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Innovation and technology transfer through global value chains: Evidence from China's PV industry

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HIGHLIGHTS

- The value chain analytical approach is synergized with the theories of technology transfer and innovation systems.
- A detailed review of how China integrated itself into the global solar PV innovation system is provided.
- Four main factors shape PV technology transfer to China across various value chain segments.
- Innovation in cleaner energy technologies is a combination of global and national innovation processes.

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ABSTRACT

China's success as a rapid innovation follower in the infant Photovoltaic (PV) industry surprised many observers. This paper explores how China inserted itself into global clean energy innovation systems by examining the case of the solar PV industry. The paper decomposes the global PV industrial value chain, and determines the main factors shaping PV technology transfer and diffusion. Chinese firms first entered PV module manufacturing through technology acquisition, and then gradually built their global competitiveness by utilizing a vertical integration strategy within segments of the industry as well as the broader PV value chain. The main drivers for PV technology transfer from the global innovation system to China are global market formation policy, international mobilization of talent, the flexibility of manufacturing in China, and belated policy incentives from China's government. The development trajectory of the PV industry in China indicates that innovation in cleaner energy technologies can occur through both global and national innovation processes, and knowledge exchange along the global PV value chain.

1. Introduction

The explosive growth in the photovoltaic (PV) industry beginning in the 2000 s came as a surprise to many observers. In 1999, there was less than 0.7 Gigawatts (GW) of PV installed capacity globally but in 2014, around 40 GW were installed, bringing the cumulative installed PV capacity to 180 GW (IEA, 2015) as shown in Fig. 1. The average annual growth of newly installed PV capacity annually amounted to 49.5% per year since 2000. Meanwhile, the price of crystalline-silicon PV modules rapidly decreased by an average of 35% per year between 1997 and 2014.

China's success as a rapid innovation "follower" in the PV industry was a second surprise to market observers. China effectively entered the global PV industry in 2001 when the global market was just emerging. In only six years, China surpassed Japan to become the largest solar cell producer in the world, even though there was practically no domestic market in China at the time (Fig. 2). In 2011, China produced more than 20 GW of solar modules, accounting for 60% of global production. Of the 20 GW produced, only about 2 GW were installed in China that year. The traditional Chinese strategy for emerging industries was to adopt an import-substitution approach where the "infant industry" initially produces for the Chinese market with some government

Abbreviations: PV, photovoltaics; IEA, International Energy Agency; IEA PVPS, IEA Photovoltaic Power Systems Programme; EPIA, European Photovoltaic Industry Association; CREIA, Chinese Renewable Energy Industry Association; GW, Gigawatt; FIT, feed-in tariff; MOF, Ministry of Finance; MOST, Ministry of Science and Technology; NDRC, National Development Reform Commission; RMB, Renminbi; OEM, Original Equipment Manufacturer; ODM, Original Design Manufacturer; CEO, Chief Executive Officer; GDP, Gross Domestic Product; FDI, foreign direct investment; R&D, research and development; REN21, Renewable Energy Policy Network for the 21st Century; BOS, balance of system; SEMI, Semiconductor Equipment and Materials International

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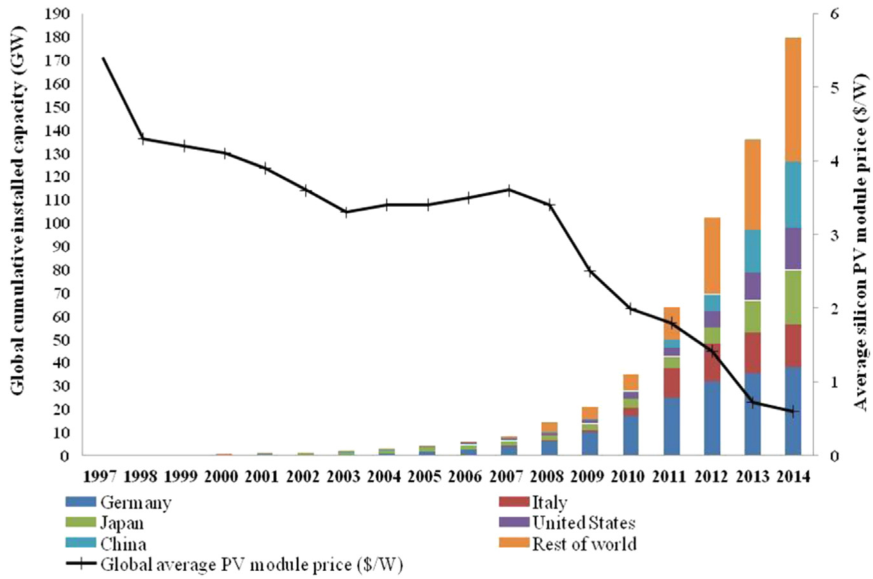

Fig. 1. Global cumulative installed PV capacity and average silicon PV module price (1997–2014). Note: silicon PV module price refers the average price of global market. (Source: IEA, 2010, 2013, 2014, 2015; EPIA, 2015; SEMI, 2012; Mints and Donnelly, 2011).

protection, and then gradually begins to export when the firms reach an international level of competitiveness, such as in the automobile and telecommunication industries (Mu and Lee, 2005 and Gallagher, 2006). The emergence of the Chinese PV industry, however, was achieved through a completely different strategy.

The scholarship on technology catch-up in industrializing countries (Lall and Teubal, 1998) and clean-energy-technology transfer both emphasize strong government policy support (Ockwell et al., 2008; Zhi et al., 2013). More specifically, stable, predictable, transparent, and medium-to-long term market-formation policy is essential for clean energy diffusion, as demonstrated in the cases of the wind power, advanced coal, and biofuel industries in China, India, and Brazil (Lewis and Wiser, 2007; Zhang et al., 2009; Ru et al., 2012; Gallagher, 2014). When China entered the PV industry, however, there were very few domestic policy incentives for the PV industry, especially before 2009 (Zhi et al., 2014; Zhang, et al., 2015). Recent literature emphasizes the complex multi-scalar networks within which the Chinese PV industry emerged (Dewald and Fromhold-Eisebith, 2015; Iizuka, 2015; Quitzow, 2015; Zhang and White, 2016).

Against this background, this paper will explain China's success as a rapid innovation "follower" in the PV industry by focusing on Chinese firms' strategies to upgrade their competitiveness through vertical integration, as well as by identifying the main drivers of the transfer of PV technology from developed countries to China. The paper thus synergizes the perspective of global value chain analysis with that of technology innovation and technology-transfer. Our three main research questions are: (1) Where did China initially insert itself into the global PV value chain and thereby connect with the global PV innovation system? (2) How did the Chinese PV industry dynamically build its global competitiveness across different segments of the global PV value chain? (3) What were the main factors that supported or constrained China's upgrading through technology transfer across different value segments?

2. Literature review and methodology

2.1. Literature review

2.1.1. Energy Technology Innovation Systems

Innovation is not just "invention" or "R&D" but rather a set of processes that as a whole should be thought of as a system (Carlsson and Stankiewicz, 1991). It is strongly affected by the social system, including different actors, networks, and institutions (Rogers, 1995). A technological innovation system is a set of networks of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion and utilization of variants of a new technology and/or a new product (Markard and Truffer, 2008).

The idea of an energy technology innovation system was developed more recently (Grubler et al., 1998), and it applies the technological innovation system approach to energy innovation. The key elements of the energy technology innovation system include all aspects of energy systems (supply and demand); all stages of the technology development cycle; as well as all innovation processes, feedbacks, actors, institutions, and networks (Gallagher et al., 2012). Energy technology innovation systems include multiple functions: knowledge creation, expectations, entrepreneurial activities, guidance of the search, legitimize, market formation, and allocation of resources (Bergek et al., 2008; Gosens et al., 2015; Hekkert et al., 2007; Markard and Truffer, 2008).

The energy technology innovation system can be applied to both national and global levels of analysis assuming that they are largely determined by organizations and institutions inherently characterized by a certain territorial sphere of influence and interaction. It is emphasized that no innovation system is located in one place only (Oinas and Malecki, 2002), and innovation systems are increasingly internationalized (Carlsson, 2006). Thus, there is a need for multi-scalar approaches rather than ones using bounded regions, which calls for exploring interconnections and interrelations between and across scales (Bunnell and Coe, 2001; Fromhold-Eisebith, 2007). The two common recognized connections between different scales are human migration and firm networks (Coe and Bunnell, 2003).

2.1.2. Clean energy technology transfer

Clean energy technology transfer is a key function or process of the global energy innovation system. International technology transfer covers hardware transfer, such as tooling for factories, and intangible asset transfer, including product design and the capability of manufacturing a product (Grubler, 1998). Technology