ARTICLE IN PRESS

Energy Policy xx (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Spatial lifecycles of cleantech industries – The global development history of solar photovoltaics

Christian Binz[a,*], Tian Tang[b], Joern Huenteler[c]

[a] Centre for Innovation, Research and Competence in the Learning Economy - CIRCLE, Lund University, Lund, Sweden
[b] Askew School of Public Administration and Policy, Florida State University, FL, USA
[c] The World Bank, Washington, DC, USA

ARTICLE INFO

Keywords:
Industry lifecycle
Product lifecycle
Patent analysis
Solar photovoltaics
Cleantech

ABSTRACT

New industries develop in increasingly globalized networks, whose dynamics are not well understood by academia and policy making. Solar photovoltaics (PV) are a case in point for an industry that experienced several shifts in its spatial organization over a short period of time. A lively debate has recently emerged on whether the spatial dynamics in new cleantech sectors are in line with existing industry lifecycle models or whether globalization created new lifecycle patterns that are not fully explained in the literature. This paper addresses this question based on an extensive analysis of quantitative data in the solar PV sector. Comprehensive global databases containing 86,000 patents as well as manufacturing and sales records are used to analyze geographic shifts in the PV sector's innovation, manufacturing and market deployment activities between 1990 and 2012. The analysis reveals spatial lifecycle patterns with lower-than-expected first mover advantages in manufacturing and market activities and an earlier entry of firms from emerging economies in manufacturing and knowledge creation. We discuss implications of these findings for the competitive positions of companies in developed and emerging economies, derive new stylized hypotheses for industry lifecycle theories, and sketch policy approaches that are reflexive of global interdependencies in emerging cleantech industries.

1. Introduction

In the globalizing knowledge economy, industry lifecycles are getting subject to increasing spatial complexity (Bunnell and Coe, 2001; Crevoisier and Jeannerat, 2009; Ernst, 2002; Gallagher, 2014; Quitzow, 2013). This observation is particularly relevant for many recently emerging clean-tech sectors: Empirical studies in the solar power, wind power, water recycling or urban transportation sectors all suggest that knowledge and other key resources for emerging industries are increasingly circulating between places and getting mobilized by a diverse set of actors around the world (Binz et al., 2014; Lewis, 2011; Quitzow, 2013; Sengers and Raven, 2015). This has far reaching consequences for policy-making and innovation theories. In particular, well-established industry lifecycle theories are challenged to explain the rapid spatial shifts in key growth sectors, e.g. from Western countries to Asia or from developed to developing economies.

In the past, firms in developed countries that led new products' and industries' early innovation and manufacturing efforts often achieved sustained first mover advantages (Abernathy and Utterback, 1978; Beise and Rennings, 2005; Klepper, 1996). Industrial and innovation policies accordingly focused on creating lead markets and lead manufacturers in specific national or regional contexts (Anadón, 2012; Beise and Rennings, 2005; Lundvall, 1992; Lundvall et al., 2002). In today's globally interconnected knowledge economy, the effectivity of such national initiatives is increasingly questioned (Dicken, 2007; Pietrobelli and Rabellotti, 2009; Quitzow, 2013). In particular, emerging economies in Asia, and especially China and India, have become significant competitors in global clean-tech industries over a very short period of time and are now starting to challenge Western technology leadership (Nahm and Steinfeld, 2014; Peters et al., 2012).

Solar photovoltaics (PV) are a case in point for a sector that emerged in a highly globalized pattern with a significant shift of activity towards emerging economies, and in particular China (Quitzow, 2013; Varadi, 2014). By 2016, more than 70% of crystalline PV panel manufacturing was concentrated in China and Taiwan, and also the upstream and downstream parts of the value chain were increasingly shifting towards Asia (Gallagher and Zhang, 2013; Gress, 2014). A lively debate has emerged in the literature about whether this spatial shift can be conceptualized with existing industry lifecycle theories or

* Corresponding author.
E-mail address: christian.binz@circle.lu.se (C. Binz).

http://dx.doi.org/10.1016/j.enpol.2016.10.034
Received 29 June 2016; Received in revised form 17 October 2016; Accepted 24 October 2016
Available online xxxx

Please cite this article as: Binz, C., Energy Policy (2016), http://dx.doi.org/10.1016/j.enpol.2016.10.034

whether it constitutes a new pattern of catching-up that asks for improved theoretical explanation (Binz and Diaz Anadon, in preparation; Gallagher and Zhang, 2013; Nahm and Steinfeld, 2014; Quitzow, 2015; Schmidt and Huenteler, 2016).

So far, most work that has addressed this question based on in-depth case studies. A more quantitative assessment of the spatial dynamics in the solar PV sector and other emerging cleantech sectors is still largely missing. Also, existing theorizing explains lifecycle dynamics mostly from the supply-side (manufacturing), while downplaying the importance of co-evolving knowledge creation and market deployment processes. This paper aims at addressing this gap based on an in-depth analysis of patenting, manufacturing and market deployment data in the global solar PV sector and juxtaposing it with findings from existing industry lifecycle literature.

In this venture, two main research questions guide the analysis: (1) How did the location of innovation, manufacturing and market deployment in the solar PV industry evolve over time? (2) How would existing industry lifecycle theories have to be adapted to explain the spatial dynamics in the PV sector (and other clean-tech industries with similar properties)? These questions are explored based on a comprehensive global patent dataset containing 86,000 PV-related patents from the 50 major patent offices around the world over the period 1965–2012, as well as on a collection of manufacturing and market deployment data for key countries from 1990 to 2012. The data is analyzed for spatial shifts in innovation, manufacturing and deployment centers related to each other in different phases of the industry lifecycle.

The remainder of the paper is structured as follows: We first introduce current industry lifecycle theories and identify gaps in this literature's conceptualization of co-evolving innovation-, manufacturing-, and market dynamics. Section 3 introduces the cases study, database and methods before exploring the global lifecycle patterns of the PV sector in detail in Section 4. Sections 5 and 6 discuss the implications of our findings for lifecycle theories as well as for policy making in cleantech sectors and introduce promising future avenues of research.

2. State of the art

Spatial shifts in the organization of industries are of key importance for national and regional development (Storper and Walker, 1989). Several streams of literature have developed hypotheses on how and why an industry's knowledge base, manufacturing base, and markets shift in space. Among the various approaches from evolutionary economics and economic geography, this paper analyzes two approaches in more detail: product and industry lifecycle approaches (Abernathy and Utterback, 1978; Klepper and Graddy, 1990; Klepper, 1996).

2.1. Existing theories on spatial lifecycle dynamics in new industries

Product and industry lifecycle approaches predict that over the maturation of a product or industry, three stylized development phases follow each other that differ in their spatial setup (Vernon, 1966): In the very early, 'fluid', phase, inventors experiment with a new to the world idea. Uncertainty is high, user needs are unclear, manufacturing volumes are low and small entrepreneurial firms compete with each other based on frequent product design innovation (Abernathy and Utterback, 1978; Vernon, 1966). Early companies depend on flexible inputs, well-trained labor and dense user-producer interaction. This first lifecycle phase accordingly depends on narrowly confined geographic areas where early user needs and product innovations get aligned through regular face-to-face interaction. The initial region where an industry develops (usually located in a developed economy) is consequently assumed to possess significant locational advantages also in later development stages (Klepper, 1996; Vernon, 1966).

In the subsequent 'transitional' phase of a maturing product, innovation dynamics change. Manufacturing volumes start rising, the innovation gets more standardized and new entrants and specialized suppliers enter the industry (Abernathy and Utterback, 1978). Search processes shift from product innovation to process innovation; parts of the manufacturing process get automated, and firms increasingly try to reap economies of scale while decreasing input factor costs (Utterback and Abernathy, 1975). A first spatial shift in the industry accordingly happens in this phase: As markets for the innovation develop in foreign countries, the initial inventors will consider establishing manufacturing plants abroad (Vernon, 1966). As the manufacturing process is still relatively complex and prone with uncertainty, manufacturing will be outsourced to other developed countries with slightly lower labor costs, but sufficient supply of well-trained social capital (ibid.). In some cases, international subsidiaries of the initial firms will start exporting to third party markets or even back to the original region.

In the final development phase of a 'standardized product', a dominant design and mass markets with well-articulated user needs emerge. Activities in the industry now evolve around incremental process innovation and manufacturing is organized in highly automated, capital-intensive, large scale plants (Abernathy and Utterback, 1978; Vernon, 1966). As economies of scale play an increasingly important role, a shakeout occurs and less efficient producers exit the industry (Klepper, 1996). In this last phase, locational dynamics shift towards developing/emerging economies with significantly lower factor prices (especially labor costs) and additional untapped market potential (Klepper and Graddy, 1990; Vernon, 1966). Usually, only low value-added and highly standardized manufacturing processes get outsourced to developing economies while more complex parts of the value chain remain concentrated in firm headquarters in the initial region (Abernathy and Utterback, 1988; Vernon, 1966).

The validity and use of this analytical framework has been confirmed with a broad set of conceptual and empirical studies (Abernathy and Utterback, 1988; Anderson and Tushman, 1990; Klepper, 1996; Suarez and Utterback, 1993; Vernon, 1966). Yet, lifecycle concepts have also been criticized on various grounds, some of which are of key significance for the locational dynamics of emerging cleantech industries. We here focus on one key line of thought, which posits that the literature has emphasized the supply side (manufacturing processes and the emergence of dominant designs), while downplaying the demand side (market diffusion and the active construction of new market segments) and knowledge network's role in the spatial dynamics of new industries (Jeannerat and Kebir, 2016; Malerba, 2006; Murmann and Frenken, 2006). A key open question in lifecycle literature accordingly is whether and how spatial shifts in manufacturing activities co-evolve with shifts in knowledge networks and market deployment (Malerba, 2006).

In terms of innovation activities, traditional lifecycle literature assume somewhat simplistically that key knowledge centers remain concentrated in the initial regions as firms outsource only manufacturing, but not innovation, design and management functions to latecomer regions (Dicken, 2007; Utterback and Abernathy, 1975; Vernon, 1966). Especially latecomers in emerging economies enter knowledge networks only in the latest development phase when a dominant design and standardized manufacturing processes have emerged. They are expected to remain in a lagging position for extended periods of time, as they have to absorb outside knowledge in a long-term technology transfer and capability upgrading process (Gereffi, 1999; Morrison et al., 2008).

Similar assumptions are put forward for the market dimension, where the initial markets of a new industry (often 'lead markets' in developed economies) retain a key role throughout all phases of the industry lifecycle (Klepper and Graddy, 1990; Vernon, 1966). Lead market literature posits that regions which develop first mass markets for a new product will not only retain significant market shares over time, but also profit from sustained first mover advantages in the