the joint venture, thus challenging for firms in emerging economies lacking financial resources. While WFOEs can be a powerful mechanism for creating production capabilities, they may not be as effective in fostering innovation capabilities in subsidiaries because intellectual properties are tightly controlled by their parent firms.

Greater financial resources of recipient firms support accumulation of innovation capabilities through technology transfer and in-house R&D. When intellectual property regime is weak, the choice may be restricted to transfer mechanism that ensure greater control over proprietary technology (e.g., WFOEs, M&A).

Policy makers should be cognizant of the fact that, while production capabilities can be created through any transfer mechanism, innovation capability accumulation requires deliberative support for transfer mechanisms that encourage recipient firms' R&D effort. The creation of a predictable, performance-oriented market enhances firms' financial resources and consequently encourages knowledge acquisition and capability development.

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Figure 1 Wind turbine market shares in India, FY2012-2013

Note: The shaded manufacturers were interviewed. In “Others,” nine manufacturers were interviewed and three were not interviewed.

Source: Consolidated Energy Consultants (2015).

Figure 2 Installed wind power generation capacity and its annual growth rate in India, FY1991-1992–FY2014-2015

Source: Consolidated Energy Consultants (2015).

Figure 3 Number of manufacturers supplying wind turbines in India, FY1991-92–FY2014-2015

Source: Consolidated Energy Consultants (2015).

Figure 4 Maximum unit size of installed wind turbines in India by company ownership, FY1991-1992–FY2014-2015

Note: Manufacturers' names appear when a new manufacturer(s) takes the top position in terms of wind turbine size installed in India. Foreign manufacturers' names are underlined.

Source: Consolidated Energy Consultants (2015).

Table 1 Definitions of technology transfer mechanisms

Transfer mechanism	Definition	Location of manufacturing	Ownership of manufacturing	Origin of proprietary technology	Ownership of proprietary technology
Trade	Import of technology hardware designed and manufactured abroad. It usually comes with the knowledge required for O&M, including manuals and training provided by manufacturers.	Foreign	External	External	External
Joint venture	A business partnership between local and foreign firms agreeing to share equity capital, risks, and decision-making authority. The foreign partner typically provides technology design for the local partner's manufacturing. In some cases, the local partner may also engage in R&D.	Domestic	Shared	External	External, shared, or internal
Licensing	A legal contract where a licensor transfers intellectual property to a licensee for a specified duration. Licensing may occur as part of a joint venture or wholly foreign-owned subsidiary. In this study, this category refers to licensing agreements without any such organizational association.	Domestic	Internal	External	External
Wholly foreign-owned enterprise (WFOE)	The establishment of a wholly foreign-owned subsidiary by a multinational company, involving resource transfer from a parent company to its subsidiary, often via FDI. The subsidiary conducts manufacturing and/or R&D.	Domestic	Internal (subsidiary)	Internal (parent company)	Internal (parent company)
Merger and acquisition (M&A)	Merger refers to the mutual consolidation of two or more firms to form a new enterprise. Acquisition is the takeover of another firm, including its assets and operations. In both cases, the capital and technological knowledge of the merged or acquired firm become the new owner's asset.	Domestic or foreign	Internalized	External	Internalized
Joint development	A collaborative effort between local and foreign companies sharing R&D resources and costs to develop new technologies, without equity capital investments. In some cases, R&D costs may be fully paid by a local firm and R&D mainly undertaken by a foreign engineering contractor. Frequently, joint development builds upon existing designs owned by one of the partner firms. The resulting intellectual property may be shared or fully transferred to the local company.	N/A	N/A	External or internal	Shared or internal
International R&D center	The establishment of overseas R&D centers for technology development based on the knowledge gained from regional learning networks related to a specific technological expertise.	N/A	N/A	Internal	Internal

Source: Author, based on Gallagher (2014), Lema and Lema (2013; 2016), Lewis (2007; 2013), Todeva and Knoke (2005).

Table 2 Key interview questions

Category	Interview questions
Technology development and transfer strategy	<p>How does the technology development strategy of your company compare to that of other wind turbine manufacturers in India?</p> <p>How has your company engaged in technology acquisition from other companies in the past?</p> <p>What have been your company's key motivations for the technology acquisition?</p> <p>How did your company benefit from the technology acquisition?</p> <p>What challenges did your company encounter in the technology acquisition?</p>
Firm characteristics	<p>Are there any specific characteristics of your company that determined your technology acquisition strategy in the past (e.g., technological capabilities, financial resources, company ownership)?</p>
Contextual factors	<p>How did market growth in India or other countries affect your company's technology acquisition strategy?</p> <p>Is there any difference in the way your company acquired technology in times of strong market growth and in times of weak market growth?</p> <p>What are the key policies for market demand creation in India or other countries that affected your company's technology acquisition strategy?</p> <p>How did the intellectual property regime in India or other countries or related to World Trade Organization's decisions affect your company's technology acquisition strategy?</p>

Source: Author.

Table 3 List of expert interviewees

	Name of organization	Type of organization
1	Ministry of New and Renewable Energy	Central government
2	Centre for Wind Energy Technology	Central government
3	Tamil Nadu Electricity Board	State government
4	Karnataka Renewable Energy Development	State government
5	Maharashtra Energy Development Agency	State government
6	Indian Wind Turbine Manufacturers Association	Industry Association
7	Indian Wind Energy Association	Industry Association
8	Emerson Industrial Automation	Equipment manufacturer
9	World Institute of Sustainable Energy	Research institute
10	The Energy and Resources Institute	Research institute
11–12	Two anonymous consultancies	Consultancy

Source: Author.

Table 4 Technology transfer and firm characteristics of wind turbine manufacturers in India, March 2013

Name	Year of incorporation	Annual turbine sales (MW) in 2012	Max. turbine size (kW) in 2013	Cumulative number of wind power patents		Technology transfer			
				In 2013	Prior to technology transfer	Year of technology transfer	Technology transfer mechanism	Technology source	
Chiranjeevi Wind Energy Ltd.	1998	1 (India)	250	0	0	N/A	Licensing	DeWind	Germany
Gamesa Wind Turbines Pvt. Ltd.	2010	2,631 (world) 95 (India)	2,000	198 (0 assigned to Gamesa India)	151	2010	WFOE (with local R&D center)	Gamesa Innovation and Technology S.L.	Spain
General Electric India Industrial Pvt. Ltd.	2004	6,686 (world) 86 (India)	1,600	1,320 (0 assigned to GE India)	88	2004	WFOE (with local R&D center)	GE Infrastructure Technology International, LLC.	USA
Global Wind Power Ltd.	2007	20 (India)	2,500	0	0	2007	Licensing	Norwin A/S	Denmark
					0	2007	Licensing	Lagerway Wind B.V.	Netherlands
					0	2008	Licensing	Fuhrlander AG	Germany
					0	2008	M&A	Norwin A/S	Denmark
					0	2012	M&A (acquired by Ming Yang)	Ming Yang Wind Power Group Ltd.	China
Inox Wind Ltd.	2009	244 (India)	2,000	0	0	2009	Licensing	AMSC Windtec GmbH	Austria
Kenersys India Pvt. Ltd.	2007	10 (India)	2,500	18 (1 co-assigned to Kenersys India)	2	2007	M&A	RSB Consult GmbH	Germany
Leitwind Shriram Manufacturing Ltd.	2007	8 (India)	1,800	0	0	2007	Joint venture (Shriram: 51%; Leitwind: 49%)	Leitwind B.V.	Italy
NuPower Technologies Ltd.	2008	0 (India)	2,050	0	0	N/A	Licensing	W2E Wind to Energy GmbH	Germany
Pioneer Wincon Pvt. Ltd.	1994	6 (India)	750	0	0	1994 (until 2003)	Joint venture (ownership ratio unknown)	Wincon West Wind A/S	Denmark
					0	2004	M&A	Wincon West Wind A/S	Denmark
Regen Powertech Pvt. Ltd.	2006	267 (India)	1,500	0	0	2007	Licensing	Vensys Energy AG	Germany
RRB Energy Ltd.	1987	0 (India)	600	0	0	1987 (until 2008)	Joint venture (RRB: 51%; Vestas: 49%)	Vestas Wind Systems A/S	Denmark
Shriram EPC Ltd.	2000	4 (India)	250	0	0	2004	M&A	TTG Industries Ltd.	India

Sinovel DB India Pvt. Ltd.	2012	1,380 (world) 0 (India)	1,500	280 (0 assigned to Sinovel India)	278	2012	WFOE (without local R&D center)	Sinovel Wind Group Co. Ltd.	China
Siva Windturbine India Pvt. Ltd.	1999	0 (India)	250	0	0	N/A	Licensing	Wind Technik Nord GmbH	Germany
Southern Wind Farms Ltd.	2005	0 (India)	225	0	0	2005	M&A	NEPC India Ltd.	India
Suzlon Energy Ltd.	1995	3,191 (world) 414 (India)	2,250	361 (3 assigned to Suzlon Energy)	0	1995	Licensing	Suedwind GmbH	Germany
					0	1997	M&A	Suedwind GmbH	Germany
					0	2000	M&A	AE-Rotor Technik B.V.	Netherlands
					0	2001	M&A	Aerpac B.V.	Netherlands
					0	2001	M&A	Enron Wind Rotor Production B.V.	Netherlands
					0	2001	International R&D center	Suzlon Energy B.V.	Netherlands
					16	2002	International R&D center	Suzlon Energy GmbH	Germany
					16	2004	International R&D center	Suzlon Energy A/S	Denmark
					16	2004	Joint venture (Suzlon: 75%; Elin: 25%)	Elin EBG Motoren GmbH	Austria
					18	2006	M&A	Hansen Transmissions International N.V.	Belgium
					39	2007-2011	M&A	REpower Systems GmbH	Germany
Vestas Wind Technology India Pvt. Ltd.	2006	6,039 (world) 128 (India)	2,000	1,007 (0 assigned to Vestas India)	126	2006	WFOE (with local R&D center)	Vestas Wind Systems A/S	Denmark
Wind World (India) Ltd.	1994	411 (India)	800	0	0	1994 (until 2008)	Joint venture (Enercon India: 44%; Enercon Germany: 56%)	Enercon GmbH	Germany
WinWinD Power Energy Pvt. Ltd.	2009	314 (world) 21 (India)	1,000	13 (0 assigned to WinWinD India)	12	2009	WFOE (without local R&D center)	WinWinD Oy	Finland

Note: The global turbine sales figures are for the calendar year 2012, while the turbine sales in India are for FY2012-2013. The maximum turbine size is based on the wind turbine models certified by C-WET. The number of wind power patents includes all the patents held by multinational corporations and those held by merged or acquired companies. Trade is omitted from technology transfer mechanisms because almost all manufacturers have imported wind turbine components.

Source: Author, based on interviews, C-WET (2012a), C-WET (2012b), Navigant Research (2013), IEA Wind TCP (2013), and Thomson Reuters (2016).

Table 5 Technology transfer mechanisms and technological capabilities of wind turbine manufacturers in India, March 2013

	Sample A: All firms		Sample B: Firms with single transfer mechanism	
	Maximum turbine size (kW)	Cumulative number of wind power patents	Maximum turbine size (kW)	Cumulative number of wind power patents
Joint venture				
without R&D by recipient firms	600 – 1,800	0	600 – 1,800	0
with R&D by recipient firms	<u>2,250</u> ¹	<u>361</u> ¹	N/A	N/A
Licensing				
	250 – <u>2,500</u> ²	0 – <u>361</u> ¹	250 – 2,050	0
WFOE				
without local R&D centers	1,000 – 1,500	13 – 280	1,000 – 1,500	13 – 280
with local R&D centers	1,600 – 2,000	198 – 1,320	1,600 – 2,000	198 – 1,320
M&A				
without R&D by recipient firms	225 – <u>2,500</u> ²	0	225 – 250	0
with R&D by recipient firms	<u>750</u> ³ – 2,500	<u>0</u> ³ – <u>361</u> ¹	2,500	18
International R&D center				
	<u>2,250</u> ¹	<u>361</u> ¹	N/A	N/A

Note: The underlined figures are for firms that pursued a combination of technology transfer mechanisms: 1 Suzlon: Joint venture, licensing, M&A, and international R&D center; 2 Global Wind Power: Licensing and M&A; 3 Pioneer Wincon: Joint venture and M&A. Other figures are for firms that pursued only one type of technology transfer mechanism.

Source: Author.