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Scale-up Nation: China's Specialization in Innovative Manufacturing

JONAS NAHM
Massachusetts Institute of Technology, Cambridge, USA

and

EDWARD S. STEINFELD *
Brown University, Providence, USA

Summary. — On the basis of more than one hundred interviews conducted in 42 firms in China's wind turbine and solar PV sectors during 2010–2013, this article seeks to specify the nature and extent of China-based technology innovation. We argue that Chinese firms have developed unique capabilities surrounding technology commercialization and manufacturing-related innovation. We provide a taxonomy for understanding such capabilities, showing the ways in which they are related to multidirectional, cross-border learning among firms. Our analysis points the way toward new frameworks for understanding national competitiveness and industrial upgrading.

Key words — manufacturing innovation, industrial upgrading, national competitiveness, renewable energy industries, Asia, China

1. INTRODUCTION: THE PHENOMENON OF CHINESE INNOVATIVE MANUFACTURING

China's extraordinarily rapid emergence as a global manufacturing powerhouse is a well-known fact. Less well understood are the drivers of this emergence. Some observers have pointed to the role of state subsidies (Bergsten, 2010). Others have emphasized more general issues of factor cost advantages (Li, Li, Wu, & Xiong, 2010; Lin, Cai, & Li, 1996). A growing recent literature, however, has pointed to the existence in China of distinct forms of industrial innovation. These forms pertain not to upstream research and development (R&D) or new-to-the-world invention, but instead to downstream efforts involving both the redefinition of existing technologies and the commercialization of new ones (Breznitz & Murphee, 2011; Ernst & Naughton, 2008, 2012; Ge & Fujimoto, 2004; McKinsey Quarterly, 2012; Thun & Brandt, 2010).

This article seeks to build on that nascent literature by going further in specifying the exact nature and extent of the firm-level capabilities driving China-based innovation. We do this on the basis of qualitative, interview-based data collected from 42 firms spread across two sectors within the renewable energy technology domain, wind turbine manufacturing, and solar photovoltaic (PV) panel production.

Our study has three main aims. First, we seek to develop a typology for classifying and identifying the full range of capabilities and activities surrounding what has come to be known as Chinese innovation. Previous literature has pointed to the existence of this phenomenon, identified select aspects, and described elements of it in sectorally-specific contexts. We seek to extend the effort by providing a perspective that is at once more comprehensive in terms of the phenomenon as a whole, and more specific in terms of its constituent elements. We believe that this initial effort to better pinpoint the phenomenon represents an important step ultimately toward understanding causal drivers. While our data do not permit conclusive causal statements about what drives Chinese innovation, the study is structured methodologically to suggest certain future directions for deeper causal analysis.

Second, we seek to contribute to a growing global discourse on the competitiveness implications of China's industrial rise. Given current challenges surrounding climate change and resource scarcity, governments and commercial actors worldwide have identified renewable energy technology production as an important area for long-term investment and growth. As indicated by recent solar PV-related trade disputes between China and the United States and China and the European Union, leading economies across the world now treat renewable energy technology production as a key benchmark of national industrial competitiveness (Bullis, 2012; USITC, 2012). By illuminating how innovation operates in China's renewable energy sector, and how it relates to what happens in comparable sectors in other economies, we seek to draw broader conclusions about national competitiveness in increasingly interdependent, globalized technology production systems.

Third, by choosing methodologically to focus on two particular sectors—solar PV production and wind turbine manufacturing—we aim to demonstrate the extent of Chinese innovation across a full spectrum of manufacturing-related activities. Some observers might be inclined to dismiss solar PV and wind turbine production as mere niche areas within an already narrowly circumscribed portion of the energy technology sector. We argue, however, that these two areas, if considered in terms of their whole supply chains, encompass the entire spectrum of technological, regulatory, and production

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characteristics associated with virtually all of modern industry. The technology production systems surrounding wind and solar certainly include a number of very traditional, well-established industrial activities (i.e., the fabrication of standard steel towers for wind turbines, the use of basic chemical processes invented in the 1950s to fab solar cells, *etc.*). But so too do they include activities residing at the technological frontier (i.e., the application of advanced aerospace designs to turbine blades, the development and incorporation of advanced nanomaterial coatings for solar cells, *etc.*). Just within China, let alone globally, these industries in process terms span the range from the electromechanical to the electrochemical; in skill terms span the range from basic manual fabrication to advanced engineering design and complex systems management; and in disciplinary terms draw upon everything from mechanical and electrical engineering to materials sciences, chemical engineering, and systems dynamics. Portions of each of these industries are labor intensive, while others are extremely capital and technology intensive. And at the institutional level, again even just within China, some portions of these industries are highly protected by the state, while others are left exposed to unbridled, and often quite cutthroat, free market competition. Our typology suggests that Chinese innovation can be found across all these spectra.

The various forms of China-based innovation found in our typology all share four basic attributes. First, the know-how involved at the firm level is concentrated primarily in engineering design teams that operate at the intersection between upstream R&D and actual physical fabrication. Second, Chinese innovation involves more than mere emulation or mimicry of what outsiders are already doing, but instead amounts to learning and the development of proprietary know-how. Third, learning and know-how accumulates through the innovator's participation in multi-firm networks, many of which extend across national boundaries. And fourth, the learning, as opposed to traditional technology transfer, is multidirectional, moving back and forth across firms engaged with and embedded in global production networks.

Our typology, then, demonstrates how these attributes get manifested across three modalities. The modalities differ primarily in terms of the newness of the technologies involved. At one end of the spectrum, we witness innovation surrounding existing products. Further along the spectrum, we witness innovation surrounding the introduction of new products. And then on the far end of the spectrum, we witness the integration of multiple new technologies, materials, and components into an entire technology system.

2. ENGAGING THE LITERATURE ON CHINESE INNOVATION

Our work builds upon, but differs somewhat, from those who have preceded us in the study of China-based innovation (Ernst & Naughton, 2008, 2012; Ge & Fujimoto, 2004; Thun & Brandt, 2010). In many respects, we all bear the influence of the seminal theoretical work of Henderson and Clark (1990) and Baldwin & Clark, 2000. Those latter scholars, in their efforts to conceptualize the often unexpected ways in which firms create value in advanced industrial economies, moved beyond the traditional focus on product innovation, and beyond the traditional distinction between radical and incremental innovation. Instead, they focused on "product architecture," the design information that determines how a product's subcomponents connect and interact to determine the product's ultimate functionality. Firm-induced shifts in this design information—essentially, "architectural innovation"—may not change the product's physical appearance or even functionality (at least in the near term), but may radically affect other aspects of the product, including its cost, its interoperability with other products, and even in some cases its functionality over the longer run. The key example identified by Baldwin and Clark is the IBM System/360, a computer design that by standardizing and codifying the linkages between the processor and its various peripherals, transformed the computer from an "integral" to a "modular" product architecture. This shift, embodied today by objects like the standard USB connection, enabled the computer's various subsystems to embark on independent trajectories of innovation, trajectories that have given birth to industry giants such as Intel, Microsoft, and Apple.

A number of scholars in recent years have identified important instances of such architectural innovation in the Chinese business ecosystem. Ge and Fujimoto (2004) describe how Chinese motorcycle assemblers, through reverse engineering, effectively modularized the firm-specific, integral designs of Japanese lead firms. What the Chinese were doing was more than mere copying, for the newly engineered designs, though perhaps sacrificing some product functionality and quality, substantially lowered production costs, and created new options for interoperability with after-market parts. Ernst and Naughton (2008) identify a similar pattern in their discussion of the information technology (IT) equipment industry and the rise of Chinese newcomers like Huawei.

Recent scholarship has also identified cases in which Chinese firms, even if they do not themselves initiate changes in product architecture, move quickly to exploit modularization pioneered by others. Hence, as Ernst and Naughton (2012) point out in the case of semiconductor design, Chinese fabless design houses like Spreadtrum—by purchasing key integrated circuit design tools and intellectual property from abroad, while also partnering with industry-leading foundry operators like Taiwan Semiconductor—have become key suppliers to China's booming "Shanzhai" ("no brand") smart phone market.

As some scholars have reasonably argued, these instances of architectural innovation at least in some cases lead to actual product innovation. In their study of the Chinese automobile, construction equipment, and machine tool sectors, Thun and Brandt (2010) suggest that Chinese indigenous firms, by reengineering the focal models of global incumbents, have essentially created new "middle market" products, ones whose functionality and cost are particularly suited to what in many countries, including China, is the fastest-growing market segment. That Brandt and Thun's "new product innovation" may be indistinguishable from the architectural innovation, reverse engineering, and creative mimicry observed by Ge and Fujimoto (2004) or Ernst and Naughton (2008) hardly undercuts the point. After all, as Henderson and Clark (1990) emphasized in their original article, architectural innovation and product innovation frequently go hand in hand.

Our notion of Chinese innovative manufacturing has much in common with these previous perspectives, particularly our collective emphasis on reengineering, product architecture transformation, and cost reduction. However, our view of Chinese innovation differs from the existing literature in three key ways.

First, we observe not just the mimicry of overseas designs, but close inter-firm—and, in most cases, cross-border—collaboration on the development of new knowledge and new designs. Second, we observe not just one-way learning (from advanced industrial incumbents to Chinese latecomers), but