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Multi-scalar Networks and Urban Context Influence on Invention in Photovoltaic Clusters

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Extended Abstract

The invention output of the photovoltaics sector (solar cells, solar panels) as measured by patents, has rapidly increased since the early 2000s. Annual growth amounted to more than 10 per cent due to a continuous rise of investments in R&D, concerning for example, efficiency of solar cells, new applications like included in construction material, but also cheaper production processes. From a global perspective, it is highly plausible that some cities or clusters are more successful in developing advanced R&D and inventions in photovoltaics than others. But there is a lack of understanding as to the causal background of divergence in performance, specifically to what extent urban agglomeration economies, national situations and international networks are favorable to inventive activity in the clusters.

While it is clear that international research activities are rapidly growing, especially in terms of their global distribution and importance of global knowledge networks (Audretsch, Lehmann, & Wright, 2014), there are also indications that internationalization by multinational firms (MNCs) may weaken or limit the development of knowledge networks within clusters (Van Geenhuizen & Nijkamp, 2012; Ye, Yu, & Leydesdorff, 2013). Concomitantly, the invention performance of some knowledge intensive industries may decrease (Stek & van Geenhuizen, 2015). In fact, the question is to what extent the agglomeration factor, including supportive activity from specialized service firms (KIBS) has remained of key importance or is (strongly) complemented with relational proximity in long-distance networking in which particular power realities between the research partners may emerge (Ertur & Koch, 2011). This, against the background of influence of the national innovation systems (NIS) as proposed by many scholars (e.g. Edquist, 1997; Freeman, 1995; Lundvall, 1992). Accordingly, the paper is centered on the following research question: *How do urban agglomeration, national context and knowledge networks of different kinds influence the inventive performance of industry clusters in the photovoltaic sector worldwide?* To clarify the 'spatial dimension', this paper adopts a focus on the specific characteristics of cities as science bases and as hubs in global invention networks.

First, spatial clusters are identified in a period from 1991 to 2014. This is mainly based on bibliographic sources (patents and scientific publications) which enable the observation of changes over longer time periods, while offering global coverage of units (universities, companies) in local clusters. Bibliometric indicators such as patent counts and citation counts seem like valid indicators in high-technology industries and tend to show close statistical overlap with other innovation indicators such as R&D inputs and new product announcements (Hagedoorn & Cloodt, 2003; Lanjouw & Schankerman, 2004). For this study, bibliometric data is obtained from two sources. Patent data is obtained from the Spring 2015 edition of the Patent Statistical Database (PATSTAT), published by European Patent Office (EPO) and contains data from all major patent offices. Scientific publications are downloaded from the *Scopus*® database, which is maintained by Elsevier, an academic publisher. For the delineation of the technological domain this study uses the new Y02E cooperative patent classification (CPC) from the full (USPTO) and the European Patent Office (EPO), which contains renewable energy technologies, including a subcategory for photovoltaics (Y02E/5) and hybrid thermal and photovoltaic technologies (Y02E/6). For scientific publications the authors are not aware of a similar classification, and therefore rely on the advanced search option in *Scopus*®.

Clusters in this study are conceived as "geographic concentrations of industries related by knowledge, skills, inputs, demand, and/or other linkages" (Delgado, Porter, & Stern, 2014). Accordingly, geographic concentration is used to identify clusters. Concentration refers to the intensity of patent output in geographic space based on the stated place(s) of residence of inventors. These addresses can be geo-located using mapping applications, in this case we use TwoFishes, an open source geocoder previously applied by other scholars (Leydesdorff et al., 2014; Leydesdorff & Persson, 2010). The geo-location of addresses allows the locations of inventors to be plotted on a map and clusters are identified by using the standard "heat map" algorithm, formally known as kernel density estimation (Parzen, 1962; Rosenblatt, 1956). In this study a standard quartic (biweight) kernel shape is used with a radius of 20 km. The radius is based on a previous study (Alcácer & Zhao, 2013), an analysis of commuting distances (Groot et al. 2012; Kneebone and Holmes, 2015; Chen, 2015; Department of Transport, 2015), and robustness checks. In total 89 cluster locations are identified using all patents from the entire 24-year period.

The 89 clusters identified worldwide witness presence of Tokyo, Osaka and San Francisco consistently over the whole period among the top-five largest clusters of photovoltaic inventive performance. Taipei (Taiwan) has gained a position among the 10 largest clusters only in the period of strong growth. In Western Europe, the cluster of Frankfurt is consistently among the 10 largest, followed by the cluster of Basel. In more detail on the country level, in Western Europe, photovoltaic inventive activity is concentrated in Germany, the Netherlands, Belgium, Switzerland, Eastern France and the Southwest of England, where a large number of clusters exist. More isolated clusters are found elsewhere in Europe, including in Spain, Italy and Scandinavia. A number of clusters cross national borders, particularly those between Germany, Switzerland and France. Overall, we observe large metropolitan areas as well

as sets of smaller sized cities acting as a hub of PV R&D. The last one is exemplified by Basel, including Lausanne and Neuchatel in Switzerland.

In a next step, a quantitative model is developed to assess the influence of multiple and multi-scalar knowledge networks and urban and national factors on the invention performance of industry clusters. This multi-scalar approach is based on emerging theories about the role of spatial and relational proximity in innovation and a multidimensional understanding of knowledge networks as consisting of different types of relationship. In this paper, the personal co-invention network, which is often embedded within institutional collaboration networks (Dodgson, 1992), and the MNC branch network are also analyzed. Together these networks provide a broad and differentiated perspective on relational proximity. The model is assessed using General Methods of Moments (GMM) regression analysis.

The preliminary findings suggest that a high-invention performance PV cluster is located in a strong national innovation system and is faced with high partner diversity in research collaboration and influence of MNCs. Successful small clusters compensate a lack of scale by developing a diverse co-invention network and attracting research labs from MNCs. Successful large clusters tend to have a lower presence of MNCs and a less diverse co-invention network (relative to their size), but instead they appear to have strong applied research by universities and public research institutions that supports local industry. Agglomeration factors tend to be of minor importance.

The paper makes a theoretical contribution to the understanding of global patterns of inventive performance in industry clusters. This contribution consists of assessing how the physical proximity factor (agglomeration) and the relational proximity (long-distance networks) factor influence spatially concentrated knowledge creation, including the possibility of knowledge flows mainly in one direction, eventually raising invention performance of the receiving industry cluster. This latter option is considered to be a possibility for the MNC branch networks, which are conceptualized as directed networks indicating information flows *from* and *to* a particular network node (industry cluster) (Wasserman & Faust, 1994). The paper also makes a methodological contribution by using mainly bibliographic data to extract invention indicators, combining spatial analysis and scientometric network analysis approaches. This method involves the identification of industry clusters, the extraction of cluster invention input and output indicators and the construction of multiple inter-cluster knowledge networks from which network indicators are calculated. Because mainly bibliographic data are used, the method has the potential to be applied in many other knowledge intensive sectors, especially when other invention data are not available, which is often the case for studies that encompass the urban region and/or global scale in networks.