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Forging high-technology: Organizational configurations of organic electronics in seven countries

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Abstract

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1) State-of-the-art and theoretical argument
A cluster is a ?geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities? (Porter, 1998: 199). Although the cluster concept is often used broadly and fuzzy (Rosenfeld 1995; Hofe and Chen 2006), clusters increase the productivity of firms located inside, they drive innovation, and enable new businesses (Porter 1998). A number of elements, besides the aspect of geographical concentration, have been identified as being important to the composition of a cluster. Universities, large corporations, SMEs, start ups and star scientists are prominent examples in the literature. Together, the combination of these ingredients defines the composition of a cluster and leads to a specific innovation capacity. Innovation capacity is the ?ability of the cluster to generate the key innovations that are relevant to competitive advantage in the industries in question? (Enright 2003: 101). Previous studies attribute one or two factors as being decisive for a cluster?s success. We argue instead that it is the interaction of different factors simultaneously driving clusters and their respective innovation capacity. This is in line with Fiss (2007: 1181) stating: ?configurational approaches [?] are based on the

fundamental premise that patterns of attributes will exhibit different features and lead to different outcomes depending on how they are arranged.?.

2) Research gap

This paper answers two research questions. First, is there a difference in how clusters are organized in various nation-states? Second, does a difference in cluster organization and structure have an effect on the innovation capacity of the respective cluster?

3)Method

To answer these two questions, this paper uses a comparative analysis of eight different clusters. We came up with this sample by asking 22 experts both from academia and industry to identify the most important clusters on one technology, organic electronics, worldwide. Holding the technology constant across cases allows us to compare clusters and to find out commonalities and differences among cases. The interviewees have a long personal history in the technology and some of them belong to leading organizations in the field of organic electronics. This generated the sample of eight clusters. We subsequently interviewed these experts on key characteristics of each cluster in a semi-structured way asking first what they think was remarkable in each cluster. Thereafter, we asked about the technological focus of each cluster, the cluster composition, the research done there, and relevant organizations in the cluster. Interviews took place during the year 2012 and 2013. Later on, we grouped the information and gathered further data on each cluster from business reports, strategy documents, government reports, academic articles, internet homepages, and newspaper articles. From these data, we compiled eight mini-case-studies, one on each cluster. These case studies highlight the most important aspects of each cluster. The nation-states, the organizational configuration, and the approach to the technology vary. The technology is constant. This enables us to contrast the similarities and differences of these clusters and lays out patterns among these clusters. To compare these cases more systematically, we also executed a Qualitative Comparative Analysis (QCA).

4) Results

From our eight case studies we can clearly conclude that cluster composition is different across the world in organic electronics.

The QCA revealed two necessary conditions for high cluster innovation capacity. First, having a university in place is an essential component. Second, an industry structure consisting of start-ups and SMEs also proves to be necessary for successful clusters. Both factors are present in cases with a high innovation capacity and we argue that those enable cross-level innovation processes. The advantage of QCA is that it allows analyzing cluster configurations with low innovation capacity. In doing so, we are able to identify causal conditions that limit cross-level innovation processes in high-technology clusters.

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Forging High-Technology: Organizational Configurations of Organic Electronics in Seven Countries

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It does not only matter whether an organization is located inside or outside a cluster; it also matters where the cluster itself is located. This paper looks at a nascent technology, organic electronics, and compares different approaches to this technology in various nation-states. Almost all of these efforts are concentrated regionally in clusters within each country. While the literature on clusters usually emphasizes the regional environment inside a cluster as the main driver of growth and technological advancement, we highlight the importance of both cluster composition and the wider national environment. This leads to a more nuanced picture of cluster composition. The study takes spatially concentrated centers of organizations, universities, and research institutes and fleshes out commonalities and differences of these clusters. It applies case study methods and Qualitative Comparative Analysis (QCA) to generate more systematic insights. It turns out that when holding the technology constant across cases, there are enormous differences in how the technology is approached. Additionally, organic electronics as an emerging technology works as a blueprint of national understandings about how to organize a technology efficiently and the paper identifies three different categories of cluster composition. Those have also consequences for the innovation capacity of clusters.

INTRODUCTION

New technologies have two key characteristics. First, they are social efforts in which many organizations partake to create a market turning inventions to innovations and later into products and applications. Technologies are based around a technical core consisting of patents and distributed elements of knowledge with no single organization possessing all. This calls for companies to coordinate their activities so that they can establish first a niche for the technology and later a whole industry. Simultaneously, corporations compete with one another for customers and market share. Second, technologies are not intrinsically defined in terms of their content and structure. A technology enables a variety of products.

The internet for instance enables communication, e-commerce, social networks, and mobile banking among others. In early stages of a technology it is also unclear whether and how a technology will be turned into a market at all. Organic electronics is such an industry based on a nascent technology. The industry of organic electronics is still fluent with its content, products, the product categories and its main features undefined. Today, even the name of the technology is undecided. Sometimes, organic electronics is called plastic electronics. Other times printed electronics, flexible electronics, or large area electronics. Organic electronics is a disruptive technology (Christensen 1997) with a predicted market size in excess of $ 300 bn by 2030 (IDTechEx 2009). Hence, many nations try to turn organic electronics into a market and in most cases, this happens in clusters where economic activity is spatially concentrated. However, these clusters vary with regard to their composition, their structure, and the involvement of the government and represent various approaches to organize a technology.

We study clusters on organic electronics for three reasons. First, there is no research on clusters in this specific technology yet and this paper occupies a research gap. Second, much research on technology clusters takes well established industries such as ICT (Breshnahan, Gambardella, and Saxenian 2005) or biotechnology (Powell, Koput, and Smith-Doerr 1994; Powell, White, Koput, and Owen-Smith 2005; Whittington, Owen-Smith, and Powell 2009) that are already successful in the market and looks at how clusters are organized. This entails a selection on the dependent variable bias since it takes both a mature technology and well developed clusters and analyzes them. Finally, since organic electronics is a nascent technology, there are no best practices how to organize the technology and each nation will adopt an approach that seems to them the “natural way of doing things”.

This paper answers two research questions. First, is there a difference in how clusters are organized in various nation-states? Second, does a difference in cluster organization and structure have an effect on the innovation capacity of the respective cluster? To address these questions, this paper uses a comparative analysis of eight different clusters ranging from Asia (South Korea, Japan) and Europe (e.g. Germany, Finland) to the United States (Silicon Valley). It lays out the similarities and differences how these clusters are structured and organized. The technology, organic electronics, is constant across these eight cases and is in its early stages. The nation-states, the organizational configuration, and the approach to the technology vary. This enables us to contrast the similarities and differences of these clusters and to lay out patterns among these clusters. Additionally, holding the technology constant across cases also enables us to flesh out national differences in the approach to organize a new technology on its way to the market. As this paper demonstrates, it does not only matter whether a single firm is located inside a cluster or not. It also matters where the cluster itself is located.

The paper is structured as follows: First, we briefly review the literature on clusters, their configuration, and their key characteristics. Second, we introduce the technology of organic electronics and introduce the eight clusters in mini-case-studies. In order to compare cases more systematically, we use Qualitative Comparative Analysis (QCA) to contrast the cases and to find patterns. Finally, the paper concludes with insights about how technology is organized differently across the world.

LITERATURE REVIEW

Cluster Definition and Cluster Advantages

A cluster is a "geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities" (Porter, 1998: 199). Although the cluster concept is often used broadly and fuzzy (Rosenfeld 1995; Hofe and Chen 2006), clusters increase the productivity of firms located inside, they drive innovation, and enable new businesses (Porter 1998). Main arguments for clustering are economies of scale, specific factor conditions, knowledge externalities, environmental conditions, and high-technology entrepreneurship. The key characteristic of a cluster is geographical concentration. This holds true, according to the cluster literature, wherever the cluster itself is located.

Furthermore, arguments on industrial clusters stem from a variety of academic fields and the cluster literature overall fragmented (Baptista and Swann, 1998; Krugman, 1991; Martin and Sunley 2003; Porter 1990) proposing a wealth of arguments in favor of clusters. Overall, densely populated region are more central and therefore more innovative than are areas in the periphery (Fritsch 2003: 79). The cluster literature in general (Almeida and Kogut 1999; Baptista and Swann 1998; Audretsch and Feldman 1996; Porter 1998) could show that innovation activity in general is locally concentrated. Nevertheless, these arguments do not take into account where the respective cluster is located and they describe processes and mechanisms in a cluster as being universal.

Cluster Elements and Cluster Environment

A number of elements, besides the aspect of geographical concentration, have been identified as being important to the composition of a cluster. Entrepreneurs drive cluster formation and are considered as a critical element in the formation of regional clusters (Feldman, Francis, and Bercovitz 2005). High technology start ups are founded close to essential resources like venture capital, skilled labor, or complementary ventures (Stuart and Sorenson 2003). Previous studies showed how start ups foster the development of biotechnology clusters (Feldman and Francis 2003; Powell, Koput, and Smith-Doerr 1994; Powell et al. 2005). Small and medium sized enterprises (SMEs) are a main actor in the cluster development process, as they drive incremental innovation and complement both start-ups and large firms in their activities (Karaev, Koh, and Szamosi 2007; Audretsch 2001; Khan and Ghani 2004). Large firms can also be drivers of innovation (Audretsch 2001). Universities are at the heart of clusters (Rothaermel and Ku 2008; Petruzelli 2011), and are a source of knowledge transfer (Agrawal 2001). They supply high quality graduates (Sohn and Kenney 2007). Overall, universities increase innovation in clusters (Garnsey and Heffernan 2005; Agrawal 2001; Schiller and Diez 2010; Sohn and Kenney 2007; Rothaermel and Ku 2008; Petruzzelli 2011). Star scientists, leading figures in their academic field, help to diffuse crucial knowledge in a cluster(Garnsey and Heffernan 2005). Hence, they are a starting point of regional systems of innovation (Niosi and Banik 2005). In addition, star scientists create riskier ventures (Corolleur, Carrere, and Mangematin 2004) and investors perceive star scientists' affiliation to a start up as a quality indicator for the respective firm (Higgins et al. 2011). Finally, government support can be crucial to induce cluster formation, innovation and growth (Feldman and Francis 2003; Mattsson 2009; MacNeill and Steiner 2010; Lundequist and Power 2002). The following table 1 summarizes crucial cluster elements identified by previous literature.

Insert Table 1 about here

Together, the combination of these ingredients defines the composition of a cluster and leads to a specific innovation capacity. Innovation capacity is the "ability of the cluster to generate the key innovations that are relevant to competitive advantage in the industries in question" (Enright 2003: 101). The studies cited above however attribute one or two factors as being decisive for a cluster's success. We argue instead that it is the interaction of different factors simultaneously driving clusters. It is the specific combination of elements together with the wider cluster environment that is key. Since, as Saxenian (1989: 450) notes, "by focusing solely on the resource attributes of the locality, the high-tech recipe overlooks the complex relationships between politics and markets which shape economic outcomes. […] However, there exist few systematic studies comparing different clusters around the world." And "the prevailing approach to high-tech regions locates the determinants of growth in the attributes of the regional environments" (Saxenian 1989: 448). Our argument is that clusters vary in their organizational structure and composition depending in which country they are located.

Comparative Research on Clusters

There exists a variety of comparative cluster studies looking at cluster composition, policy measures taken to promote clustering, and key mechanisms spurring cluster formation. There exist however few systematic studies. Bresnahan, Gambardella, and Saxenian (2005) for instance compare young growing clusters in ICT in the US, Ireland, Cambridge, Israel, India, among others. The majority of cases exhibit high entrepreneurial activity and the authors show that there is no single best way how a cluster is organized. Nevertheless, while they control for technology in their case selection, they do no compare clusters systematically across cases and variables. An example of a systematic comparative study is van der Linde (2003). He conducts a meta-study and analyzes 833 clusters in 49 countries and he finds large differences among clusters, e.g. North American and British clusters tend to be much larger than their equivalents in Europe or Asia. Though the study takes into account a multitude of clusters, there is no clear indication how cluster composition relates to innovation capacity. Ketels, Lindqvist, and Solvell (2006) studied 713 cluster initiatives in 71 countries and found a significant difference between clusters in liberal market economies (LMEs) as opposed to clusters in coordinated market economies (CMEs). Markusen (1996) compares different clusters in Brazil, the United States, Japan, and South Korea and finds considerable differences in the composition and governance of these clusters. Fritsch (2003) compares eleven European regions regarding their innovation systems but the paper does not control for the composition of the clusters outside R&D activites and does not take into account wider political or economic differences among countries.

The Importance of the National Environment

Different levels of analysis reveal how clusters are influenced also by their wider environment in which they are located. Saxenian (1989: 466) remarks: “Locations cannot simply choose ‘to grow the next Silicon Valley’. […] The development of an innovative region is not simply a matter of combining ingredients: it is dependent upon the broader political and economic environment”. Thus, a thorough analysis of clusters needs to take into account the broader environment in which a cluster is located. Systematic studies exist on nation-states and economic organization and how they vary. Hall and Soskice (2001) compare the political and economic institutions across countries and state that they vary systematically regarding their financial system, inter-firm relations, the labour management, and the vocational system. At the same time there are complementarities among the elements. Their framework, Varieties of Capitalism (VoC), aims at describing institutional similarities and differences across countries and the effect these differences have on the type of innovation activity. Hall and Soskice distinguish between liberal market economies (LMEs) and coordinated market economies (CMEs). In liberal market economies firms coordinate their activities mainly through the market place and hierarchies. In coordinated market economies (CMEs) the state has a strong role in setting standards in the marketplace. Coordination between firms depends strongly on business associations and trade unions and the financial system relies heavily on long term relationships and a strong banking system.

Whether a country is a LME or a CME has consequences for the kind of innovation that it can realize. Hall and Soskice discern radical and incremental innovation. Radical innovation is particularly needed in fast-moving and disruptive technologies such as semiconductors, biotechnology and organic electronics. Incremental innovation is key for maintaining competitiveness in heavy machinery and factory equipment. LMEs are well suited for radical innovation since they have high labor mobility, fewer restrictions on lay-offs, and dispersed ownership structure. Additionally, Hall and Soskice point out the importance of institutional complementarities including causal complexity and interaction effects.

So far, there have been few studies adopting the VoC framework to clusters such as Ketels et al. (2006) and Sternberg, Kiese, and Stockinger (2010). While Ketels et al. (2006) study over 700 cluster initiatives and shows a difference between LMEs and CMEs on clusters, they do not control for technology. Sternberg, Kiese, and Stockinger (2010) apply the VoC framework only to the cluster policy level and do equally not consider technology.

METHODOLOGY

This paper answers two research questions. First, is there a difference in how clusters are organized in various nation-states? Second, does a difference in cluster organization and structure have an effect on the innovation capacity of the respective cluster? To answer these two questions, this paper uses a comparative analysis of eight different clusters in South Korea, Japan, the Netherlands, the UK, Finland, the US, and two in Germany. We came up with this sample by asking 22 experts both from academia and industry to identify the most important clusters on one technology, organic electronics, worldwide. Holding the technology constant across cases allows us to compare clusters and to find out commonalities and differences among cases.

The interviewees have a long personal history in the technology and some of them belong to leading organizations in the field of organic electronics. This generated the sample of eight clusters in our study: Silicon Valley, USA, the cluster around Cambridge, UK, the cluster around Holst Center, the Netherlands, Yamagata Valley, Japan, Forum Organic Electronics, Germany, Organic Electronics Saxony, Germany, Oulu cluster around VTT, Finland and Crystal Valley, South Korea.

We subsequently interviewed these experts on key characteristics of each cluster in a semi-structured way asking first what they think was remarkable in each cluster. Thereafter, we asked about the technological focus of each cluster, the cluster composition, the research done there, and relevant organizations in the cluster. Interviews took place during the year 2010 and 2011. Later on, we grouped the data in a matrix with one column for each cluster and a row on technological coverage, regional density, coverage of a value chain, research strength, infrastructure, and others. Based on this matrix, we gathered further data on each cluster from business reports, strategy documents, government reports, academic articles, internet homepages, and newspaper articles. From these data, we compiled eight mini-case-studies, one on each cluster. These case studies highlight the most important aspects of each cluster. The technology, organic electronics, is constant across these eight cases and is in its early stages. The nation-states, the organizational configuration, and the approach to the technology vary. This enables us to contrast the similarities and differences of these clusters and lays out patterns among these clusters. To compare these cases more systematically, we also executed a Qualitative Comparative Analysis (QCA) which is described after the mini-case-studies and an introduction to the technology of organic electronics.

From the theory section, we extracted these variables and operationalized them in t he following way:

Insert Table 2 about here

Organic Electronics

Organic electronics is a new technology based on organic materials having electrical properties. The basic materials can be carbon molecules such as conductive polymers or small molecules and the technology consists of four broad areas: organic light emitting diods (OLED), organic photovoltaic (OPV), organic field emitting transistors (OFET), and organic sensors. While traditional electronics uses inorganic silicon as its main resource, organic electronics deploys organic resources like carbon polymers. Academic research on organic electronics started already in the 1950s and research done by Alan Heeger, Alan MacDiarmid, and Hideki Shirakawa, was awarded with the Nobel Prize in Chemistry in 2000. There are two broad schools on organic electronics, namely small molecules and carbon polymers. While small molecules must remain in powder form, carbon polymers can be placed in solution, which makes them printable. Small molecules need to be patterned through vacuum evaporation, which is both more difficult and more expensive. Printing techniques for polymers include inkjet and roll-to-roll printing just like newspapers production leading to low costs and high output. Nevertheless, product applications of the technology only exist in the form of prototypes or niche applications such as mobile phone OLED screens.

MINI CASE STUDIES

Silicon Valley, USA

Silicon Valley is the paradigm for a successful cluster worldwide. It is known for the local density of start-ups which is very high with over 22,000 companies employing 1.15 employees in 2005 (Joint Venture 2008). There is also a prominent venture capital scene including Sequoia Capital, Kleiner Perkins Caufield & Byers and Morgenthaler which provide seed and risk funding to promising business ideas. A further characteristic of the Silicon Valley are the densely tied networks of informal relations stemming from individuals often changing their job and while doing so taking with them tacit knowledge about new technologies. "Moving from job to job in Silicon Valley was not as disruptive of personal, social, or professional ties as it could be elsewhere" (Saxenian 1994: 35). She also adds that risk taking was highly valued and information freely exchanged enabling the diffusion of novel technologies and standards quickly. Additionally, Silicon Valley provides an environment of collective learning. This enables the region to generate radical innovation constantly, since the penalty of failure and the risk attached to founding a venture are lower than anywhere else. Breshnan et al. (2005) describe Silicon Valley as entrepreneurial, decentralized, and loosely coupled with only little connections to broader national institutions.

One main center of organic electronics is the Center for Advanced Molecular Photovoltaics (CAMP) at Stanford University, which is led by Profs. Michael McGehee. CAMP brings together leading scientists in the OE field, e.g. Prof. Jean-Luc Brédas, Prof. Bao or Prof. Michael Graetzler, the inventor of the Graetzler solar cell. Together these star scientists filed more than 100 patents. The center's research focus lies on OPV, OLED, as well as OFET and over 60 research students and post-doctoral fellows work here. In 2008 CAMP could secure $25 million over five years through collaboration with the King Abdullah University of Science and Technology (KAUST) in Saudi Arabia.

In order to increase the exchange with industry, CAMP offers an industrial affiliate program in which companies can send employees to the research sites to advance joint projects. Partners in this program include mainly resident SMEs or start ups but also selected international firms. A start-up in the field of organic electronics is Kovio Inc. which was founded in 2007. Kovio develops printed electronics devices that can be used for large area displays or solar cells. The origins of the firm trace back to the MIT Media Lab, but the company was founded in Silicon Valley due to the venture capital firm Kleiner Perkins Claufield & Byers that provided initial funding. The VC insisted the company was founded there so that Kovio could use Kleiner's network managers, scientists, and other VC firms (WashingtonPost 2007). Nanosolar and Vitey Systems are two examples of smaller local companies. The first is based in San Jose in the Silicon Valley and produces thin film printed solar cells. The second is also located in San Jose and developed barrier encapsulation, a technology that is important in OLED production to spate different layers. Vitey Systems was able to license its technology to Samsung and LG who use it in their manufacturing process. Southwall Technologies is a larger company located in Palo Alto next to Stanford University. It was founded in 1979 as a result of a government funded research project at the MIT and today the firm produces thin film solar cells based on flexible polymers. Other important companies in the field of organic and printed electronics are Fujifilm Dimatrix in Santa Clara producing ink printers which can be used to manufacture printed electronics and Parc, a subsidiary of Xerox, that is also active in the field of flexible organic electronics. Still, it is obvious that no large firm is proactively fostering the local cluster formation in the OE field.

Forum Organic Electronics around Heidelberg, Germany

One of two clusters in Germany that engage in this technology is the cluster Forum Organic Electronics around Heidelberg. The cluster itself is rather young and traces back to a cluster initiative driven by local corporations and research institutes and is funded also by the German government. In early 2008, the German DAX corporations BASF, Merck, SAP, Roche Diagnostics, Heidelberger Druckmaschinen, and Freudenberg together with the universities of Heidelberg and Mannheim founded the InnovationLab GmbH. All of them are located in or close to Heidelberg. InnovationLab in its original conception aims at exploring disruptive future technologies. In the course of the year 2008, InnovationLab was also considered a hub organization for a future cluster devoted to organic electronics. The focus on organic electronics was chosen due to three reasons. First, there were estimated of a future market for organic electronics in the size of €100 billion in ten years' time. Second, BASF in particular already had a strong interest in the technology and was funded by the German Ministry of Education and Research in an OLED initiative leading to a Joint Innovation Lab at the BASF facilities in Ludwigshafen. However, the company recognized that in order to realize a new technology they needed more partners. Third, there was the German "Leading-Edge Cluster Competition" (Spitzenclusterwettbewerb), a German governmental program to foster innovative cluster or cluster initiatives starting in 2007. The competition was to award € 40 million to five clusters each. In the course of 2008, InnovationLab formed a management team from its founding organizations that could attract 18 other organizations to form the cluster Forum Organic Electronics. The majority of cluster members are located around 90 kilometers around Heidelberg and the cluster consists of 14 companies, three of which are listed on the German DAX (SAP AG, Merck KGaA, and BASF SE). There are also nine universities and research institutes part of the cluster but among those the University of Heidelberg can be perceived as the main actor in cluster formation.

In 2008, the cluster was awarded with the German Leading-Edge Cluster competition and received €40 million of government funding over five years to advance research and product applications in organic electronics. Due to the requirements of the cluster competition, the member organizations of the cluster had to contribute to the budget and thus around €60 million were devoted resulting in a cluster budget in excess of €100 million over five years.

The cluster composition, the type of member organizations, both from business and science, and the funding structure which is both public and private, lead to a specific configuration of this cluster. Hence, the cluster has developed an own identity comprising a brand and a management entity. Additionally, the cluster has given itself a vision, which is to “become a world leader in the field of organic electronics by integration research, development, and production”. Furthermore the members of the cluster aim at promoting innovation in the field of organic electronics by enhancing the knowledge transfer inside the cluster by supporting start-ups. Finally, the objective is to be recognized as “one of the most attractive places for researchers and graduate students”. InnovationLab was designed as an “application-oriented research and transfer platform for business and science in the Rhine-Neckar Metropolitan region” (InnovationLab 2011).

Yamagata Valley, Japan

Japan is one of the main centers in organic electronics. Sony brought the first television based on an OLED display to the market in 2008. Konica Minolta and Panasonic are working on OLED lighting, but have not started mass production yet. Mitsubishi developed the largest OLED screen in the world with a size of 155 inches. While there are many decentralized activities in organic electronics in Japan, there are also geographical centers for the technology.

One of these clusters for organic electronics activities is Yamagata Valley. The valley is located around 350 km north of Tokyo around the city of Yonezawa. Three elements are crucial with regard to organic electronics. First, Prof. Junji Kido at Yamagata University invented the first white organic light emitting diode display in 1993, which is the basis for organic lighting panels. Furthermore, he invented a multi photon emission (MPE) OLED, increasing the lifetime and overall efficiency of the device which is one of the hurdles of the technology, in 2002. He also filed 161 patents in organic electronics during his career and is one of the leading scientists in the technology. Prof. Kido is head of a research group at Yamagata University that specializes in the development of new materials for OLED. Second, the major company Pioneer, has a manufacturing subsidiary, Tohoku Pioneer, in the valley and was the first to commercialize a white OLED panel worldwide while working closely with Prof. Kido. Finally, there are many other electronics and machinery in the region (Nozawa 2011:4).

In order to involve the private sector, the local government and Prof. Kido founded the "Research Center for Organic Electronics" (RIOE) in 2002. The idea was to let local firms use the research generated inside the university and transfer it to the market. This initiative also aimed at establishing a recognized cluster specifically grounded in OLED and is a collaboration of Yamagata University, companies, and government agencies. Later on, the Yamagata OLED valley emerged consisting of around 30 research institutes and companies. Local authorities supported the initiative with around € 370 million over seven years. During this time, many projects were carried out to commercialize OLED lighting and by 2006, four years after the initiative had started, there were 16 firms participating in the RIOE. However, 10 out of 16 firms were not from the same geographical region but had chosen to participate due to their own competencies in the field and the quality of research carried out at the center. Six firms were from Yamagata Valley. One of the companies resulting from this effort is Lumiotec, which was founded in 2008 by Mitsubishi Heavy Industries, Rohm Co, Toppan Printing Co, and Mitsui & Co together with Prof. Kido. The firm aims at developing and producing white OLED lighting panels and launched a white OLED for $450 in the fall of 2011. Lumiotec also has a manufacturing plant for OLED panels since 2009 in Yonezawa. The plant has a manufacturing capacity of 60,000 panels a year making it the first company having achieved mass production of panels (Lumiotec 2011). RIOE filed patents for 44 products overall, the Institute had 16 participating companies in 2006 with six of the being located in the region while the other came from across Japan. Nevertheless, entrepreneurship in the region is low and many large companies dominate the field of organic electronics in Japan (Nozawa 2011: 8).

For the whole of Japan, the New Energy and Industrial Technology Development Organization (NEDO) set up an OLED development plan in 2008 devoting 3.5 billion yen over five years to develop manufacturing technologies for OLED displays. The multinational corporations Sony, TMD, and Sharp are among the project partners.

High Tech Campus Eindhoven, the Netherlands

Eindhoven, a major city in the Netherlands, is home to the country's most promising high technology cluster, the "High Tech Campus". The driving force for this center was Philips who decided to spread R&D activities around its founding place in Eindhoven (HTCE 2011). Since 1998, the campus gradually developed a center for joint research and cooperative commercialization. Holst Center, located on-campus, fosters new technologies such as organic electronics. Together with Philips, the Eindhoven cluster is at the forefront in lighting and smart displays based on organic electronics. The cluster is mainly industry-driven with no university in place.

The Holst Centre defines itself as an independent open innovation R&D center established by IMEC[1] (Flanders, Belgium) and TNO[2] (Netherlands) with the Dutch Ministry of Economic Affairs and the Government of Flanders, in 2005. In 2004, the management of the Philips research division decided to adjust its strategy towards a stronger open innovation approach to foster collaborative research and innovation. In search for potential partners, Philips successfully approached IMEC and TNO to create an independent research center. Until today, the company remains among the most central and dedicated actors in the Holst Centre. Located in Eindhoven's High Tech Campus, a region with approximately eight thousand engineers and researchers, the Holst Centre has access to a variety of state-of-the-art on-site facilities (Holst 2011). First, MiPlaza as a division of Philips Research offers Holst R&D services and access to its infrastructure. Second, Holst experiences strong support from IMEC and TNO. Both provide easy access to their research facilities in Eindhoven, Leuven, and Delft. The center's core research focus is wireless technologies and large-area flexible electronics. The latter is considered as a cornerstone in the center's own research infrastructure. Since 2008, significant investments were made

[1] IMEC is a public research center and it is headquartered in Leuven, Belgium. Its research focuses on micro and nano-electronics. The institution collaborates with international companies and research organizations alike.
[2] TNO is an independent Dutch research organization offering services to private and public institutions. The organization has seven core research areas, e.g. Quality of Life, Science and Industry, Built Environment or ICT.

to build up complete manufacturing process on its roll-to-roll R&D line (Holst 2011).

While Holst is an independent entity, maintaining vital partnerships with industry and academia is at the core of its mission statement. Although a variety of strong national and international academic partnerships exist (e.g. Eindhoven University of Technology), neither an academic partner was involved in the founding process nor holds a stake in the Holst Centre. The collaborations are rather institutionalized through framework agreements, bilateral research projects, and the exchange of human capital (Holst 2011). Holst cooperates with major multinationals in the relevant fields, with Philips leading the way. As of 2011, over 30 corporate partners, covering the complete value chain, work with Holst. SMEs are considered as valuable to the cluster as they can contribute crucial application expertise.

Oulu cluster (VTT), Finland

VTT is the largest applied research centre in Northern Europe and highly active in the field of organic electronics. Among its 14 locations in Finland, the research site in Oulu is the largest (VTT 2011b). Here, the organization established one of its “spearhead research programs”, namely the Center for Printed Intelligence (CPI) (VTT 2011b: 33). Reacting to the increasing importance of organic electronics, the research center teamed up with University of Oulu and Oulu University of Applied Sciences to launch PrintoCent, an innovation program to boost Finland’s efforts in the domain of organic electronics. PrintoCent can draw on crucial technological know-how in paper, ICT and electronics. Since 2009, the Oulu region has positioned itself as the leading Northern European cluster in printed electronics. More than 40 industry partners joined the Oulu community to engage in pilot projects.

Established in 1942, VTT is a part of the Finish innovation system administered by the local Ministry of Employment and the Economy (VTT 2011a). In 2006, VTT aimed at combining multidisciplinary know-how in paper, ICT and electronics to advance its competence in printed intelligence. Basic level of funding got increased and within two years activities doubled (Ver-Bruggen 2008). In 2009, VTT and the Oulu-based universities launched PrintoCent, an innovation program and simultaneously a community for joint pilot projects. Since then, over 40 industry partners joined the community (Hast, Koivu, and Kopola 2009). Furthermore, PrintoCent is particular keen to encourage Finish SMEs in participation as CPI already gathered positive experience with SMEs in former research projects (VTTReview 2010: 35). The initial duration of this program is three years and the project budget adds up to over € 10 mill. Although companies invested in piloting, no significant financial commitment was made by a blue chip from a related industry. The majority of the funding is provided by public sources, e.g. the EU. In 2010, over 100 man-working years are devoted to PrintoCent's activities (Koivu 2011). This is considered as a critical mass and the CPI started to actively encourage its employees to search for spin-off opportunities (CPI 2010). It is the explicit target of the center to set up at least one start up each year. The first new venture, Nicanti, was already established in 2007 by VTT and two Italian companies in order to commercialize a VTT technology.

Organic Electronics Saxony, Germany

There is a considerable amount of industry and research on organic electronics around Dresden, Germany, and this cluster now encompasses more than 39 companies and 17 research organizations active in the organic and printed electronics. Today, the cluster claims itself to be the largest organic electronics cluster in Europe. In 2008, seven companies and three research institutes decided to launch a registered association, named Organic Electronics Saxony e.V. (OES). Its mission is to provide individual support, facilitate excellent communication, and to foster internal know-how transfer among its members. The association is headed by the board of directors, consisting of three chairmen. The board can appoint a full-time managing director for the operation of the Organic Electronics Saxony Management GmbH, the association's separate cluster management entity.

As of 2011, the registered association counts 26 member organizations, employing over 800 coworkers. All industry partners that are working on organic electronics are either SMEs or start ups. The cluster does not include a blue chip. The fact that Plastic Logic, a spin-off company from Cambridge University's Cavendish Laboratory, decided to open its factory for mass-production in Dresden proves that the cluster's unique conditions are recognized internationally. Besides industry partners, collaborations with research institutions and universities are essential for the cluster. Two leading application-oriented research organizations, namely the Fraunhofer Society and the Leibniz Association exhibit strong commitment with four and respectively three unique research centers on organic and printed electronics in Saxony (Pratap 2010). These centers collaborate with other partners in the cluster. For instance, in 2009, the Fraunhofer Institute for Photonic Microsystems (IPMS) founded in collaboration with the Zumtobel Group the joint-venture LEDON OLED Lighting GmbH & Co. KG (LEDON 2011). Local universities as academic partners also play a vital role in the OES network because they provide, among others, skilled labor and basic research. The Technical University of Dresden is one of the key promoters of the Dresden cluster: From the beginning, the university's Institute of Applied Photophysics (IAPP) conducted basic and applied research on organic semiconductors. Over the past years, the institute recorded several spin offs, e.g. Novaled AG, Heliatek GmbH, Creaphys GmbH, and sim4tec GmbH. The director of the IAPP, Prof. Dr. Karl Leo, holds a full professorship of optoelectronics at the Technical University of Dresden. He is a key person, as he is chairman of the Electronics Saxony e.V., the Deputy Director of the Fraunhofer Institute for Photonic Microsystems (IPMS), and was for several years chairman and member of the supervisory boards of local start ups like Heliatek GmbH and Novaled AG in the Dresden cluster (iapp 2011).

Over the years, OES has developed a track record of successful start ups (Pretap 2011). Even though OES articles of association point out that it receives membership fees to achieve the association's objective, governmental funding still constitutes the major source of financial support (OES 2011).

Cambridge Cluster, UK

The University of Cambridge has a strong focus on basic research resulting in 61 Nobel Prizes. Since the 1970s, when global demand for high-technology expertise and scientific equipment amplified and the region around Cambridge steadily developed from a non-industrial area to a high-tech cluster in the field of ICT, electronics, and biotechnology with a vibrant venture capital community. Today, this agglomeration is known as the Cambridge Cluster or the Silicon Fen. The University's Cavendish Laboratory developed a pioneering technology for plastic electronics on thin and flexible plastic substrates (PlasticLogic 2011). Based on these findings two spin-off companies were formed to develop marketable applications. Professor Sir Richard Friend, the Cavendish Professor of Physics at Cambridge University, has a pivotal role in Cambridge's undertakings in the OE field.

In the beginning, the University of Cambridge did not support entrepreneurial undertakings of its staff with university resources; however, it also did not hinder these kinds of activities as long as academic obligations and responsibilities did not suffer (Garnsey and Heffernan 2005). Although the regional agglomeration was apparent, the local and central government did not support the clustering process with additional grants, nor did they invest in local infrastructure (Simmie, Siino, Zuliani, and Jalabert 2004; Athreye 2004). Furthermore, the cluster formation could not benefit from strong resident blue chips, as those are absent in the Cambridge area (Athreye 2004). However, there is a vibrant VC community and Cambridge-based ventures received more VC funding than in any other region in Europe (Evans and Garnsey, 2009; Saxenian, 1989).

The Cavendish Laboratory (Department of Physics at the University of Cambridge) provides world leading basic research in the field of organic electronics. During the 1990s, the Optoelectronics Group of this renowned laboratory (29 Nobel Prize Winners) developed a technology for plastic electronics on thin and flexible plastic substrates (PlasticLogic 2011). Two spin-off companies were formed to develop marketable applications: Founded in 1992, Cambridge Display Technology (CDT) specialized in organic light emitting diodes (OLED) displays that employ light emitting polymer (LEP) technologies.

Since its establishment the company was VC-backed (CDT 2011). Initially CDT planned to position itself as a display manufacturer. However, the management realized soon that exceeding capital intensity and patent expiration urge the company to follow an IP licensing strategy and accordingly it started to license its IP to international companies such as Philips, Toshiba, or Osram (Seldon, Probert, and Minshall 2005). In 2004, CDT was the first Cambridge venture that announced an IPO on NASDAQ. The second Cavendish spin-off company, Plastic Logic, was founded in 2000 and uses organic transistors to enable flexible paper-like displays (CavendishLab 2008). The venture started its operations from the Cambridge Science Park and has now offices in various countries. In 2007, Plastic Logic received the highest single VC investment ever made in a European high-technology venture (Technopole 2011). One year later the company opened the world's first mass-production factory for plastic electronics in Dresden, Germany, while the company's headquarter remained in Mountain View, US (Jackson 2010). Professor Sir Richard Friend has a pivotal role in Cambridge's endeavors in organic electronics: He is the Cavendish Professor of Physics, is leading the optoelectronics and microelectronics research group, and co-founded both spin-offs (Cavendish 2010).

Crystal Valley Cluster, South Korea

Since 2002, South Korea positioned itself as the global leader in the display industry. A study from Displaybank revealed that South Korea's panel makers account for 53, 9% of the global TFT-LCD display market in October 2010 (KoreaITtimes 2010). There are two regions that primarily focus on the display industry: First, the area around the city of Paju (Gyeonggi Province) with LG and the region around the cities Asan-Tangjung-Chunan (Chungnam Province) with Samsung as the central display manufacturer. Asan and its surroundings is the pivotal cluster due to Samsung's worldwide leadership position, strong commitment of the local government, and the high concentration of vertically integrated SMEs (Yun, Park, Lim, and Hahm 2010). In contrast to other high technology regions like Seoul, there were no formal plans by the central and local government to establish a display cluster in Asan-Tangjung-Chunan.

Samsung's corporate strategy was to develop the first company-driven industrial park in South Korea. A special attribute within this development process was the proactive support of the local government, which accelerated construction time and eased complex administration procedures (Yun et al. 2010). Additionally, the government constantly invested in complementary infrastructure.

Samsung invests heavily in OLED displays. It founded Samsung Mobile Display Co. (SMD), responsible for Samsung's OLED operations. In 2007, Korea was at the forefront of OLED R&D holding 52.2% of all patents filed worldwide (OLEDinfo 2011). Samsung itself is the number one patent owner worldwide in this technology. SMD took advantage of the Asan cluster and located its R&D center in Chunan. In 2009, the company built the world's first mass production facility for active matrix (AM) OLED displays for mobile devices in the same city. Since then, Samsung is the world leader in the global OLED market, holding over 70% of market share .To meet growing demand for these displays, SMD invested an additional $2 billion to open a larger AM OLED manufacturing plant in Tangjung on May 31st 2011 (SMD 2011; FT 2010).

Similar to Samsung's operations in the TFT-LCD market, the company's cluster attracts SMEs. Smaller companies and start ups are also important to the Samsung SMD cluster: In 2009, SMD collaborated with several smaller firms to create 40 new AM OLED products. Furthermore, SMD supports smaller companies through a development fund. It offers financial support for R&D projects that create innovative technologies and subsequently new ventures. The start up Ness Display Co Ltd is focusing on OLED technology and is just one example for a successful new venture. Simultaneously, the local government plans to create a business start up program to encourage young students for this alternative way of employment (KoreaITtimes 2010). Hence, the Crystal Valley Cluster is developing to a breeding ground for start ups in the South Korean OLED industry.

Although the regional cluster contains five universities, such as Dankook University (Chunan) or Hoseo University (Asan), those institutions did not have an active role in the cluster formation (InvestKorea

2008). None of these universities conduct major basic research in the OLED field.

QUALITATIVE COMPARATIVE ANALYSIS (QCA)

Qualitative Comparative Analysis (QCA) is a method combining qualitative insights with quantitative comparison (Ragin 1987). The method is particularly suited for a sample size that is larger than a handful cases but not large enough to apply quantitative models. With a sample of eight cases, the case study methods fail, as comparison among cases becomes difficult to handle. Nevertheless, eight cases do not allow for quantitative modeling, as the sample is too small. Thus, QCA bridges the gap between qualitative case-oriented and quantitative variable-oriented research. The method is well suited to draw causal inferences from a small number of cases.

By discerning patterns of similarity based on holistic comparisons of cases and their specific configuration of causal conditions, QCA combines qualitative information with quantitative comparison. “Configurational approaches are based on the fundamental premise that patterns of attributes will exhibit different features and lead to different outcomes depending on how they are arranged.” (Fiss 2007: 1181). Hence, this approach is the foundation of “diversity-oriented research” (Kogut and Ragin 2006). QCA uses Boolean logic to represent set-theoretical relationships (Ragin 1987). Causal conditions (which constitute a set) can either appear or not appear in the given cases (they can be 0 or 1). In order to understand which of these conditions contribute to the cause of a certain outcome, the researcher uses a truth table. This happens after the selection of relevant cases and after specifying relevant attributes that might be causal. (Kogut and Ragin 2006).

In a truth table, each row includes a case and its configuration of causal conditions that are either present or absent (coded as 1 or 0). Each combination of these logical conditions represents a complex causal hypothesis that can either be empirically observed or not. The number of cases that are covered by each possible configuration is only important if it seems appropriate to define a frequency threshold, i.e. a minimum amount of cases required to be worth considered in the final truth table (Skaaning 2007). In studies with a relatively small number of cases, like in the study at hand, the standard setting for the frequency threshold is one case, implying that each case configuration is considered important. The development of the truth table occurs in an iterative process (Stokke 2007). The researcher has to investigate why certain combinations of factors lead to an outcome while others do not. In sum, QCA allows systematic comparison of case configurations entailing causal complexity as well as the identification of different patterns of causal conditions that all lead to the same outcome. Hence, researchers can make broad statements about the observed cross-case patterns without being restricted by homogenizing assumptions that are associated with purely quantitative methods (Kogut and Ragin 2006).

QCA Analysis/ Crisp-set

Based on the eight mini case studies we are now able to summarize the findings in a truth table. This table facilitates all information in a dichotomized form, meaning that causal conditions and outputs are either present (coded as 1) or absent (coded as 0). The aim is to identify patterns of similarities and differences among cases. Crisp-set qualitative comparative analysis (fsQCA) is an appropriate empirical method to systematically compare cases. This technique considers each case as a combination of causal conditions that are linked to an outcome (Ragin 1987).

Table 3 illustrates the causal configurations of the eight organic electronics clusters in our sample. The outcome variable in question is innovation capacity of the cluster. In order to answer this question we investigate six causal conditions in a cluster which were derived from the relevant literature: coordinated market economy with substantial government funding, liberal market economy, blue chip, SME/ start up, key person, and university. The first two factors indicate the prevailing type of market economy and whether the government funds the cluster substantially. The following two display the business composition of a cluster and the last two factors stand for the presence of proactive key individuals and universities with a substantial role in the regional clusters. Six causal conditions can generate 64 (2^6)

logically possible combinations of these conditions. Although logically possible, some combinations are not observed in the real world. This and the fact that all but one case in our model stand for an individual combination makes us confident that our analysis will yield adequate results. Table 3 illustrates the truth table for all OE clusters in our sample.

Insert Table 3 about here

The truth table reveals that two positive cases, Silicon Valley and Cambridge, exhibit the same configuration of causal conditions. Therefore, we can handle those as one case and reduce the table to seven cases. The table shows three cases with high innovation capacity and four cluster configurations with low innovation capacity. Moreover, no contradictions occur within the sample, which adds further credibility. For compactness, the following equation uses abbreviations for each causal condition. According to previous literature, upper-case letters specify presence and lower-case letters absence of these conditions. Mid-level dots stand for intersections of sets and the addition signs for unions of sets. Based on the mentioned reduction from eight to seven cases, we are already able to present a reduced equation:

(I) INNOVCAPACITY= cme.govfund * LME * bc * SME.SU * KP * UNI +
CME.GOVFUND * lme * bc * SME.SU * KP * UNI +
CME.GOVFUND * lme * BC * SME.SU * kp * UNI

From this equation it is evident that all clusters with an established product in the organic electronics market comprise a university (UNI) and a business structure consisting of SMEs and start ups (SME.SU). This condition is related to the logic of necessary and sufficient conditions. Kogut and Ragin (2006: 48) stress that “a necessary condition always subsumes the set of outcomes. There may be cases in which a necessary cause is present but there is no effect, but there is never a case in which the effect is present but the necessary cause is not.” Accordingly, we can consider both as necessary (but not sufficient) conditions for a cluster's high innovation capacity. Additionally, the equation proves our initial assumption that there is more than just one pathway for successful cluster configuration. Although equation (I) has some explanatory value it is our aim to further reduce the expression to uncover more general patterns within the sample. We use QCA software[3] and minimization rules for simplifying complex Boolean statements. First, we apply methods of agreement and difference for the whole expression and compare each term to identify pairs that are similar in all their causal conditions except one. In this case the distinctive condition is redundant since both terms yield the same outcome (Ragin 1987: 93). Following this approach we identify that the prevailing type of market economy (LME and CME.GOVFUND) fulfill the requirements for this minimization rule in one pair and thus we replace both as redundant conditions in order to work towards a more general statement:

(II) INNOVCAPACITY= bc * SME.SU * KP * UNI +
CME.GOVFUND * lme * BC * SME.SU * kp * UNI

While equation (II) is simplified, it is still relatively complex. Even though we are not able reduce further primitive expressions we can rewrite equation (II) in order to simplify complexity:

(III) INNOVCAPACITY= UNI * SME.SU * (bc * KP + CME.GOVFUND * lme * BC * kp)

From this expression one can draw new conclusions. In our sample seven out of eight clusters comprise a university, and six out of eight exhibited a settlement of SMEs and start ups. This makes it comprehensible that the first round of minimization identified UNI and SME.SU as necessary conditions for a cluster's successful product establishment. Still, there are two pathways which complement both factors to facilitate the intended output: First, in clusters with no large companies (bc), the presence of a key person (KP) will lead to a successful output, irrespective of the prevailing market economy (cf. Silicon Valley and OE Saxony). The second path points out that clusters in coordinated market economies

[3] Downloaded at: http://www.u.arizona.edu/~cragin/fsQCA/software.shtml

(CME.GOVFUND) will profit from the presence of a large company (BC) and the absence of a key person (kp) (cf. Crystal Valley).

So far we focused on the success cases in our truth table. In regards to methodology the negative cases are used to control for potential contradictions that might crept in during the specification process of the positive scenario. If this is not the case, then all necessary and sufficient conditions obtained there will only appear in those positive cases. Hence, we can assess validity of our model through the following equation:

$$\text{(IV)} \quad \text{innovcapacity} = \text{CME.GOVFUND} * \text{lme} * \text{BC} * \text{sme.su} * \text{UNI} + \text{CME.GOVFUND} * \text{lme} * \text{bc} * \text{SME.SU} * \text{kp} * \text{UNI} + \text{CME.GOVFUND} * \text{lme} * \text{BC} * \text{SME.SU} * \text{kp} * \text{uni}$$

No configuration from the positive cases appears in the negative scenario. Both necessary conditions for the positive outcome INNOCAPACITY are not necessary conditions for the negative example of successful product establishment. In order to simplify complexity we also rewrite this term:

$$\text{(V)} \quad \text{innovcapacity} = \text{CME.GOVFUND} * \text{lme} * (\text{BC} * \text{sme.su} * \text{UNI} + \text{bc} * \text{SME.SU} * \text{kp} * \text{UNI} + \text{BC} * \text{SME.SU} * \text{kp} * \text{uni})$$

For the negative cases in our sample the presence of a CME and the absence of a LME is a necessary but not sufficient condition. Again, all three terms in in the bracket do not contradict with the causal conditions in equation (III). Hence, we can provide evidence for model validity.

FINDINGS AND DISCUSSION

This paper has two research questions. First, is there a difference in how clusters are organized in various nation-states? Second, does a difference in cluster organization and structure have an effect on the innovation capacity of the respective cluster? To address these questions, this paper used a comparative analysis of eight different clusters ranging from Asia (South Korea, Japan) and Europe (e.g. Germany, Finland) to the United States (Silicon Valley).

OE Cluster Variance

From our eight case studies we can clearly conclude that cluster composition is different across the world in organic electronics. While South Korea for instance has a long history in cluster policy dating back to the 1970s and the South Korean corporation Samsung is world-leading in the field of OLED mobile displays, other clusters such as the one around Heidelberg are a recent phenomenon and are currently focusing on basic research without any production or even prototypes. Furthermore, the role of the government is very different. In Silicon Valley the government has almost no role in the cluster and networks between Stanford University's CAMP and start ups are crucial. These examples proof that the clusters differ in their configuration and the mini cases illustrate that it is difficult to identify patterns among cases.

General OE Cluster Patterns

In order to derive more detailed conclusion from these differences we relied on QCA to compare the cases and their conditions systematically. Thus, we found several patterns. One pattern is that some clusters have both a high innovation capacity and have already placed products in the markets such as South Korea, Silicon Valley, Dresden, and Cambridge. Other clusters are still in their early phases and do predominantly basic research or develop prototypes. A further general pattern is also that all clusters except the one around Eindhoven do have a university at their center.

Moreover, there are three distinct cluster groups: The first group of clusters is located in liberal market economies and comprises Silicon Valley and Cambridge. Both clusters exhibit similar patterns with regard to strong reliance on a world-leading university, high entrepreneurial dynamism, and key persons in the field. Additionally, market exchange is important and there is little governmental support. Both clusters have launched products in organic electronics leading to a high innovation capacity. The second group of clusters has large corporations that are active in organic electronics through their past technological achievements. Samsung is the leading firm in the technology in South Korea and is both an important player in the display industry and became a leader in OLED mobile displays. Both German corporations Merck and BASF have competencies in materials production and are now driving cluster formation around Heidelberg. Philips has a long history in lighting and the cluster around Holst Center in Eindhoven concentrated on OLED. In Japan, Pioneer was the first one to commercialize a white OLED panel worldwide. All these clusters receive significant governmental support and are located in coordinated market economies where the state has a strong role. A third group are clusters in which applied research centers, bridging industry and research, play a strong role. In the cluster in Oulu, VTT, the largest multi-technological research center in Scandinavia, established the center for Printed Intelligence and is at the heart of the activities in organic electronics. In Dresden, two leading application-oriented research organizations, namely the Fraunhofer Society and the Leibniz Association together have seven research institutes on organic electronics in the cluster and the industrial structure consists largely of start-ups and SMEs.

OE Cluster Categories for High Innovation Capacity

The QCA revealed two necessary conditions for high cluster innovation capacity. First, having a university. Second, a industry structure consisting of start-ups and SMEs also proves to be necessary for successful clusters. Both factors are present in cases with a high innovation capacity. In the next step, we considered all conditions available and identified three general categories of cluster cases with a high innovation capacity. The first category, consisting of Silicon Valley and the Cambridge cluster, has exactly the same causal conditions. In both clusters there are many start-ups and SMEs, there is at least one key person in organic electronics, and there is a world-class university. The most important element that distinguishes these two clusters from all other cases is the fact that they are both located in a liberal market economies (LMEs). Thus, the market is the crucial force structuring economic activity. We will discuss the explanatory power of this later. The second category consists of the Crystal Valley in South

Korea. In this cluster one dominant element is Samsung as a world leading company in the technology serving an established market for mobile displays with its products. In fact, Samsung has also created this market. The other important element in this cluster is the South Korean government which has been supporting the clustering of large conglomerates since the 1970s. South Korea is a coordinated market economy (CME) where economic activity is structured heavily by the state. The third category is the cluster around Dresden. Dresden is also located in a CME, but the state is mainly active through the funding of applied research institutes which are numerous in the cluster. The industry structure consists of start-ups such as Heliatek and SMEs such as Novaled. There is also a key person in the cluster who is a senior researcher in the technology, holds a professorship in the local university, and is head of a research institute there. Hence, he is a central figure connecting multiple networks in the cluster. Both the South Korea and the Dresden cluster are different from the first category, Silicon Valley and Cambridge, in that the government has a strong role. However, in many other aspects South Korea and Dresden are different. Therefore, Varieties of Capitalism (Hall and Soskice 2001) can explain the difference between the first category of cases to category two and three. The theory cannot explain the difference between category two and three since both cases in these categories are CMEs.

Dobbin also calls for historical analysis. If we combine VoC arguments with Dobbin's call for historical analysis we can also explain why Silicon Valley and Cambridge are very similar to one another, while Dresden and South Korea are very different to both one another and to the first category. Both clusters in Silicon Valley and Cambridge have evolved over a long time period and both clusters were shaped through market forces. Market forces had two effects. First, although there might have been other 'possible' cluster in both countries, Cambridge and Silicon Valley were the only ones that survived and others we do not see today there. Second, since market processes shaping clusters take a long time these two clusters could achieve a high stability and serve as an ecosystem that supports the creation of new technologies. This is also what VoC predicts: LMEs are ideally suited to generate radical innovation such as organic electronics. South Korea has a long history in cluster policy. Equally, the national policy encouraged the evolution of large conglomerates. Both elements come together in the Crystal Valley. Contrasting the successful cases with those that were not able to bring a product to market adds further support to our argumentation. The QCA analysis for cases with low innovation capacity yields CME as a necessary condition. Clusters located in such market economies are much more likely to exhibit a low innovation capacity. This is also in line with VoC which states that CMEs are more likely to generate incremental and not radical innovation. Furthermore, all negative cases, except the Finland cluster, contain large companies.

Limitations and Future Research

Notwithstanding the theoretical contributions that this study makes, we have to note that it suffered from several limitations. First, this study is based on literature on clusters, which is fragmented and lacks coherent theory (Cruz, Aurora, and Teixeira 2010). Defining proper and comprehensive causal factors from theory proofed not to be easy. Future research should look into these single factors in more detail and examine their respective role in a nascent technology cluster. Second, the study at hand is based on an in-depth document analysis and required information regarding the cluster configuration was found for all cases. Still, understanding clusters, their configuration, as well as their actual development is a complex undertaking and some important factors are maybe neglected. Therefore, future research should go one step further and enrich the archival data by conducting field research and in-depth interviews with actors in each cluster.

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APPENDIX

TABLE 1: Key Elements in Clusters

Variable	Description	References
Innovation capacity	"Ability of the cluster to generate the key innovations that are relevant to competitive advantage in the industries in question"	Enright (2003)
Blue Chip (i.e. large & mature companies)	Develop close relationships with smaller firms in local clusters/ Identified as component of global clusters of innovation/ Strong complementarily with smaller firms in U.S. biotechnology clusters	Porter (2000)/ Engel and del-Palacio (2011)/ Audretsch (2001)
SME	SMEs are main actors in the cluster development process / Small firms exhibit strong complementarities with large firms in U.S. biotechnology clusters: they are a source of innovation/ Due to their specialization they help to spread risk among cluster firms	Karaev et al. (2007)/ Audretsch (2001)/ Khan and Ghani (2004)
Start up	Start ups are a critical element for cluster formation/ foster development of clusters/ Absorb more knowledge in geographic clusters / High technology start ups are established close to essential resources	Feldman et al. (2005)/ Feldman and Francis (2003)/ Gilbert et al. (2008)/ Stuart & Sorenson (2003)
Key Person (i.e. star scientist, core researcher)	Diffuse necessary knowledge in high-technology cluster/ Engage in riskier and more valuable start-ups/ Starting point of regional systems of innovation/ Knowledge gatekeepers in biotechnology clusters: more collaborators, better access to information and greater control over knowledge flow/ Their affiliation to a firm acts as quality signal to investors/ Core researchers are boundary spanners	Garnsey and Heffernan (2005)/ Corolleur et al. (2004)/ Niosi and Banik (2005)/ Boardman and Craig (2008)/ Higgins et al. (2011)/ Powell and Sandholtz (2011)
University	Knowledge spill-over/ source of innovation/ Application of research findings as a key mechanism for economic growth/ Key role in high-technology clusters is supply of high quality graduates/ critical ingredient for innovative performance in a regional technology cluster/ university- industry collaboration influences innovation outcomes	Garnsey and Heffernan (2005)/ Agrawal (2001)/ Sohn and Kenney (2007)/ Rothaermel and Ku (2008)/ Petruzzelli (2011)
Government funding	Incentives and infrastructure provided by government foster biotechnology cluster/ Explicit cluster policies implemented top-down by regional authorities to foster cluster activities/ Governmental cluster initiatives to boost innovation/ Clusters have been the most commonly adopted territorial innovation models by policy-makers	Feldman and Francis (2003)/ Fromhold-Eisebith and Eisebith (2005)/ Mattsson (2009)/ MacNeill and Steiner (2010)/ Lundequist and Power (2002)
Coordinated Market Economy	In coordinated market economies (CME) the state has a stronger role in coordinating economic activity leading to a strength in incremental innovation/ significant difference between clusters in LMEs as opposed to clusters in CMEs/ Varieties of Capitalism (VoC) framework is important for comparative cluster policy research because it emphasizes systematic variations between clusters in CMEs and LMEs	Hall and Soskice (2001)/ Ketels et al. (2006)/ Sternberg et al. (2010)
Liberal Market Economy	In liberal market economies (LME) in which the market has a strong role structuring economic activity leading to a strength in radical innovation/ significant difference between clusters in LMEs in contrast to clusters in CMEs/ VoC framework is important for comparative cluster research because it emphasizes systematic variations	Hall and Soskice (2001)/ Ketels et al. (2006)/ Sternberg et al. (2010)

TABLE 2: Definition and Operationalization of Key Elements in Clusters

Variable	Definition and Operationalization	
Innovation capacity	Construct from expert assessment of the strength of the cluster and the successful launch of at least one major product in organic electronics **1** if the cluster has high innovation assessment and significant product **0** if the cluster has low innovation assessment and no product	
Blue Chip (i.e. large mature firm)	Presence of blue chips in the cluster **1** if cluster is dominated by blue chips and **0** if blue chips are not important	
SME	Presence of SMEs in the cluster **1** if SMEs are defining the industrial structure of the cluster and **0** if not	
Start up	Presence of start ups in the cluster **1** if start ups are the main part of the cluster's industrial structure and **0** if not	
Key Person (i.e. star scientist)	Presence of a major scientist who has advanced the field of organic electronics **1** if there is such a key person in the cluster and **0** if there is not	
University	Presence of a university with significant research in organic electronics **1** if there is a university and **0** if there is no university in the cluster	
Government funding	The cluster receives substantial funding from the government **1** if there is substantial government funding and **0** if there is not	
Coordinated Market Economy	A type of capitalism in which "firm depend more heavily on non-market relationships to coordinate their market endeavors with other actors and to construct their core competencies" (Hall and Soskice 2001: 8) **1** if the country in which the cluster is located is a CME and **0** if not	
Liberal Market Economy	A type of capitalism in which "firm coordinate their activities primarily via hierarchies and competitive market arrangements" (Hall and Soskice 2001: 8) **1** if the country in which the cluster is located is a LME and **0** if not	

TABLE 3: Truth Table for Organic Electronics Clusters

Condition / Cluster	CME/ Gov.Fund.	LME	Blue Chip	SME/ Start up	Key Person	University	Innovation capacity
Silicon Valley/ Cambridge	0	1	0	1	1	1	1
VTT	1	0	0	1	0	1	0
Holst	1	0	1	1	0	0	0
Heidelberg	1	0	1	0	0	1	0
Dresden	1	0	0	1	1	1	1
Korea	1	0	1	1	0	1	1
Yamagata	1	0	1	0	1	1	0