Spatial Dimension of Lead Markets:

Evidences from Diffusion of Photovoltaic Systems in Germany

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Abstract:

Diffusion of innovations is a spatial process. Spatial conditions and demand preferences may induce creation of spatial lead markets before national and international adoptions take place. This paper aims to extend the Lead Markets concept in a spatial dimension, considering local differences. We firstly discuss theoretical underpinnings of the spatial dimension of Lead Markets concept and then apply the concept to the case of photovoltaic systems' diffusion in Germany. Based on spatial data and an extensive case study, we show how an innovation is deployed in local areas of a country before being adopted nationwide. We also apply the system of lead market attributes (demand, price, export, transfer and market structure advantages) to the case and discuss how a local lead market could take off in a particular region of a country. Our findings have significant implications not only in theory but also for practice, providing recommendations for policy makers who seek to enhance the level of diffusion for particular innovations.

Keywords:

Lead markets; deployment; innovation; spatial; solar photovoltaic systems

1. INTRODUCTION

Worldwide efforts to cope with resource scarcity and climate change have prompted national governments to support the electricity generation from renewable energy sources. An important question in public debate is whether the countries will be able to achieve the transition to sustainable energy by means of renewable sources. Although solar photovoltaic systems (PV) are an important renewable energy source to pave the way for the transition, they supply only around %1 of electricity demand in globe, %2.6 in Europe and %5.2 in Germany yet (EPIA, 2013; Ren21, 2013; Wirth, 2013). Policy makers have been searching for the most efficient ways to support national and international diffusion of environmental technologies. The literature on diffusion of innovations has long argued how internationally successful innovations, e.g. mobile phones or internet, have been diffused in some particular countries before they get adopted successfully in the global market. In this context, Lead Markets concept (Beise, 2004) explains the demand-side factors that supports and constrains the diffusion of innovations.

The Lead Market Concept assumes the presence of two markets: lead markets that are the countries adopting the globally successful innovation at initial phase, and lag markets that eventually follow the lead ones. It is common to identify the lead markets at the national scale: Israel in agriculture (Takeuchi & Porter, 1986), Japan in electronics (Takeuchi & Porter, 1986), Nordic countries in mobile phones (Beise, 2004), Denmark in wind energy sector (Beise & Rennings, 2005); the USA both in catalytic converters of automobiles (Jänicke & Jacob, 2005) and the efficient coal technologies (Horbach, Chen, Rennings, & Vögele, 2014); and Germany in fuel-efficient passenger cars (Beise & Rennings, 2005). Lead markets are often driven by country-specific factors, such as demand advantage, relative price decrease, high reliability, high export capacity and a competitive market (Beise & Rennings, 2005; Beise, 2004).

The lead market concept has been applied, however, exclusively for cross-country analysis to date. To our knowledge, there is not empirical evidence on the existence of spatial lead markets at local and regional levels. However, geography matters for diffusion of innovations. The spatial aspects are essential for understanding the diffusion paths (Blaikie, 1978; Brown, 1975; Griliches, 1957). The diffusion of innovations first occurs at local and regional scales, where essential elements of diffusion, such as communication, mainly take place. The point of departure of this paper is that spatial demand preferences and environmental conditions may induce creation of lead markets, (Ghoshal & Bartlett, 1990). This paper discusses the lead market concept as a spatial process and explains how some spatial regions adopt the innovation at initial phase and lead the rest of a country. Furthermore, we argue that, what Beise (2004) defined as basic attributes for the lead market role, price advantage, demand advantage, transfer advantage, export advantage and market structure advantage, drive some particular spatial regions in a country to take the lead in diffusion.

The diffusion of photovoltaic systems (PV) in Germany is used as empirical case because of two main reasons. Firstly, regions in Germany follow different patterns of PV diffusion whilst a homogenous national policy. Secondly, it represents the largest market in the world, having 32 percent share of global PV installed capacity (GTAI, 2013). In 2012, Germany was the top country in terms of newly connected photovoltaic systems; followed by China, Italy, the USA and Japan (EPIA, 2013). However, there is much to understand about spatial dimension of PV diffusion in Germany. Apart from this introduction, the paper consists of other four sections. Section 2 presents the theoretical framework about the spatial dimension of lead markets. Section 3 explains the research methodology and section 4 gives an overview about diffusion of PV in Germany. Based on the empirical data, section 5 presents the spatial lead markets of PV and discusses the spatial-specific attributes. Finally, Section 6 presents the conclusions with policy and industrial implications.

2. THE LEAD MARKET CONCEPT

2.1. Evolution and applications of the concept

The lead market concept (Beise, 2001, 2004) analyzes the rate of innovation diffusion in countries over time. In the vast literature on innovation and policy studies, the concept has played an important role in shedding lights on the role of demand-side factors on diffusion (Quitzow, Walz, Köhler, & Rennings, 2014), particularly for environmental innovations (Karakaya, Hidalgo, & Nuur, 2014). The theoretical underpinnings of lead market concept has family resemblance with the diamond model for the competitiveness of nations (Porter, 1990), which explains the driving factors for the competitive advantage in particular industries as: input or resource conditions (human, knowledge, physical etc.), demand conditions, supporting and supplying industries, firm strategy and structure, politics and chance (crisis and opportunities). Beise (2004) argues that lead market concept can be interpreted as an extension of Porter´s demand conditions factor for competitive advantage. Focusing on demand, particularly on diffusion curves, Beise (2004) classifies the drivers of a country to be a lead market as: price and cost advantages, demand advantage, transfer advantage, export advantage and market structure advantages. Based on different innovation designs competing on the world market, he identifies that a lead market is followed by lag markets, resulting in diffusion of an innovation in globe (see Figure 1). A lead market does not necessarily represent the country where the invention takes place, but the country where the diffusion of innovation takes off before innovation spreads globally.

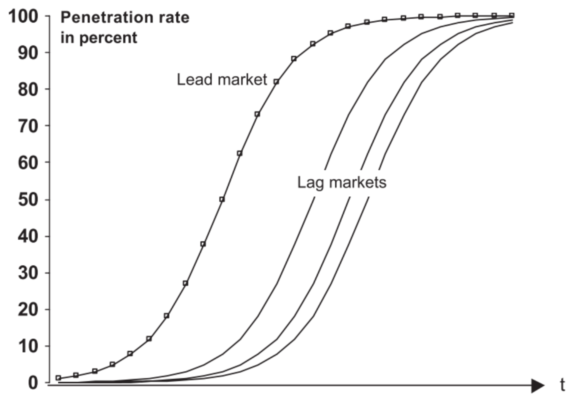


Figure 1. Lead markets vs. Lag Markets for diffusion of innovations (from Beise, 2004)

Not surprisingly, the lead market concept shares the features of other concepts that have been developed in the field of innovation studies. The dominant design, as introduced by Utterback (1994), is the focal point of the lead market concept. It explains the competition of alternative designs for an innovation, serving for the same need or function. In the same manner, Lead Users concept (von Hippel, 1986) helps to explain the demand advantage of lead markets. Lead users are the ones whose present needs will become general in globe. They can serve as a forecasting laboratory, providing the design of an innovation that will be adopted by the rest. To some extent, Vernon's (1966) seminal work on international product cycle also corresponds to the explanation of lead market concept, which explains how a high income level in a county enables an innovation to diffuse earlier than other counties with low income levels.

Since the lead market concept was introduced to the literature (Beise & Rennings, 2005; Beise, 2001, 2004), it has been a special interest of many scholars. Although the concept has some limitations (such as lack of understanding supply side influence and limited relevance for global contemporary industries, see Quitzow et al., 2014), it has been applied to several cases in the literature, including ecological innovations. However, these studies have the same spatial unit of observation, i.e. country[1]. The spatial dimension of diffusion at sub-levels has been ignored. Table 1 summarizes the studies that have applied Beise´s lead market concept.

Table 1. Applications of Beise's (2004) Lead Market Model

Study by	Aim	Empirical Case(s)	Spatial Unit of Observation
(Beise & Cleff, 2004)	Assessing the potential of countries to be the lead market	Two innovation projects of DaimlerChrysler	Country
(Lehrer, 2004)	Identification of the potential lead markets	Third-generation (3G) wireless networks	Country
(Beise & Rennings, 2005)	Extension of the concept for eco-innovations	Wind energy and fuel-efficient passenger cars	Country
(Jacob et al., 2005a)	Analyzing the international diffusion patterns	Photovoltaic solar energy	Country
(Jacob et al., 2005b)	Analyzing the political frameworks for international diffusion	Volatile Organic Compounds Reduced Paints	Country
(Beise, 2005)	Assessing the specialization of countries in international trade	Fax machines and Internet	Country
(Cleff, Grimpe, & Rammer, 2007)	Assessment of the likelihood of adoption of different innovation designs in EU	Automotive, Chemicals, ICT and Machinery Industries	Country

[1] There are some studies in regional level (Zubaryeva, Thiel, Barbone, & Mercier, 2012; Zubaryeva, Thiel, Zaccarelli, Barbone, & Mercier, 2012). However these studies do not apply the model of Beise (2005).

(Cleff, Grimpe, & Rammer, 2009)	Assessment of the likelihood of adoption of different innovation designs in EU	Energy Production	Country
(Tiwari & Herstatt, 2012)	Assessing India’s potential as a lead market	Cost-effective frugal innovations	Country
(Bär, 2013)	Analysis of the lead market potential of Germany and China	Electric Vehicles	Country
(Cleff & Rennings, 2013)	Analysis of the global market	Refrigerators	Country
(Horbach et al., 2014)	Exploring the potential lead markets	Clean coal technologies	Country
(Köhler, Walz, Marscheder-Weidemann, & Thedieck, 2014)	Assessing the potential lead markets	2nd generation biofuels for aviation	Country

2.2. The spatial dimension on the concept

Economic geographers have pointed out that location, in cognitive and physical terms, is key in understanding innovations (Boschma, 2005). The regions may become the innovation hub for either the supply or demand side, or sometimes for both. In regards to supply side, the recent literature have focused different aspects on innovation, emphasizing the importance of spatial dimension about development of innovations systems (Oinas & Malecki, 2002), implementation of innovation policy (Nuur, Gustavsson, & Laestadius, 2009) and emergence of new industries (Brachert, Cantner, Graf, Günther, & Schwartz, 2013). For example, in the European Union, twelve core regions, which are subnational spatial araes of the member states, accounted for “islands of innovation” for research and technological development (Morgan, 2004). On the demand side, the spatial factors are vital as well. Externalities that support diffusion are local (Hägerstrand, 1967) and the diffusion of innovations is determined by the local factors which can be heterogeneously spread in a country (Brown, 1975). Such heterogeneity in a country may induce some spatial regions to lead the rest of country in terms of diffusion of an innovation, followed by international diffusion. The literature has identified how spatial characteristics influence the patterns for diffusion of innovations. There are a myriad of examples that point to this: in the US, New York and Massachusetts were the leading states to adopt the policy innovations (legislative programs of welfare, health etc.) before other states (Walker, 1969). In the same token, the states of Montana and Wyoming were the leading states to adopt home food freezers (Ormrod, 1990). In Sweden, lake Sommen in the south and Lake Åsunden in the north were the leading geographic areas in terms of number of automobile ownership (Hägerstrand, 1967).

The lead market concept consists of five demand side attributes, which we discuss in a spatial context. Such discussion allows us to provide a framework to evaluate lead market role of spatial regions. The first attribute of a lead market is price and cost advantage. Price and cost advantage is mostly based on economies of scale through mass production (Beise, 2004) and also determined by spatial conditions. Cost of an innovation can vary in a country depending on local characteristics such as transportation infrastructure, availability of suppliers, natural resources, regional policies or availability of complementary goods. For example in Egypt, southern coastal region has the lowest costs of electricity delivered by an off-grid photovoltaic system (Szabó, Bódis, Huld, & Moner-Girona, 2011). In the USA, the lowest levelized cost of wind energy is in the Midwest region (Lazard, 2013). In some cases, spatial characteristics influence innovation's relative affordability indirectly. A case in point is the adoption rate of residential air conditioning, which depends also on the electricity price which can vary from state to state in a country (Ormrod, 1990). The price advantage can be one of the most important spatial lead market attributes, as adopters' decisions can be often based on economic profitability (Rogers, 2003).

The second attribute of the lead market framework is demand advantage which relates to environmental factors that increase the demand for adopting a particular innovation. Demand advantage could originate from spatial characteristics. A good example is the airline industry, where the demand for air transport significantly depends on spatial area (Graham, 1998). Another example is the demand for higher education; at which decision of prospective students depend on spatial factors, e.g. distance to university (Sá, Florax, & Rietveld, 2004). Demand differences usually arise from income level (Beise, 2004). However, demand advantage may also originate from natural endowments as discussed by Marshall (1890) more than a century ago. A case in point is wind energy in Turkey. Marmara region in Turkey has the highest annual wind density and therefore offers the highest return on investment for adopters (Oğulata, 2003). Besides, there are further factors that influence the demand for innovations, such as, among others, environmental issues, social dynamics and energy supply security issues. These factors may affect the potential adopter and therefore explain differences in local adoption patterns.

The third attribute is the transfer advantage, which is described as the ability of a country to shape the preferences of other countries (Beise, 2004). From a spatial point of view, transfer advantages could be spatial characteristics of a location. In this context, spatial diffusion of innovations depends on the intensity of communication between spatial areas (Hägerstrand, 1967). If the innovation is embraced in one region, it will spread from one region to another region in national and international levels. Transfer advantage is directly related to observability, the degree to which results of an innovation is visible to others (Rogers, 2003) and so called “demonstration effect” (Kalish, Mahajan, & Muller, 1995). The rate of diffusion of an innovation increases when the benefits of it are easier to see. Reputable adopters or markets, that adopt the innovation at initial phase, create credibility for the innovation and reduce the risk of adoption for laggards and lag markets (Beise & Cleff, 2004; Rogers, 1962). For example, Facebook has been adopted initially in the Ivy League universities, eight elite institutions in the Northeast region of the US, before it spreads in the US and then worldwide.

The fourth attribute is export advantage which is traditionally explained by three factors: similarities between local market conditions, export experience of local firms and demand push (Beise & Rennings, 2005; Beise, 2004). First, diffusion is importantly influenced by cultural similarities (Strang & Meyer, 1993). Innovations are easier to export from one spatial area to another if these spatial areas are similar to each other. Second, export experience of companies varies from local area to local area as well. For example in Germany, export quota vary from 16% to 45% depending on the region, where Saarland region has the highest export quota (SLBW, 2013). Third, local adopters can be more sensitive to global problems than potential adopters in other spatial regions. This kind of spatial demand push can trigger the local companies and potential adopters to meet global challenges ahead to companies and potential adopters in other regions.

The fifth attribute is market structure, which is mainly associated with competition. Porter (1990) indicates that national competitive advantage arises from competition in internal market. From a spatial perspective, the role of spatial location is vital for competitive advantage (Porter, 2000) and market formation dynamics (Dewald & Truffer, 2012). The spatial forms of technological specialization and comparative advantages are often originated from subnational formations such as regions and clusters (Morgan, 2004). Spatial proximity of actors is important to form cooperation for innovation (Asheim & Gertler, 2005). The companies located in competitive markets are under pressure to develop market-oriented innovations. Google for example, one of the largest companies in global internet industry, is located in Silicon Valley on the south of San Francisco Bay Area in the US, a leading geographic hub for high-tech innovation.

3. METHODOLOGY

Our empirical point of departure is the case of diffusion of PV in Germany, which is the global leader in this field (EPIA, 2013). Our analysis consists of three steps: diffusion curve analysis at spatial level, an extensive field work and assessment of lead market attributes.

In the first step, PV diffusion data is taken from the Information Platform of four German Transmission Network Operators for the Renewable Energy Sources Act (EEG) and the Combined Heat and Power Act (KWK-G). The empirical scope has two dimensions: time and spatial. In terms of time, the unit of analysis is year (t) and time span is from 2000 to 2012. For the spatial dimension, the boundary is Germany and the unit of analysis is zip code areas (i) defined by Deutsche Post AG, the main postal service provider in Germany (see Figure 2). The advantage of using zip code zones is to have relevantly uniform distribution of population and area for each geographic zone, which is a common practice in economic geography studies. The dependent variable, which is time and spatial dependent, is the number of installations rather than capacity of installations. For comparison reasons, we use the normalized cumulative diffusion number $\rho(t,i)$, calculated by dividing the number of installations in a spatial area $d(t,i)$ by its population $p(i)$,

$$\rho(t,i) = \frac{d(t,i)}{p(i)} 100$$

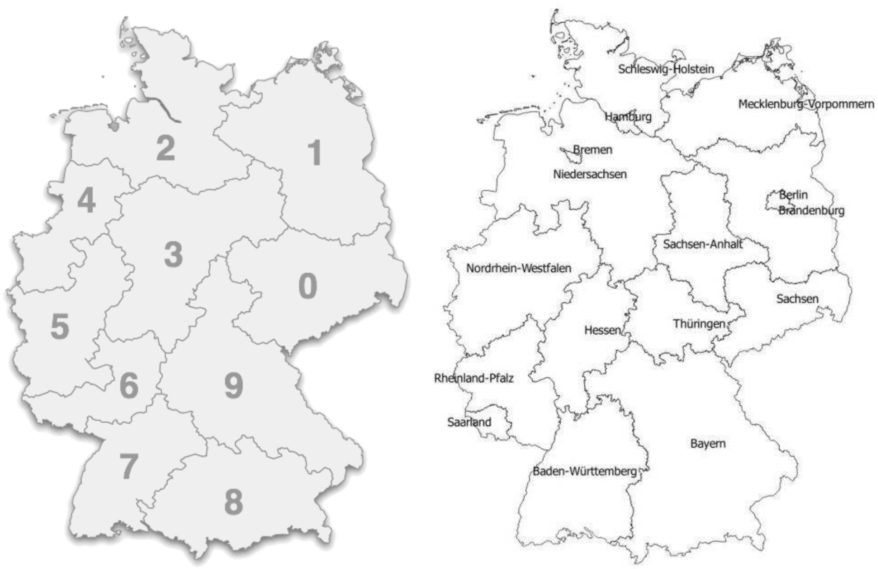


Figure 2. Geographic Zip Code Areas and States in Germany

In the second step, an extensive field study in the defined lead market of solar photovoltaics (PV) in Germany has been conducted. It consisted of a 3-month field work (from December 2012 to February 2013) and semi-structured interviews with both adopters and suppliers. The author was based in the company, Hartmann Energietechnik GmbH (HET), a PV system supplier located in zip code area 7, in Rottenburg am Neckar. The company gave unlimited access to its resources. One of the authors also attended to a 2-day-long regional workshop and interviewed with the directors of four other local system suppliers, which are located in zip code zones 7 and 8.

The last step assesses the lead market attributes in spatial dimension, providing evidence on the assumption that the region with the advantageous lead market attributes is most likely to become the spatial lead market. In order to tackle this, several indicators are identified based on the field work. The indicators are then retrieved by Federal and Regional Statistical Offices of Germany and the other studies (Berthold, Kögel, & Kullas, 2009; Drücke, 2004; Kost et al., 2013). Each indicator is categorized according to the five attributes model of lead market concept. The method is an indicator-based comparison on regional-level, approximating the lead market attributes. Because the attributes cannot be observed directly, we exemplify them with proxies (see Beise & Cleff, 2004). In addition, the indicators are mapped spatially via QGIS 2.0.1 Software, which is an open source geographic information systems (GIS) program that provides spatial data analysis. Such visualization enables us to interpret the data deeply.

4. PV DIFFUSION IN GERMANY

PV has an important contribution for electric power supply in Germany. In 2012, PV systems generated 5.2% of Germany´s electric power consumption on average, covering almost 35% of current consumption on sunny days (Wirth, 2013). Since 2004, PV diffusion has had the fastest growing rate, far front of other renewable energy sources in Germany.

The main driver of PV diffusion in Germany was the German Renewable Energy Act (EEG) which was firstly implemented in the year 2000 (Dewald & Truffer, 2011; Jacobsson & Lauber, 2006). EEG is a nationwide act and it applies same in all geographic regions in Germany. It supports PV adopters through three feed-in tariff schemes depending on the capacity of PV installation: small (less than 10 KWp), medium (between 10 and 40 KWp) and large (more than 40 KWp). The small size PV has the largest diffusion in Germany in terms of number of installations. Figure 3 presents the numbers of yearly installations in Germany in three segments. As an accumulation of all three segments, the number of yearly installations has increased from 9k in the year 2000 to 259k in the year 2010. However, it decreased first to 215k installations per year in 2011 and then to 184k installations per year in 2012.

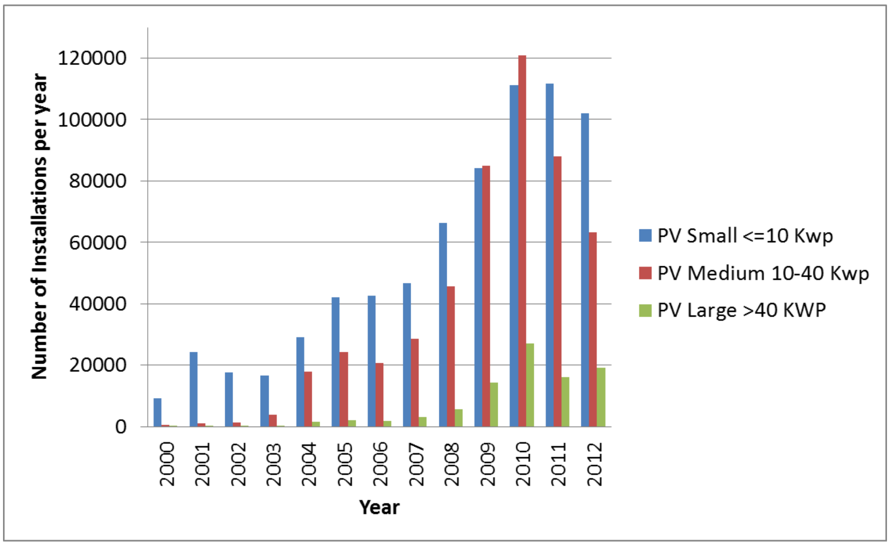


Figure 3. Numbers of yearly PV installations in Germany

Based on a case study the city of Wiesbaden in Germany, Müller & Rode (2013) showed that the adopters' decision for installing PV systems are positively influenced by previously installed PV systems that are located nearby. This phenomena is known as peer effect (see Bollinger & Gillingham, 2012). Dewald & Truffer (2012) also studied the case of market formation in Germany through technological innovations systems perspective and highlighted the positive role of local German associations for successful market formation process. This is highly associated with the complementary goods and services that depend on spatial dimension (Fabrizio & Hawn, 2013).

The continuous decrease in number of PV installations between 2010 and 2012 directly influenced the system suppliers. Turnovers of many local PV suppliers have decreased tremendously, not only because of the declined number of installations, but also because of the decreased price of PV modules. However, the diffusion paths of PV installations are not the same all over the country. Depending on the location, different diffusion trajectories can be observed.

5. RESULTS AND DISCUSSION

5.1. Diffusion curve analysis

Diffusion curve analysis provides information about whether there are some spatial areas in Germany that adopted PV early and facilitated the diffusion over the country. The results indicate that the PV diffusion in Germany has typical patterns of a lead market at spatial level. The spatial diffusion curves of PV between 2000 and 2012 shows the fact that some geographic zones had a leading role in the country (see Figure 4). This spatial lead market includes zip code area of 7 (a region composed of Stuttgart, Tubingen, Freiburg, Konstanz, Baden-Baden), zip code area of 8 (a region composed of Munich, Rosenheim, Augsburg, Ulm, Ingolstadt) and zip code area of 9 (a region composed of Nuremberg, Wurzburg, Erfurt, Weimar, Eisenach, Bamberg, Bayreuth). The diffusion curves of spatial lead and lag markets for PV (Figure 4) have the similar trajectory to Beise´s (2004) lead market concept discussed in section 2.

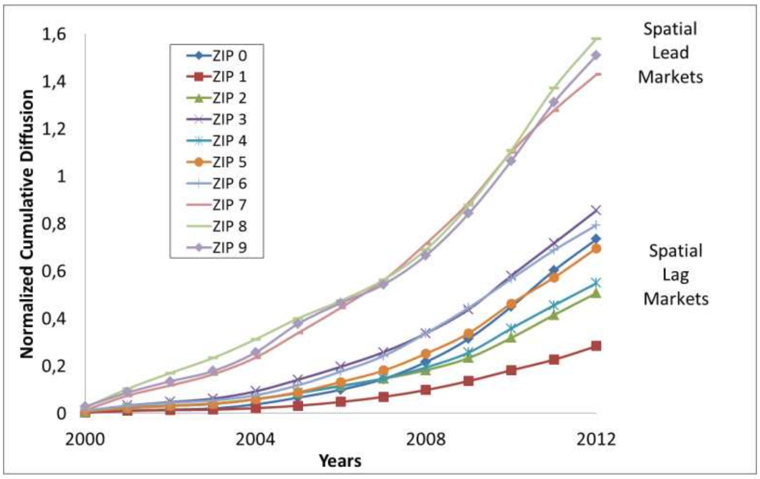


Figure 4. The spatial diffusion pattern of PV in 10 zip code areas of Germany

The spatial lead markets of PV have a rapid growth in the initial phase whereas the spatial lag markets have been catching up in the later phase. As illustrated in Figure 5, the lead markets (zone 7, 8 and 9) grew faster than the lag markets (zones from 0 to 6) between 2000, the year German Renewable Energy Act (EEG) was implemented, and 2004, the year the first amendment EEG was carried out. After 2004, the growth rate of lag markets took over the lead markets. This contradistinction between spatial growth rates of PV in Germany appears to be same as what the lead market concept explains.

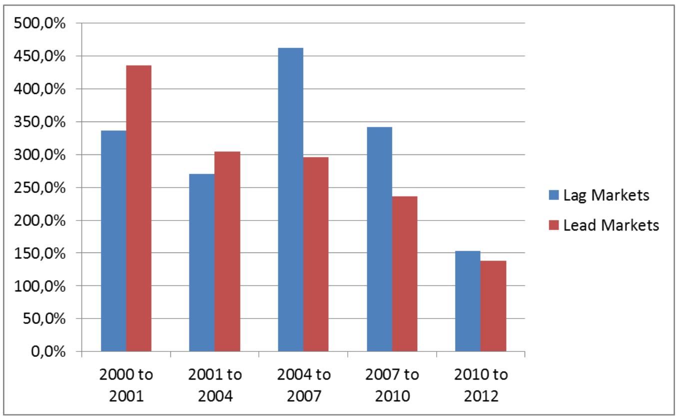


Figure 5. The growth rate for cumulative number of PV installations in Germany

5.2. Field study

The field study at Hartmann Energietechnik (HET) in Rottenburg am Neckar (a town of approximately 43000 habitants) supplied insights from the lead markets for PV (zip code zone seven, eight and nine). The case of HET is interesting for several reasons. Firstly, HET is located in zip code zone seven and it has partner companies in both zones seven and eight. Secondly, Rottenburg am Neckar represents an important case, as its PV diffusion rate, calculated as normalized cumulative diffusion number $\rho(2012, i)$, is higher than the average: 2.6 PV installations per 100 capita (see Table 2 for comparison). Thirdly, the history of HET goes back to 1990s and the company has witnessed and contributed to the PV growth in the neighborhood.

Table 2. Normalized cumulative diffusion number for PV as of 2012

Lag markets (zip code zones 1 to 6)	0.5
Lead markets (zip code zones 7 to 9)	1.5
Rottenburg am Neckar (Zip code: 72108)	2.6

The spatial area, where Rottenburg am Neckar lies, is a well-known region in Germany, and called as "Swabia". It is a cultural, historical and linguistic area, representing a major part of the lead market of PV diffusion. A special dialect of German, Swabian (Schwabish) is spoken in the region. The region struggled with poverty and scarcity until the beginning of 20th Century. Swabians are famous for hating debt, avoiding extravagance and getting the best deal (The Economist, 2014). They are also known as hard-workers, as one old saying expresses "Schaffe schaffe, Häusle baue" , which means you should work hard.

Based on the observations and interviews conducted through the extensive field work, we can draw several comments on lead market attributes from the perspectives of adopters and suppliers in the lead market.

- As Rottenburg am Neckar belongs to what we call lead markets for PV, it has an advantageous levelized cost of electricity (LCOE), thus cost advantage, in compare to lag markets. In addition, many interviewees indicated that the geographical proxy between HET and potential adopters resulted in extra decrease in LCOE due to the low transportation costs of PV Systems.
- Rottenburg am Neckar is surrounded by several villages and this geographical area is dominantly full of single/double family houses rather than multi-family apartments. There are many farmers in the surroundings; living as single families with a relatively large lands, which creates a demand advantage in this region. Interviewees explained that people usually consider adopting a PV system once they have their own properties, i.e. their own single family houses. In addition, it was observed that environmental awareness and financial stability are important factors for adoption decision of some citizens.
- Solar-Partner Association (e.V), co-founded by HET in 1990s as an association with four local partner companies located in zone seven and eight, has stimulated the market formation in local context. The association offers annual meetings and several workshops. In addition, HET organizes monthly 3-hour solar-walks, free to participate for anybody interested. It has attracted several people (both potential adopters and other suppliers from other regions and countries), making these informative solar-walks to take place every month since 2001. Some interviewees indicated that these efforts (both from Solar Partner Association and HET) have

created stimulation for PV diffusion in the region, what we relate to transfer and market structure advantages.

The field work provided not only information about how relevant the lead market advantages in local context are, but also additional perspective about other technologies that could have competed with PV technology. A good example could be solar thermal, a technology producing thermal heat from solar radiation. Number of yearly solar thermal installations was around 15k in Germany, whereas it was 18k for PV in 2012. The field work showed that adopters usually decide between PV and solar thermal. In some cases, they decide to adopt both, e.g. PV for half of the roof and solar thermal for the other half. However in some cases, they choose either of them. According to the number of yearly installations, the time period that PV had the highest growth corresponds to the time period that solar thermal had the sharpest decline. From 2008 to 2010, the number of yearly installations of PV has increased 120%, whereas the number of yearly installations of solar thermal decreased 45% as the sharpest decline in its history. This contradiction supports the argument that PV and solar thermal compete with each other, at least to get a place in the roof as the capacity of a roof is often limited.

5.3. Lead market attributes

It is a challenge to find regional data on indicators that proxy the lead market factors. Table 3 presents a set of indicators that approximate the lead market attributes for diffusion of PV in Germany. The choice of indicators are based on the case study (see Section 5.2) , relevant literature that use the lead market concept (e.g., Beise & Cleff, 2004; Horbach et al., 2014) and data availability.

Table 3. A system of indicators that proxy lead market attributes for PV

Lead Market Attributes	Available Indicators as Proxy
Cost Advantage	[LCOE] Levelized cost of electricity from PV [a], 2012 (€/KWp)
Demand Advantage	[Green] Green Party Support [b], 2009 (%)
	[Unemployment] employment Rate [b], 2010 (%)
	[Housing] House/apartment Ratio [b], 2011 (%)
Transfer Advantage	[MNC] Headquarters of multi-national companies
	[R&D] R&D Expenditure Index [c], 2009
Export Advantage	[Specialization] Krugman Specialization Index [c] , 2009
	[Export] Export Quota [b], 2012 (%)
Market Structure	[Business] Business Registration per 1000 capita [b], 2009 (%)
Advantage	[Capital] Capital Stock Index [c], 2009
	[Initiatives] Number of Solar Initiatives per capita [d], 2004 (%)

Sources:
(a) Kost et al., (2013)
(b) Statistische Ämter des Bundes und der Länder
(c) Berthold et al., (2009)
(d) Drücke (2004)

Cost advantage

Levelized cost of electricity (LCOE) [LCOE] is an indicator that expresses the cost of electricity generation over the years. It is based on the initial capital, solar radiation, continuous operation costs, service life time and costs of maintenance. Decreasing LCOE results in increasing cost advantage. As solar radiation and the complementary goods´ costs vary between geographic zones so do LCOE for PV. The lead markets of PV in Germany, mainly zip codes areas of seven and eight, have a relatively higher solar radiation and therefore lower LCOE of PV. As indicated by LCOE, cost advantage partially explains why PV systems firstly diffused in some particular spatial regions, what we call as lead markets of Germany. However, there are also some other regions, whilst a higher solar radiation, identified as lags markets for PV in Germany, e.g. the zone six. The cost advantage does not necessarily explain the diffusion of an innovation comprehensively. It should be analyzed along with the other lead market attributes.

Demand advantage

We choose three indicators to proxy the demand advantage that spatial regions may have. First indicator is the support for green party (Alliance '90/the Greens) [Green], calculated as the percentage of green party´s votes in national parliamentary elections in each region in 2009. Green party explicitly supports renewable energies in a political manner. Second indicator is the unemployment rate as of 2010 [Unemployment]. Decreasing unemployment rate results in increasing demand advantage. Third indicator is house/apartment ration [Housing], expressing the ratio of single and double family houses to total number of houses in the region. The families living in single or double family houses are expected to adopt solar PVs more than the ones living in multi-family apartments. Following the Rogers' (2003) categorization about decisions on adoption, we expect that optional decisions (e.g. the case of single-family houses where the adopting individual has almost complete responsibility for the decision) are much easier to take rather than collective decisions (e.g. the case of multi-family apartments where the individual has only a say in the decision). Members of multi-family apartments are less likely to take the decision for PV adoption, as it requires the approval of each family in the house. As a combination of three indicators, we see that lead markets in Germany (mainly zip code areas of seven and eight) have a relatively higher demand advantage than the rest. Therefore, demand advantage of spatial lead markets appear to be important for rapid diffusion of PV in these geographic zones in Germany. In addition, the lead regions are the ones with the highest innovativeness (Berthold et al., 2009). Innovativeness gives rise to demand to adopt innovations. Innovative individuals and societies are relatively earlier in adopting new ideas than other members of a social system (Rogers, 2003).

Transfer advantage

Transfer advantage relates to the ability of a region to shape the preferences of other geographical regions. We use two indicators to proxy the transfer advantage in regions. These are the quantity of headquarters of multi-national companies [MNC] and research & development expenditure [R&D]. The lead markets for solar PV in Germany have relatively higher number of MNC and higher R&D expenditure. For example, Bosch, Daimler, SAP, Festo and BMW are from this geographical area. In addition, transfer advantage is relevantly depended on the observability and visibility of the technology. In Germany, the spatial lead markets for PV host many well-known international events, such as the world's largest solar technology fair, the Inter-solar.

Export advantage

Export Advantage has three dimensions: similarities between local market conditions, export experience of local firms and demand push. Firstly, the similarities and communication intensity between markets have proved to be relevant, as both lead and lag markets share the common regulations, among others, the same feed-in tariff in Germany. The installed PV systems are similar specifications all over the country, creating export advantages for spatial lead markets. Secondly, the companies in the lead markets had a long tradition in exporting technologies to other regions and countries. Thirdly, the national demand for environmental innovations creates an advantage for spatial lead markets of PV. In order to proxy export advantage, we use two indicators: Krugman specialization index [Specialization] and export quota [Export]. The larger the value of Krugman specialization index, the more this region is specialized. Higher export quota values express the higher export advantage of these regions.

Market structure advantage

In order to proxy the market structure advantage of each region, we use three indicators. The first is number of business registration per 1000 capita [Business]. The second is capital stock index [Capital]; and the third is the number of solar initiatives that were established until 2004 [Initiatives]. Local solar initiatives play a vital role for market formation and successful growth (Dewald & Truffer, 2012). The most of the pioneer solar initiatives in Germany was located in zip code areas seven and eight, what we call as lead market. The lead market is the geographical area with the highest capital stock index and relatively high business registration ratio.

Cross-regional comparison

In order to support the argument that lead markets could be driven by spatial-specific market advantages, we need to aggregate the indicators of lead market attributes. Because of the weights for each lead market attribute is unknown in the literature , we use a simple method (similar to Beise &

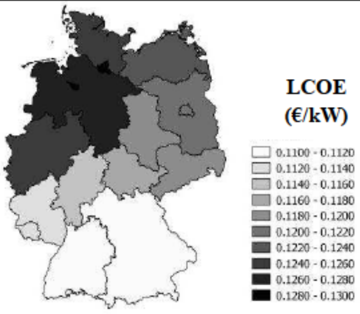
Cleff, 2004). We rank the each indicator per region and calculate the mean as shown in Table 4. Bayern and Baden-Württemberg (representing the major geographic area of identified lead markets-which are zones 7, 8 and 9) have the highest rankings at most of the lead market attributes. In addition, we map the lead markets factors in spatial level in Table 5.

Table 4. Ranking of indicators for each region

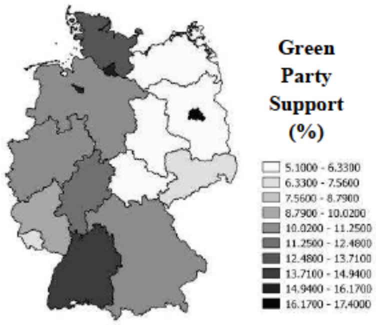
	Baden-Württemberg	Bayern	Thüringen	Schleswig-Holstein	Hamburg	Niedersachsen	Bremen	Nordrhein-Westfalen	Hessen	Rheinland-Pfalz	Saarland	Berlin	Brandenburg	Mecklenburg-Vorpommern	Sachsen	Sachsan-Anhalt
1/[LCOE]	2	1	6	12	16	14	15	13	5	4	3	10	9	11	7	8
[Green]	4	7	14	5	2	8	3	9	6	10	11	1	13	15	12	16
1/[Unemployment]	2	1	10	7	8	6	13	9	4	3	5	16	11	15	12	14
[Housing]	9	5	8	3	15	4	13	12	7	2	1	16	6	11	14	10
[MNC]	2	1	6	9	6	4	9	3	5	9	9	6	9	9	9	9
[R&D]	1	2	12	11	4	6	5	9	3	8	13	7	14	16	10	15
[Specialization]	9	4	11	8	15	2	10	1	7	3	5	16	13	14	6	12
[Export]	4	6	11	12	2	7	1	9	13	5	3	16	14	15	8	10
[Business]	8	4	15	5	2	11	9	7	3	6	14	1	12	13	10	16
[Capital]	3	1	16	8	2	10	6	11	4	7	5	9	13	12	14	15
[Initiatives]	3	2	8	15	1	4	6	7	11	13	10	5	14	9	12	16
Average	2	1	13	10	5	6	8	9	3	4	7	11	14	15	12	16

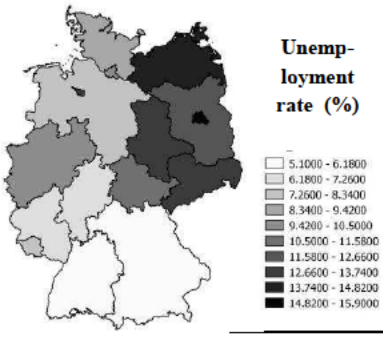
Table 5. The spatial visualization of lead market attributes

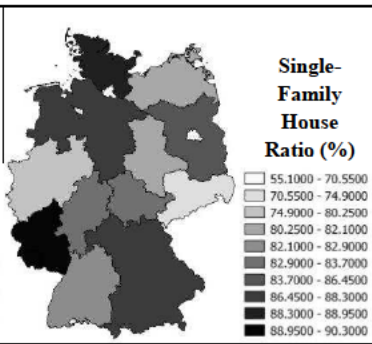
Cost Advantage



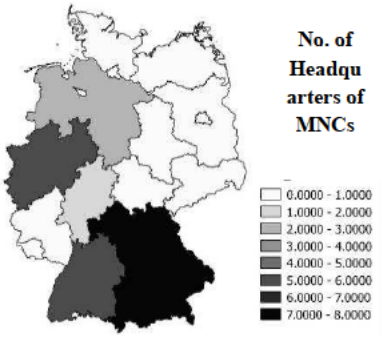
Demand Advantage

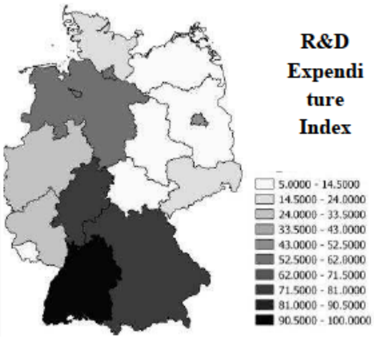




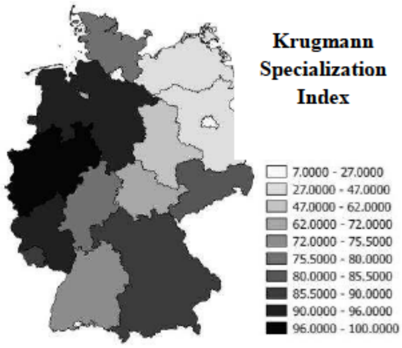


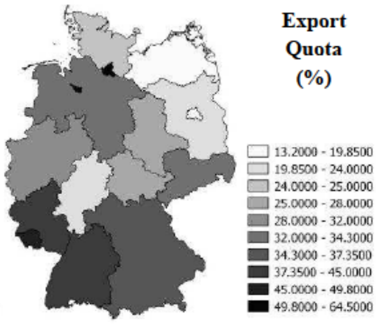
Transfer Advantage



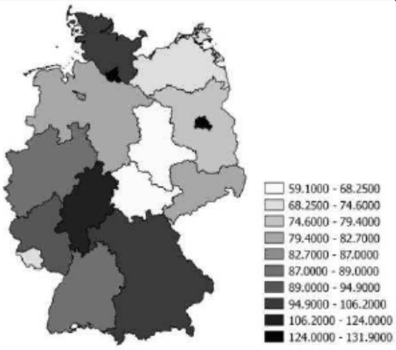


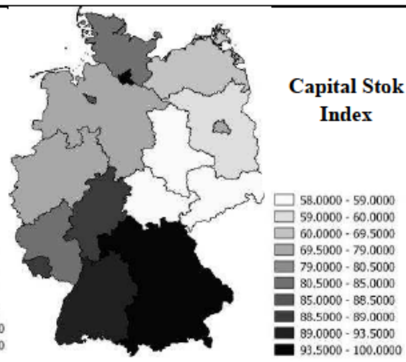
Export Advantage

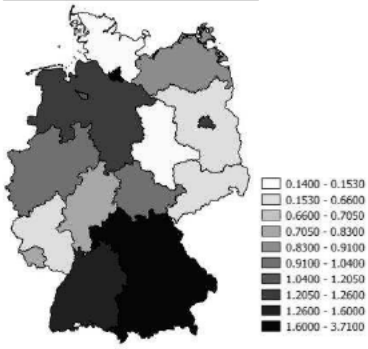




Market Structure Adv.







6. CONCLUSIONS

Innovation studies have long discussed the geographical patterns and important factors behind the diffusion of innovations. Lead Market concept (Beise, 2004) describes the demand side factors of diffusion, explaining how some countries become leaders for adoption of particular innovations. However, studies on Lead Market concept have suffered from lack of explaining sub-national markets. In this paper, we investigated the spatial dimension of diffusion patterns, providing a theoretical extension of lead market concept supported with an interesting empirical contribution.

This study explained how some regions could become the lead markets for particular innovations at subnational level. Based on the case of PV diffusion in Germany, we identified the regional lead markets and assessed the importance of spatial-specific attributes for each region. We also showed that how lag markets in PV in Germany grew faster than lead markets in the later phases, as evidence to the theoretical roots of Lead Markets concept. The theoretical implications of our study are twofold. First, we develop a spatial perspective extension on lead markets concept, which has been neglected in the literature to date. Second we provide empirical contribution, showing that lead markets can exist at sub-national levels and these spatial lead markets have a higher level of the lead market attributes: demand advantages, price advantages, export advantages, transfer advantages and market structure advantages. All lead market advantages appear to have some relevance to spatial dimension.

Our findings are particularly important for policy makers seeking to influence the diffusion of environmental innovations through regulations and subsidies. Our study shows that country-level policies do not perform in the same manner in all regions of a country. This means that it may be critical for the governments to design regional level policies if a rapid diffusion of environmental innovations is needed. For companies, we can derive some recommendations as well. When an innovation is adopted by a regional lead market successfully, companies may consider of entering to the lag markets, as the diffusion rate in the lag markets will then take off too. This means that monitoring the spatial paths of diffusion of innovations may help companies to revise their market strategies.

This study, nevertheless, has some limitations that we consider as future research. For example, finding regional level indicators is a challenge and there is no common agreement in the literature how to choose and aggregate the indicators. Therefore, further research can examine revising and extending the indicators used for lead market attributes of PV at sub-national level. Moreover, scaling down the unit of observation can provide new insights, i.e., using two digits of zip code zones instead of one digit. For further future research purposes, it will be also important to apply the lead market concept with its spatial dimension to additional cases, where different innovation designs compete with each other. We hope that this study will provide additional insights to further theoretical development of lead market concept.

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