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Gone with the wind: A learning curve analysis of China's wind power industry

Daisuke Hayashi[a,b,*], Joern Huenteler[c], Joanna I. Lewis[d]

[a] Department of International Relations, Ritsumeikan University, Japan
[b] Department of Political Science, University of Zurich, Switzerland
[c] Department of Management, Technology and Economics, ETH Zurich, Switzerland
[d] Science, Technology and International Affairs Program, Edmund A. Walsh School of Foreign Service, Georgetown University, United States

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ABSTRACT

This study examines how accumulation of experience and knowledge by wind farm developers and turbine manufacturers contributed to productivity gains in China's wind power industry during its rapid expansion phase between 2005 and 2012. A learning curve analysis is conducted on an original dataset of 312 Chinese wind farms under the Clean Development Mechanism. A key strength of the dataset is that it includes data on *actual*, wind-farm level power generation. The analysis, based on third-party verified data, reveals that the experience and knowledge accumulation did not result in improvements in generation performance, turbine size, or unit turbine costs of Chinese wind farms. Rather, generation performance was driven by capital investments (i.e., larger and more expensive wind farms performed better). Turbine cost reductions were achieved by intense price competition which hampered investments in technology improvement and quality assurance. The Chinese wind power case demonstrates how market expansion, in the absence of carefully designed innovation policies that complement deployment policies, does not necessarily lead to technological learning. Fostering the technological capability of local industry can take a long time. When scale-up happens quickly, it is crucial to develop and refine local technological capability.

1. Introduction

Since Arrow (1962) conceptualized the notion of learning by doing, numerous empirical studies have shown that productivity of workers and firms often rises with accumulation of experience (e.g., Barrios and Strobl, 2004). The analysis linking experience accumulation and productivity gains (learning curve analysis) has recently been extended to low-carbon technology fields, primarily to assess learning in renewable energy technology fields in industrialized countries. For example, a number of studies examined learning in wind power technology for Europe (e.g., Söderholm and Sundqvist, 2007) and the United States (Nemet, 2012). However, the learning curve literature has so far paid much less attention to low-carbon technologies in developing countries.

The emergence of China's wind power industry is one of the most impressive cases of technological catch-up. China's wind power market expanded exponentially over the last decade and now represents more than a quarter of global wind power installations (GWEC, 2014). The rapid increase in wind turbine installations was accompanied by the emergence of a successful local industry, which currently dominates China's wind power market (Lewis, 2013). However, despite the growth in wind power installation and manufacturing capacity, China has struggled to improve its wind power generation performance (Huenteler et al., 2018). This is largely due to grid connection delays and a widespread problem of wind power curtailment. Curtailment is when grid operators choose to “spill” wind generation, meaning it is not captured by the grid, but essentially wasted. Such curtailment is usually done in order to preserve grid stability, but may be done for a variety of other factors, both technical and political. Whatever the motivation, curtailment results in foregone revenue to wind generators, and has a large impact on the financial performance of wind farms. The curtailment problem started in 2009, and remains a major problem (Lewis, 2016a). China experienced record levels of curtailment in 2016 accounting for 17% of the annual wind power generation (Reuters, 2017).

Previous learning curve analyses on the Chinese wind power

Abbreviations: CDM, Clean development mechanism; CER, Certified emission reduction; GHG, Greenhouse gas; GW, Gigawatt; kW, Kilowatt; kWh, Kilowatt-hour; MW, Megawatt; MWh, Megawatt-hour; O&M, Operation and maintenance; PDD, Project design document; R&D, Research and development; SOE, State-owned enterprise; UNFCCC, United Nations Framework Convention on Climate Change

* Correspondence to: 56-1 Toji-in Kitamachi, Kita-ku, Kyoto 600-8577, Japan.
E-mail address: dhayashi@fc.ritsumei.ac.jp (D. Hayashi).

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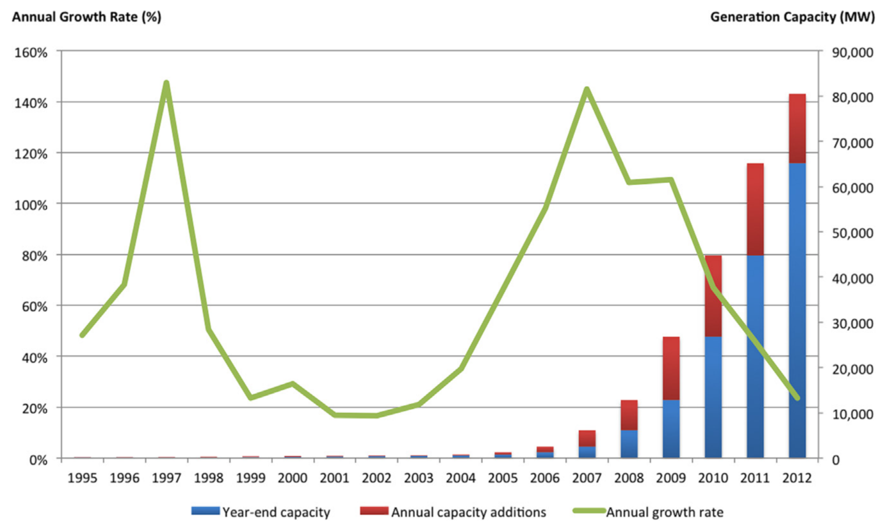

Fig. 1. Expansion of the Chinese wind power market, 1995–2012.
Source: Huaxia Wind (2013)

industry were conducted using *predictive* measures of costs and generation performance of wind power. Using the bid prices offered under China's Wind Resource Concession Program between 2003 and 2007, Qiu and Anadon (2012) found that learning through wind turbine installation and manufacturing as well adoption of new wind power technologies led to bid price reductions of 4.1% − 4.3% per doubling of installed capacity and new technology adoption. Tang and Popp (2016) analyzed *ex ante* estimations of costs and capacity factors[1] of China's wind farms registered under the Clean Development Mechanism (CDM) between 2002 and 2009 and found that wind turbine installation experience, especially the cooperating experience between a developer and its partner foreign turbine manufacturer, led to cost reductions and improvement in the predictive measure of generation performance. Lam et al. (2017) also analyzed China's wind farms registered under the CDM between 2004 and 2012 to find that the learning rate on the *predicted* levelized cost of electricity was between 3.5% and 4.5% per doubling of installed capacity, which was much lower than those experienced in Denmark and Germany during similar stages of industry development.

Given the current mismatch between capacity and generation in the Chinese wind power industry (Yang et al., 2012), questions remain about whether experience drives not only installations but also *actual* wind power generation in China. The main purpose of this study is to provide a quantitative analysis of how the experience and knowledge of wind farm developers and turbine manufacturers contributed to both capacity-related productivity (turbine size and unit turbine costs) and *actual* power generation of wind farms in China during the rapid market expansion phase between 2005 and 2012. This is an important period for the learning curve analysis because the industry accumulated a significant amount of experience in this phase, while wind power curtailment became a serious problem. This study uses an original dataset of 312 Chinese wind farms that were registered and issued carbon credits under the CDM. The wind farms in this dataset represent 16.5 gigawatts (GW) of installed wind turbine capacity or 21% of China's total grid-connected turbine capacity in 2012. A key strength of the dataset is that it contains the actual amount of electricity generated from the CDM wind farms. Therefore, this study can analyze the relationship between capacity- and generation-based output measures and the experience and knowledge levels of developers and manufacturers, while controlling for capital stock, wind resources, wind support policies, and other factors that may influence the productivity measures. The capacity and generation data were third-party verified as part of the CDM approval process. The analysis demonstrates that the experience and knowledge accumulation during the rapid market expansion phase did not lead to productivity gains in the output measures. This indicates that even the unprecedented market growth did not result in technological learning.

This study begins with explaining the context of technological learning in the Chinese wind power industry (Section 2). Section 3 introduces the empirical strategy for data analysis, the results of which are summarized in Section 4. The contributions, policy implications and limitations of this study are discussed in Section 5, followed by conclusions in Section 6.

2. Technological learning in the Chinese wind power industry

2.1. Expansion of China's wind power market

The Chinese government initiated wind power technology development efforts during the sixth Five-Year Plan period of 1981–1985 (Shi, 1986). Until the mid-1990s, the efforts were mostly confined to small domestic wind turbines and a few imported models from Denmark. The Chinese wind power market began expanding in 1994, when the Ministry of Electric Power issued the Provisions for Grid-Connected Wind Farm Management (MOEP, 1994). The provisions required grid operators to remunerate wind power with wind farm costs plus a reasonable profit. A series of support policies followed, including preferential loan schemes (e.g., the "Double Increase Program" in 1995, and additional loans for wind farm development in 1996), which led to the government successively increasing national wind power installation targets (e.g., the 10th Five-Year Plan in 2001) as well as industrial policy support schemes for wind turbine science, technology and local manufacturing (e.g., National High Tech Research and Development—R&D—Programs, or 863 Programs, in 1996 and 2001). As a result, the industry experienced its first wave of rapid expansion from 1994 to 2002, with annual growth rates exceeding 100% over several years, and annual installations mostly in the double-digit megawatt (MW) range (see Fig. 1).

The second wave of expansion started in the mid-2000s with a triad of significant policies targeting the wind power sector. First, the Chinese government started the Wind Resource Concession Program in 2003 (NDRC, 2003). This program was a key driver of the wind market expansion between 2003 and 2007, totaling 3350 MW of new wind

[1] A capacity factor measures the amount of power generation as a share of how much could be generated if the wind turbines operated at full capacity.