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DOI
10.1016/j.indmarman.2016.07.007

Publication date
2017

Document Version
Final published version

Published in
Industrial Marketing Management

Industrial Marketing Management 61 (2017) 20–29

Contents lists available at ScienceDirect

Industrial Marketing Management

Global connectivity and the evolution of industrial clusters: From tires to polymers in Northeast Ohio

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ARTICLE INFO

Article history:
Received 3 May 2016
Received in revised form 4 June 2016
Accepted 22 July 2016
Available online 4 August 2016

ABSTRACT

Industrial clusters are a critical component of the competitive viability of economies around the world. However, clusters are not static but evolve in response to technology and competition. This process has garnered interest from scholars and from practitioners, with the focus primarily on local linkages and networks. Although global knowledge ties have the potential to fuel innovation, scant attention has been given to global knowledge connectivity in the context of cluster evolution. We analyze a comprehensive 30-year patent dataset (1975–2005) associated with the Akron industrial cluster in Northeast Ohio. The results also show that innovation in the cluster has survived in spite of a long-term decline in manufacturing activity and employment. The survival of innovation in the Akron cluster is driven by increasing specialization at the local level with an emphasis on technologies rather than products and growing connectedness to global innovation systems. A key implication of our study is the importance of anchor tenant multinational enterprises and research institutions in ensuring the persistence of local innovation through two key processes (a) orchestrating knowledge networks; and (b) spawning startup activity. We provide support for recent work in industrial marketing suggesting that network evolution has both deterministic and strategic aspects.

1. Introduction

Industrial clusters form the backbone of the economy due to their ability to support and sustain economic growth (Casper, 2007). The ability of a geographic location to reinvent itself can depend on the flexibility of that backbone and the strength of system connections. This is a critical area for new research, since in many advanced economies, the manufacturing clusters that supported their growth and prosperity in the nineteenth and twentieth centuries are not as robust as they once were. Some of these clusters have declined, while others have evolved in terms of the nature of the activities that are undertaken locally.

The importance of connectivity and collaboration to the economic viability of industrial clusters is well established (Hannigan, Cano-Kollmann, & Mudambi, 2015), but relatively few studies have measured global knowledge connections or assessed their role in cluster evolution. To illustrate and analyze the phenomenon of industry cluster evolution in a global knowledge-sharing context, we study the automotive tire cluster located in Akron, Ohio, and its evolution to become a polymer cluster. The transformation of Akron has been the subject of other recent studies (e.g., Scalera, Mukherjee, Perri, & Mudambi, 2014). We add value to this literature by examining multiple dimensions of cluster performance, and pay particular attention to the technology dimension and the role of global connectivity. This approach leads to new insights, not just about Akron, but more generally about industrial marketing management and industrial cluster evolution.

Clusters can evolve and change in surprising ways. Clusters have been defined as "geographic concentrations of industries related by knowledge, skills, inputs, demand, and/or other linkages" (Delgado, Porter & Stern, 2016, p. 38). The "driver industries" of a region are a cluster's main source of competitive advantage (Carlsson & Mudambi, 2003). Within such industries, clusters often exhibit a dependence on a few lead firms. However, while clusters are geographically immobile, firms are not. The immobility of locations, coupled with the mobility of firms, creates a conceptual and practical divergence between cluster evolution and industry evolution (Cano-Kollmann, Cantwell, Hannigan, Mudambi, & Song, 2016). Technological advancements push industries to evolve, but not all firms and geographic locations are able to create and leverage new technology. The forces of innovation can enable old industries to feel and act younger, with more knowledge creation, start-ups and new product development. Industry evolution occurs through intertwined technological and organizational processes (e.g., Van Assche, 2008). Along the technological dimension, industries

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http://dx.doi.org/10.1016/j.indmarman.2016.07.007
0019-8501/

typically emerge through a process of radical product innovation, and become established through continuing or incremental process innovation. For a mature industry to evolve, multiple firms in the industry need to be involved with generating innovation, and adopting innovation.

Along the organizational dimension, processes can encourage or discourage innovation. The continuing conversion of tacit into codified knowledge through process standardization often lead to outsourcing, offshoring and increased geographic mobility (Mudambi, 2008; Vernon, 1966). As firms and their key employees are pushed to adapt, this sometimes means a move of firm activities to a new location, and falling spatial transaction costs have stimulated such firm mobility. Firms can widely disperse their activities over geographic space (Cantwell & Mudambi, 2005). This can spark new ideas and tap new sources of innovation, but an increase in coordination and communication costs can also hurt innovation (Meyer, Mudambi, & Narula, 2011). When the leading firms geographically disperse important activities, this has important implications for industry evolution and cluster viability. As industries change, these technological and organizational processes underpin the rise and decline of clusters, and complicate the measures of cluster success.

In order to thrive – or even to survive – clusters in advanced market economies must lead rather than follow the processes of innovative change. Clusters act as conduits of knowledge diffusion (Corsaro, Cantù, & Tunisini, 2012; Felzensztein, Stringer, Benson-Rea, & Freeman, 2014), and offer firms and regions the potential to better compete in the modern, globally connected knowledge economy (Romanelli & Khessina, 2005; Simmie, 2004; Tallman & Phene, 2007). The continuing disaggregation of global value chains has highlighted the phenomenon of constituent activities following different evolutionary paths. For instance, Menzel and Fornahl (2010) identify local employment and the "heterogeneity of accessible knowledge" as two distinct metrics of cluster success. Along similar lines, Awate, Larsen, and Mudambi (2012) distinguish output capabilities from innovation capabilities. In the case of the Detroit, recent evidence indicates that the automotive cluster's failures have been confined to the sphere of manufacturing and output, while innovative capabilities and performance have continued to thrive in the region (Hannigan et al., 2015). This line of argument suggests that in the context of clusters, success and decline are multidimensional constructs. Success along one dimension, such as innovation, is often accompanied by decline along another dimension, such as manufacturing or employment. While this is not inevitable, the nature of these inter-relationships is unclear.

Further, global innovation is naturally accompanied by obsolescence. To maintain innovation success, clusters must encourage continuous local technology creation and the diffusion of knowledge (Felzensztein et al., 2014). Today's specialized, tacit activities can become tomorrow's standardized, codified ones (Cano-Kollmann et al., 2016). In order to remain centers of innovative excellence, advanced economy clusters must be able to generate knowledge while riding the waves of creative destruction. This requires the harmonious operation of an entire system (Lundvall, 2007; McCann & Mudambi, 2005), including leveraging the basic science capabilities of area universities, the commercializing capabilities of a healthy population of startup firms, and the scale and network capabilities of large orchestrating multinational enterprises (MNEs). As evident from the definition of industrial clusters, network linkages are important, as they allow for the interaction of the entities that cooperate in the creation, integration, transfer and absorption of knowledge (Cabanelas, Omil, & Vázquez, 2013; Corsaro et al., 2012).

The literature suggests that local institutions can shape the fate of clusters (Lorenzen & Mudambi, 2013). In advanced market economies, the institutions of innovation are often deeply entrenched and resistant to change, and this can discourage technology-driven change. Yet, university, government and economic institutions also have the power to promote innovation, as the locally embedded knowledge base can represent a significant source of novel and unique knowledge resources. The collaboration of universities, entrepreneurs and local government helped transform an agricultural valley into Silicon Valley, a powerhouse of business creation and innovation (Engel, 2015). A lesser-known example is how the cluster of Waterloo, Ontario was shaped by the creation of a university that became a major knowledge generator for the region (Wolfe & Gertler, 2004). From the vantage point of both theory and practice, the nature of local institutions is immensely important for the overall success and evolution of clusters.

Beyond the role of specific local institutions, the innovative performance of advanced market economy clusters is sensitive to the link between innovation and value creation. As global connectivity and knowledge flows become increasingly important, innovation in the cluster will be successful only if activities undertaken locally follow the migration of value. Clusters need to remain focused on those activities that generate the most value, and play down those whose value is dissipating. This depends on the responsiveness and initiatives of local institutions, local entrepreneurial ventures (Felzensztein, Gimmon, & Aqueveque, 2012) and the leading MNEs in the industry.

To illustrate and analyze industry cluster evolution within a global innovation system, we study how the automotive tire cluster of Akron, Ohio evolved into a polymer cluster over the 30-year period beginning in 1975. We unpack the cluster performance along the dimensions of employment, manufacturing and innovation. We demonstrate a steady process of technology evolution in the cluster's innovation efforts and the strong role of global connectivity. The technology evolution occurred along two fronts. First, the cluster moved from its nineteenth and mid-twentieth century strengths in rubber and tire manufacturing, so that by the turn of the twenty-first century, it was steadily re-applying its expertise to cutting-edge polymer science. Second, the cluster kept up with the worldwide trend away from laboratory-science-based innovation toward more design-driven processes, led by orchestrating MNE firms with strong local ties (Scalera et al., 2014).

Past research suggests the importance of considering the extent and nature of global knowledge connectivity. Fleming, King, and Juda (2007) argue that the perfect recipe for increased innovation is the combination of dense, clustered, local, "small-world linkages" that enable trust and close collaboration, and distant and diverse relationships that provide novel, non-redundant information. However, few studies have explored both local linkages and distant global ties (Fleming et al., 2007, p. 938). Have global knowledge connections enhanced the evolution of the Akron industry cluster from tires to polymers? The transformation of Akron provides an opportunity to analyze the complex dynamics of cluster evolution and international knowledge connectivity in an advanced economy.

2. Industrial clusters: technological evolution within and across geographical boundaries

The origin of the concept of industrial clusters or industrial networks is rooted in the notion of Marshall's notion of "industrial districts" (Marshall, 1920). Such clusters form an agglomeration where local companies and institutions interact to share and generate new knowledge solutions (Cabanelas et al., 2013). Interactions among actors and innovation remain at the heart of the concept of industrial clusters. Innovation is driven by the creation of a social space that helps in the exchange of knowledge due to geographical proximity of firms and actors within a cluster. Geographical closeness allows the cluster firms to create ties and bridges, both local and distant that help in the assimilation and transformation of heterogeneous knowledge.

The next two sections are devoted to providing a theoretical framework applicable to mature high-tech industrial clusters located in advanced countries. These clusters are facing technological disruptions and operational transitions more frequently, discontinuities that can significantly alter their performance trajectories. More specifically, we apply the co-evolution model of firms and locations (Cano-Kollmann et al., 2016), to analyze the trajectories of industrial cluster evolution.

Within this framework we focus on the dynamic innovation process from the cluster's perspective, understanding how anchor firms and international connectivity shape this process.

2.1. The evolution of industrial clusters in advanced countries

Industrial cluster evolution is a current priority on the agenda of both researchers and policy makers in industrial marketing, economic geography, innovation studies and related fields (Martin, 2010; Moodysson & Sack, 2016). In recent years, we have witnessed a number of examples of prominent mature clusters in advanced economies that have emerged from secular decline through (often dramatic) transformations. For example, the Marche (Italy) musical instruments cluster used its historically developed competencies in the production of accordions to move into electronic musical instruments (Tappi, 2005). The Northern Germany shipbuilding cluster shifted into the production of wind turbines (Fornahl, Hassink, Klaerding, Mossig, & Schröder, 2012). These examples have often been explained through path renewal, path dependence and evolutionary economic geography (e.g. Fornahl et al., 2012; Martin & Sunley, 2006).

To take a complementary perspective, we see the benefit of applying the concept of global value chain (GVC) disaggregation and the dynamic innovation process model (Cano-Kollmann et al., 2016) to the case of cluster evolution. In this view, the location assumes the perspective of the flower in the metaphorical *flower-and-bees* model. Cluster evolution can be seen as the ultimate outcome of the co-evolution between firms and locations, where firms are mobile and dispersed, and locations are geographically defined. While the cluster is the source of tacit and location-specific knowledge, MNEs coordinate resource use and integrate networks of multiple locations and actors dispersed across space (Meyer et al., 2011).

The decline in spatial transaction costs has facilitated the fine slicing of GVCs (Mudambi, 2008), and the geographical dispersion of firm activity has generated a new threat for clusters, i.e., the obsolescence of cluster-specific competences. It follows that the ability of clusters and locations to renew their technological profile is a fundamental factor in avoiding cluster decline. But it is also true that the firms are dependent on locations and resource availability, and this interaction determines the co-evolution process (Cano-Kollmann et al., 2016). The ability of MNEs to leverage network advantages (Cantwell, 1989) can be the key driver of a cluster's evolution, by shaping its path and connecting it to global innovation networks.

As Table 1 suggests, the co-evolution between firms and locations within the cluster can generate different scenarios, determined by the interaction between the cluster evolution process and the role played by the lead or anchor MNEs. Cluster evolution can diverge into two distinct directions, i.e. *upgrading* and *domain shifting*. Upgrading refers to the process of moving to higher orders of innovation within the extant industry. This is primarily a process of increasing specialization, often by bringing in new skills and knowledge to innovate new generations of the current product. It typically generates increasing technological focus on the existing industry. On the other hand, domain shifting refers to the process of re-applying extant competencies to new product or service domains. This is primarily a process of technological recombination where extant technologies are re-purposed through integrating them with knowledge from related domains. It is typically associated with a transition away from the existing industry and a move into new, sunrise industries.

The lead or anchor MNEs can drive both the upgrading and domain shifting processes. As they orchestrate GVCs, they retain the most highly tacit knowledge and capabilities in-house. Innovation activities are typically co-located with the headquarters in the cluster. The MNEs' local activities morph over time to higher levels of specialization, in order to maintain the firms' control over the "creative heart of the value chain" (Mudambi, 2008: 702). In this way, the upgrading process is very congruent with the orchestration process. Spawning is a more advanced process whereby the anchor MNEs take stakes in next generation technologies and shape the future industrial landscape. This requires significant knowledge and capabilities along two dimensions: (a) entrepreneurial process knowledge and capabilities; and (b) network knowledge of the key players in the entrepreneurial eco-system and the associated social capital. These include creators of basic knowledge (universities and research labs), sources of finance (angels and venture capitals) and commercialization launch pads (incubators and accelerators). Table 1 emphasizes that the orchestration role is more effective on the upgrading dimension of the cluster evolution process, while the spawning role is more active on domain shifting.

2.2. Local linkages and global ties in industrial cluster evolution

Building on the previous discussion, the co-evolution process shows the crucial role played by local institutions in shaping and driving the evolution of the clusters (Lorenzen & Mudambi, 2013; Moodysson & Sack, 2016; Zucchella, 2006). We argue that the ultimate mechanism through which these institutions act is the creation and management of local linkages and global connections as well as coordination between the two.

Past research suggests that local linkages are important for industrial cluster success. Local linkages, owing to their geographical proximity, often generate rich and highly valuable knowledge (Giuliani, 2013). Close and face-to-face interactions among the actors reduce from the uncertainty and ambiguity associated with the transfer of tacit knowledge, and embeddedness in the local environment helps companies to come up with context-specific solutions that form the basis of their differentiation strategies (Perez-Aleman, 2011).

However, there are limitations to the effectiveness of local linkages. Geographical proximity can be problematic. Knowledge spillover among local firms may severely constrain the rent generating abilities of local knowledge solutions. For instance, Yang, Phelps, and Steensma (2010) observe that Kodak's OLED technology invented in 1985 was exploited and recombined by 30 other firms in the next 15 years. Rival firms in the same cluster may be able to observe and copy the technologies and use them to their own advantage. In addition, the business partnerships and linkages created by the firms in a cluster with low geographic distance are very similar, and so knowledge may be transferred to other local firms using the same network of business partners or suppliers (Spencer, 2008). Geographic proximity may also reduce the information asymmetry surrounding knowledge acquisition and application. Low geographic distance enables rival firms to copy the relevant knowledge from the originator and apply it appropriately. In

Table 1
A model of cluster evolution process and the role of MNEs.

		MNE role	
		Orchestration	Spawning
Cluster evolution process	Upgrading	Increasing focus on higher knowledge processes in the current industry	Outsourcing of standardized processes to new startups
	Domain shifting	De-centralization of knowledge production to foreign subsidiaries	CVC activity and spinouts, leading to new industry creation

short, geographical proximity and local linkages facilitate spillovers that may reduce the benefits of innovation to the innovators.

The drawbacks of geographical proximity highlight the importance of complementing local ties with external linkages to boost the innovativeness and competitiveness of industrial clusters (Uzzi, 1997). Given the increasing complexity of knowledge creation, the recombination of different sources of technology and innovation is key to creating and maintaining the dynamic and renewed technological profile of the cluster. External ties and connectivity can provide the cluster and its actors with novel and geographically diverse technological competencies and approaches, complementary skills and human capital, and a larger pool of managerial and organizational alternatives (Fleming & Sorenson, 2001; Lorenzen & Mudambi, 2013; Owen-Smith & Powell, 2004). External ties, particularly international connections, may reduce the risk of lock-in within the cluster, thus allowing for more effective knowledge production and recombination (Breschi & Lenzi, 2015, 2016; Mudambi, 1998; Narula, 2002; Storper & Venables, 2004). This underlines the importance of creating and maintaining distant, global ties for new knowledge generation by the local firms.

Thus, to understand the dynamics of industrial clusters, it is essential to examine local linkages and global connectivity together. We situate our analysis of local linkages and global connectivity within the context of the cluster evolution literature. In doing so, we acknowledge the insight that "network studies tend to suggest that evolution of the macro structural characteristics of a network is driven by concurrent forces operating at the micro level" (Giuliani, 2013, p. 1407).

In the following section, we briefly discuss the dynamics of the Akron, Ohio, cluster and take a closer look at its leading firms, their local linkages and global ties. The Akron case serves as an illustration of our underlying theory of cluster evolution in mature economies.

3. The industry cluster of Akron, Ohio

Akron is the center of the Northeast Ohio industry cluster, in the heartland of the United States. This cluster has witnessed significant changes in its specialized employment, manufacturing and innovation over the last century. For many decades, Akron was known as the "Rubber City," but the area is now recognized as the "Polymer Valley" (Safford, 2004). Akron's transition from tires to polymers is a complex story that reflects the challenges of industrial marketing in the global economy, and highlights the roles of MNEs, universities and global knowledge collaborations.

After BF Goodrich settled its operation in Akron in 1871, the city became the main U.S. center of the automobile tire industry. Akron used to be called the "rubber capital of the world", and its evolution has been fueled by a self-reinforcing process driven by the "Big Four" tire firms of Goodyear, BF Goodrich, General Tire and Firestone, all located in Akron (Buenstorf & Klepper, 2009; Scalera et al., 2014). These companies established manufacturing plants in the Akron cluster. By 1935, they produced over 67% of the tires manufactured in the U.S. (Buenstorf & Klepper, 2009).

The 1980s and 1990s were a tumultuous time for the tire cluster, as the tire industry consolidated significantly following the breakthrough technological innovation that replaced the 'bias ply' technology with new radial tires. The Akron-based tire companies were slow to innovate their technological and organizational processes, and competition from foreign tire makers such as Continental, Bridgestone and Michelin took market share away. Akron tire factories closed, and tire production and tire manufacturing jobs moved to southern states in the U.S. and to locations in emerging markets. The local anchor firms were acquired by foreign rivals. Firestone was acquired by Japan-based Bridgestone, the BF Goodrich-Uniroyal joint venture was acquired by Michelin, and General Tire was bought by the German company, Continental (Scalera et al., 2014; Sull, Tedlow, & Rosenbloom, 1997).

The foreign MNEs acquired the Akron tire firms for their downstream marketing and distribution assets, not their upstream R&D assets. Hence, as predicted by the theory of subsidiary evolution (Cantwell & Mudambi, 2005), Akron-based innovation activity at Firestone, BF Goodrich and General Tire declined precipitously. The weaknesses of these leading tire firms contributed to the economic decline of the Akron area. The loss of manufacturing and related jobs, coupled with the shuttering of a significant portion of its local R&D activities led to unemployment rates consistently higher than the U.S. average, population loss and a brain drain throughout the 1980s and early 1990s.

Despite the turbulent and complicated years since then, Akron has remained a central location for the innovative activities related to tires and rubber-related technologies. This has been possible due to the stable presence of R&D centers and operations of multinational tire companies, the generation of spinoff companies participating in the incumbent's global value chain (Buenstorf & Klepper, 2009), and the know-how and scientific-related knowledge provided by universities in the region. The co-location of different actors contributing to the global value chain of the tire industry stimulated the concentration of knowledge activities in the area, intensifying the specialization process of the ecosystem and providing a fertile ground for the technological evolution of the cluster.

The Goodyear Tire and Rubber Company was the dominant firm in "The Rubber City." It is the largest employer these specialized workers in "The Polymer Valley" as well as in the state of Ohio. Goodyear avoided acquisition partly due to its innovation resilience, but it also witnessed a significant decline in its market share during the transition period (Scalera et al., 2014). The Polymer Valley industry cluster in northeastern Ohio today consists of more than 1300 firms, has a total employment of approximately 87,000, and contributes $13.7 billion to local GDP (Greater Akron Chamber of Commerce Report, 2013). The region hosts 20 of the U.S. Fortune 1000 companies. Some of these large companies, including Eaton, Goodyear, Parker-Hannifan, A. Schulman, and PolyOne, have maintained their global headquarters in Akron for many years.

The Akron region is also home to numerous small and medium size firms in polymer related industries. The industrial products of the cluster are related to polymers, plastics, resins and rubber. These Ohio factories are nationally ranked 1st in rubber products and 2nd in plastic products. In 2012, $2.1 billion worth of plastic and rubber products were exported, an increase of 52.5% over the previous three years. In addition, freight companies such as Roadway and Yellow Freight were long associated with Akron, while FedEx, Custom Critical and Panther are continue to have a large presence in the Akron cluster.

3.1. Institutional linkages in the evolution of clusters

Lester (2005) summarizes the role played by the universities in industry cluster development. First, universities often act as incubators of new technology as they seek to exploit new innovations from their research laboratories by transferring such technology to local firms via licensing. Second, they act as local adaptors of non-local and distal knowledge by attracting new human capital and financial resources. Such adaptation entails the integration of diverse streams of technological activities, an important precondition for innovation (Datta, Mukherjee, & Jessup, 2015). Third, research universities are crucial suppliers of human talent to the local cluster firms and are an essential source of new business formation in the area (Mudambi & Santangelo, 2016). Finally, the cluster also benefits from the physical proximity of the research institutions as the universities facilitate inter-firm mobility and provide a "neutral ground" for interpersonal contacts. Such relational mechanisms help in the diffusion of the tacit knowledge generated locally.

The University of Akron (UA) played a pivotal role in shaping the innovation and new business formation in the transition of the Akron cluster from tires to polymers. The University's interactions with industry can be traced back to the 1930s when the engineers and scientists from the city's tire manufacturers started to attend a research seminar held by Professor Frank Knight (Safford, 2004). As the rubber industry grew exponentially after the Second World War, UA's role became even more central and was formalized in the 1950s by the creation of a material sciences department. By the 1970s, the polymer science PhD program was rated as one of the nation's top programs, along with prestigious institutions such as MIT. In more recent years, nearby Kent State University and Ohio State University also built expertise in polymer science, and generated research that supported the polymer cluster development.

3.2. Innovation, technology transfer and new business formation

Universities have the capability of providing a common knowledge-sharing platform for the regional tire companies and for polymer-related businesses, especially if the focus is on applying academic expertise to business problems. For example, UA's College of Engineering established a new tire research center with funding from the National Science Foundation (NSF) Industry/University Cooperative Research Centers (I/UCRC) Program. The Goodyear Polymer Center is co-located with the Department of Polymer Science of UA, and it hosts the Applied Polymer Research Center. Since the establishment of the University of Akron Research Foundation (UARF) in 2001, UARF has helped in the formation 54 startups and has enabled many of these companies to commercialize their technologies. Its affiliated ARCHAngel Network has attracted $485 million in follow-on funding (Ball & Preston, 2014). UA's Office of Technology Transfer also enabled the continued interaction between UA and the tire and polymer companies. Several tire and automotive firms support the efforts of these centers to help disseminate industry knowledge.

There is more to polymer science than tires. Akron Polymer Systems, which was founded in 2002 by Frank Harris and Stephen Cheng, has been a beneficiary through the licensing of polymer coating technology applied to HDTV and smart phones. UARF holds 5% equity in this company (University of Akron, 2015). Another company that benefited from university technology licensing is SNS Nano Fiber Technology Company whose products have applications in custom manufacturing and medical devices. UARF holds a 25% equity stake in this company (University of Akron, 2015). In 2005, UA researchers, led by Dr. Joseph Kennedy, developed and patented a new polymer coating which has been translated into a less-invasive surgery for coronary care. The innovation has led to polymer coated stents to that are infused with a slow releasing drug to treat arterial blockage, and this has helped reduce coronary bypass surgeries by 85%. A superabsorbent nanofiber material, invented by Professor Darrell Reneker, is another example of UA's technology commercialization success. The university generated $1.4 million dollar in licensing revenue when the invention was licensed to P&G (for use in baby care) and Milliken (for use in oil spill absorption) (University of Akron, 2015). UA has also collaborated on polymer-based coatings with A. Schulman, a leader in plastic compounds, and with Timken, a leader in bearings technology.

Innovation, technology transfer and the encouragement of polymer-based entrepreneurs were essential components of the reinvention underlying Akron's transformation from "The Rubber City," to a city of closed tire factories, to the high tech center of "The Polymer Valley." Economic vitality depends on an appropriate balance of manufacturing, employment and innovation. The loss of manufacturing jobs during the evolution of the cluster from tires to polymers has been well documented. Less well publicized has been the resurgence of manufacturing and related jobs in the polymer cluster. With many new polymer-related firms, polymer-related jobs at the levels of tire factory employment at "Rubber City" heyday (Greater Akron Chamber of Commerce Report, 2013), and a growing output of patented innovation, the evolution from tires to polymers has generally been viewed as moderately successful, although certainly more work can be done.

3.3. Local links and global connections

Although the UA and other area universities have actively promoted academic polymer science and commercialization through business start-ups, this has involved more than technology transfer. In the last decade or so, the role of UARF and other organizations has evolved from a technology transfer agent to a mentor-connector organization (Ball & Preston, 2014). The goal has been to support the local cluster by creating, nurturing, and connecting local innovative and entrepreneurial talents to the polymer industry. Universities, corporate research centers and government agencies and other organizations have all worked to make and build these local linkages.

However, the viability of an industrial cluster rarely depends solely on strong ties to local institutions and firms. What is less established in previous research is the extent and nature of associated changes in the cluster through the global knowledge-sharing connections that have arisen during this time. While local linkages within the Akron cluster are highly relevant, the role of distant and diverse global ties are less clear (Fleming et al., 2007). To fill this crucial void, we analyze the dynamics of the Akron industry cluster from the perspective of international knowledge collaboration. In doing so, we hope to understand the influence of global knowledge connections in the evolution of the Akron industry cluster from tires to polymers.

4. Data and methods

Using patent data from the U.S. Patent & Trademark Office (USPTO), we analyze the innovative activity in the Akron Core-based Statistical Area (CBSA) from a longitudinal perspective. USPTO patent data have been extensively used by scholars as source of innovation data and as an indicator of cluster dynamics (see Buenstorf & Klepper, 2009, 2010; Hannigan et al., 2015). USPTO patent data represent a rich and unique source of information, providing details about the technological classification of the invention, the name and location of inventors, and the ownership of the intellectual property (IP) of the invention. There are problems associated with the collection of patent data, but many of these have been mitigated by publicly accessible databases such as the National Bureau of Economic Research (NBER) (Hall, Jaffe, & Trajtenberg, 2001) and the *Harvard Patent Dataverse Network* (DVN) (Li et al., 2014).

We build on previous efforts to map the knowledge creation networks of individuals, and leverage data from the DVN database, which provides disambiguated patent-inventor observations from 1975 to 2010. We include in our sample only patents with an application year between 1975 and 2005, and granted before 2010. This choice has been made in order to have the most accurate estimation of the innovative activity measure by patents. Data provided by DVN database are severely right-censored because most of the patent applications submitted in the period 2006–2010 are likely to be granted after the cutoff date of December 21, 2010.[1] Therefore, we use the data for the first 30 years (1975–2005) because we can rely on its having near perfect accuracy.

In order to track innovative activity in the Akron area, we used the CBSA as our unit of analysis. These are defined by the Office of Management and Budget (OMB) as urban centers and adjacent areas of at least 10,000 people. The Akron CBSA includes two Ohio counties: Summit and Portage. Using the address zip code provided by the DVN database for each U.S.-based inventor, we identified all the patents that have at least one inventor located in the Akron CBSA, and classified these as Akron-based patents. Our final sample is composed of 19,394 Akron-based patents filed between 1975 and 2005, and granted by the end of 2010.

[1] The lag between application and grant year is on average 3 years, even if many patents may take more time than that (Hannigan et al., 2015).

5. Results

5.1. Akron-based innovative activity: from local linkages to international knowledge ties

Akron is a clear example of a Marshallian cluster created by industry agglomerations (Beunstorf & Klepper, 2010). The leading tire companies all located in Akron, and the cluster remains strongly influenced by the tire industry. Although tire manufacturing moved elsewhere, local tire research has continued and evolved. Goodyear and the other incumbent firms continued to pursue research and innovative activities, and university-based research stimulated innovation from MNEs and startup firms (Sull, 1999).

This analysis aims at longitudinally unpacking the performance of the Akron cluster along different dimensions of innovation, and deepening the understanding of its impact on employment and manufacturing activities. In contrast with the manufacturing decline of the cluster, Table 2 shows the innovative health of Akron. From 1985 to 2005 there is a steady increase of knowledge production, both in terms of patents' absolute number and also relative to the size of the civilian labor force. Additionally, the data highlight that the growth rate of knowledge productivity (patents/million civilian labor force) was higher than that of the overall United States in the last 10 years of analysis, i.e., patents per million population nearly doubled between 1990 and 2005. In other words, while the manufacturing declined in the Akron area, the resilience of local knowledge production maintains the vitality of the cluster.

Fig. 1 supports this insight, showing that knowledge production of the Akron area increased while unemployment rate remained flat. From 1995 to 2005, the unemployment rate of the area remained almost stable, while the number of patents increased substantially and steadily. Even though the Akron population dramatically decreased in the last decades, the data demonstrate that from 1995 to 2005 the unemployment rate fluctuated between 4 and 6.50% and the growth rate of patent productivity was positive. This corroborates our argument on the transformation of the Akron cluster from a production center to an innovation center, with an increased specialization in knowledge-intensive activities.

The evolution of the Akron cluster is inevitably related also to the increasing geographical dispersion of activities involved in the global value chain related to tires. Table 2 shows that Akron-based innovation is lower than the U.S. average and displays lower international connectivity. However, starting from 1990, the number of internationally connected patents (patents with at least one inventor located outside the U.S.), is growing faster than the overall U.S. average. Analyzing the location of foreign inventors participating in Akron-based innovation, it appears that internationally connectedness is driven mainly by inventors in Luxembourg and Japan. However, Table 3 shows that starting from 1990, the number of foreign countries included in Akron-based innovation networks is rising, while the concentration in specific foreign countries is declining. All of the top 10 countries connected to the Akron innovation system are known for having well-established tire and automotive clusters.

Tire MNEs drive the international connectivity of knowledge creation in the Akron cluster. As measured by percentage of patents granted, the top innovators in the cluster are Goodyear, Firestone (acquired by Bridgestone in 1988), and BF Goodrich (see Table 4). As noted by Scalera et al. (2014), Goodyear has consistently been ahead of the other two major domestic tire producers in terms of patent production. Why Luxembourg and Japan? Knowledge connections established with Luxembourg reflect the location of Goodyear's second most important R&D center, and Japan is where the headquarters of Bridgestone is located, together with its major R&D laboratory. It is also worth noting that the (UA) is among the top 10 Akron-based innovators. UA efforts to shape and boost the knowledge production of the area by working both independently and in collaboration with local high technology companies, have paid off in the form of patents.

The global distribution of the Akron-based innovation networks, and the specific foreign locations to which they are connected enable us to highlight three key findings: (a) the Akron cluster has evolved from a local focus to a more internationally connected cluster, mainly through the innovation activities of leading MNEs (Cantwell & Mudambi, 2011); (b) the tire global value chain creates connections among worldwide centers of R&D excellence; and (c) leading incumbent firms in the cluster (primarily Goodyear) and academic institutions (primarily UA) play crucial roles in creating and driving knowledge connectivity within and between clusters.

5.2. Technology evolution and cluster innovation

Akron lost its identity as a tire manufacturing center, but the innovative competencies associated with this industry remain embedded in the cluster. Traditional indigenous actors, such as producers, suppliers, universities and research centers continue to focus on tire-related problems and benefit from their local and global connections. The transformation of the industry and the changing geography of the tire value chain have inevitably modified the cluster and shaped its activities. The transition from production to innovation is evident not only from the numbers of patents produced, but also from changes in the technological space. The resilience of the knowledge within the cluster is evident in the technology evolution of the cluster's innovation efforts.

To analyze the industry composition of the innovative activities in the Akron area we use the technological classes of the Akron-based patents. Relying on the taxonomy proposed by Hall et al. (2001), we divided the patents in our sample into six categories: chemical, computers and communications, drugs and medical, electrical and electronic, mechanical and others. Fig. 2 provides an overview of the technological evolution of the innovation centered in Akron. The relative stability of the technological categories shows the predominance of the chemical patents within the knowledge portfolio of the cluster. The chemical technological class includes the vast majority of rubber- and tire-related inventions, and are used here as proxy for the tire

Table 2
An overview of the innovative activity in Akron (compared to the Unites States).

Period	Akron-based patents			U.S.-based patents		
	Patents	Patents/millioncivilian labor force	% Internationally connected patents	Patents	Patents/million civilian labor force	% Internationally connected patents
1975–1979	1721	116.40	0.76	202,909	216.38	1.39
1980–1984	1690	110.48	0.36	183,256	171.36	1.74
1985–1989	1607	99.45	1.99	217,618	188.48	2.69
1990–1994	1789	104.36	2.79	296,885	235.92	3.70
1995–1999	2884	159.76	4.68	447,469	338.21	5.31
2000–2004	3690	200.61	6.56	512,768	359.63	6.99
Growth rate 1990–2004 (%)	51.52	47.98	57.47	42.10	34.40	47.07

Note: Adapted from Hannigan et al., 2015.

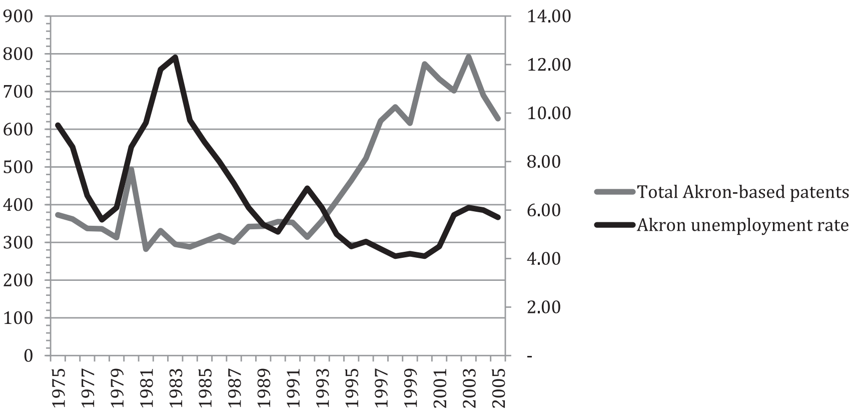

Fig. 1. Total number of Akron-based patents and Akron unemployment rate (1975–2005).

Table 3
Akron-based patents connected to the top 10 foreign locations (% of total internationally-connected Akron-based patents, 1975–2004).

	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2004
Japan	0.00	30.77	5.88	23.94	29.18	10.86
Luxembourg	23.08	23.08	27.45	14.08	18.45	18.18
Canada	7.69	15.38	7.84	14.08	9.44	12.86
Belgium	0.00	0.00	31.37	12.68	8.15	7.98
Germany	0.00	0.00	9.80	2.82	7.30	8.87
UK	15.38	0.00	1.96	15.49	6.44	7.32
Australia	0.00	0.00	0.00	2.82	2.58	2.44
Italy	7.69	0.00	1.96	2.82	3.00	4.88
The Netherlands	7.69	0.00	5.88	2.82	1.29	2.22
Czech Republic	0.00	0.00	0.00	0.00	0.00	4.43

industry. From 1975 to 1999 the key role played by chemical patents in shaping the technological profile of the cluster is very clear, as on average it represented at least the 40% of the overall patent production of the area. But, starting from the late 1990s, two trends marked the technology evolution in the cluster's innovation. First, the core strengths in rubber and tire manufacturing have been steadily transforming into polymer science innovations. Second, the pure laboratory-science-based innovation has shifted toward a more design-driven process.

In order to identify the innovations related to polymer science and to show its evolution over time, we selected subcategory 15 from the Hall et al. (2001) taxonomy (Chemicals: Resins[2]) to represent the core polymer science patents behind the overall chemical patents. Table 5 presents a classification of Akron-based chemical patents and distinguishes between polymer science- and non-polymer science-related innovation. It shows that starting from the period 1995–1999 and then continuing in the 2000–2004, the polymer science-related patents represented more than 56% of the overall chemical patent production, with the share growing significantly, compared to the previous years. In other words, as Akron was declining as a tire manufacturing center, its technological space witnessed a transformation by redeploying traditional rubber and tire competences into complementary products and industries. Synthetic polymers have been used as basis for producing innovation related to synthetic fiber and plastic, employed for pipes, bottles, auto parts, industrial fibers and textile materials. This transformation is also the result of a fruitful university-corporate partnership between Goodyear and the UA.

As shown in Fig. 2, starting from the 1990s, chemical innovation started to lose its predominance, and in turn has been increasingly complemented by other types of innovation. More specifically, design innovation took off, due to local orchestrating firms such as Goodyear (Scalera et al., 2014). Table 6 presents the evolution of the design patents production over time (share of the overall local patents), by comparing Ohio-based and Akron-based patents. Data are gathered directly from the USPTO website, by looking for patents with at least one inventor located in Ohio or only in Akron, respectively, and we distinguished between utility and design patents. While the growing trend of design patents is clear by looking the shares of Ohio-based design patents, what is surprising is the dramatic jump in the percentage of Akron-based design innovation. In fact, in Akron the percentage of design patents over total patents was 9.96% in the period 1985–1989, in line with the average of Ohio, but became 20.07% in 1990–1994, and maintained a substantial rate also in 1995–1999. The evidence suggests that the shift to a design-driven innovation process in the area has been mainly driven by inventors based in Akron. More specifically, innovation efforts orchestrated by the major innovator of the Akron area, i.e. Goodyear, have played a key role in shaping the evolution toward technical innovation strictly related to the functional and ornamental elements of the product, with a particular emphasis on shape, configuration and surface (Scalera et al., 2014). Our data provides initial evidence on a transition in the Akron area to a higher level of innovation, which links together novel technical features, aesthetic appearance and product diversification (Bruce & Bessant, 2002).

6. Discussion and implications

Using a rich dataset comprised of 30 years of USPTO patents, we have created an analysis of knowledge evolution and global collaboration related to the Akron industrial cluster. Our longitudinal analysis shows that the level of innovative activity in Akron has risen steadily over three decades. Over the period 1990–2004, Akron's total innovation output as well as its innovation per capita has grown faster than the U.S. as a whole. We also find that the co-invention networks of the

[2] We included in the polymer-related category patents listing as primary USPTO technological classes from 521 to 528. It is worth mentioning that resins and polymers are different from a chemistry point of view: while resins are compounds, polymers are macromolecules generally bigger and with longer chains than resins.

Table 4
Akron-based patents of the top 5 assignees (% of total Akron-based patents, 1975–2004).

	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2004
Goodyear Tire Rubber	23.649	16.331	17.486	17.233	18.374	18.347
Bridgestone[a]	9.820	6.864	5.414	6.485	7.638	7.751
B F Goodrich	9.064	8.580	9.770	5.312	2.006	0.678
Standard Oil	6.450	8.284	7.218	2.409	1.338	0.190
Diebold Incorporated	0.174	0.059	0.000	0.185	1.302	3.442

[a] It includes also Firestone Tire and Rubber Company, acquired in 1988 by Bridgestone Corporation (Japan).

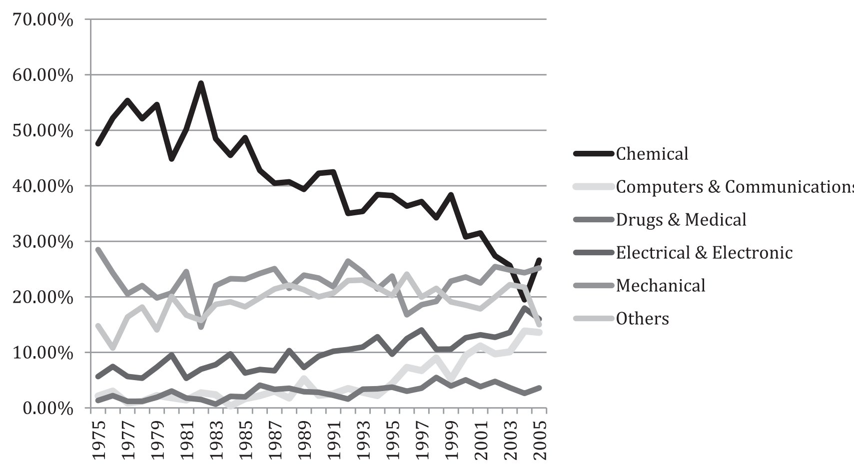

Fig. 2. Technological composition of Akron-based patents (% patents, by category, 1975–2005).

Akron cluster show a level of global connectedness that is growing faster than the average for the country. Our data also show that the major tire companies in the region played a vital role in developing and maintaining healthy 'knowledge pipelines' that helped the cluster retain some innovative activities even as its manufacturing activities declined. In essence, in spite of drastic economic and technological changes, the Akron cluster has remained engaged in specialized knowledge activities with strong locally-embedded innovation roots and increased global connections.

This process of transformation of the Akron cluster against the backdrop of a rapidly changing and disruptive environment presents an illustrative template of the multi-dimensional nature of cluster performance. Akron, in common with many other Rust Belt cities in the U.S. (see Hannigan et al., 2015 for an analysis of the Detroit auto cluster) is often held up as an example of industrial decline. However, our analysis shows that this picture has serious omission bias, and is overly focused on the single dimension of manufacturing employment. By focusing on the dimension of innovation, we demonstrate that the story of Akron is one of transformation rather than decline per se. In particular, we have shown that Akron industrial cluster has evolved in two parallel innovation trajectories: a) a broader application of its core technological capabilities, by shifting the application of chemical competences from tires to polymer science; b) a higher form of innovation within tires, moving from rubber-based innovation to design innovation. This multi-dimensional view is key to understanding of a cluster's performance and constitutes an important theoretical contribution.

Our research offers several contributions to the industrial marketing literature. First, our research shows that "Polymer Valley" is more than a marketing slogan aimed to put a positive spin on Rust Belt decline. The analysis of patent trends that originated in the Akron cluster tells the story. The Akron area has become the "Polymer Valley" on the foundation of scientific research and global collaboration, showing an evolution from a tire manufacturing center, to an innovation hub centered on polymer science and revitalized by the collaboration between core contributors of the cluster, i.e., companies and research institutions. This finding contributes to understanding of the industrial marketing concept of "network embeddedness,"' and addresses the need for examining the co-evolution of embeddedness with other social and economic factors over time (Lin, Huang, Lin, & Hsu, 2012). We also build on previous research on how and why the structure of knowledge networks matter (Mudambi, Oliva, & Thomas, 2009). Our findings also throw light on the role of key institutions in driving structural changes in industrial clusters (Matthyssens, Vandenbempt, & Van Bockhaven, 2013).

Our findings also contribute to the literature to the related research stream on system resilience. The term *resilience* in Latin refers to

Table 5
A comparison of Akron-based patents in chemical technological class: polymer science- vs. nonpolymer science-related patents (% of chemical Akron-based patents, 1972–2004).

Period	Chemical patents	
	Polymer science-related	Non polymer science-related
1975–1979	50.53	49.47
1980–1984	47.44	52.56
1985–1989	48.15	51.85
1990–1994	51.30	48.70
1995–1999	59.93	40.07
2000–2004	56.71	43.29

Table 6
A comparison of design patents' production in Ohio and Akron (% of total Ohio and Akron patents, 1975–2004).

	Ohio	Akron
1975–1979	7.10	4.79
1980–1984	8.97	6.24
1985–1989	10.32	9.96
1990–1994	12.46	20.07
1995–1999	14.19	25.31
2000–2004	15.04	25.39

jumping back or returning back to the original state after withstanding the shocks of unforeseen challenges. Researchers have highlighted three characteristics that demonstrate resilience in a system: (a) the maintenance of positive changes during the disruption; (b) the capacity to keep focusing on core functions and (c) the ability of bouncing back from the crisis, or, transformation. Our results demonstrate that the Akron cluster successfully exhibited resilience. This is important from a theoretical vantage point as well. Van der Vegt, Essens, Wahlström and George (2015, p. 973) observed that to "*understand a system's resilience, it is important to identify the capabilities and capacities of important parts of the system, and to examine how they interact with one another and with their environment to predict key performance outcomes at different levels of analysis before and after a disruptive event*." We take a small but impactful step in this regard. Our contribution is in line with the recent findings in the industrial marketing literature that highlights the role of 'border agents" or individual actors in fueling innovation and creating dynamic capabilities in industrial networks (Cabanelas et al., 2013).

Finally, we aim to add to the proliferating literature that stresses the importance of "local contexts in global business" (Meyer et al., 2011). We achieve this by depicting the evolution of a major U.S. cluster in terms of its innovation capabilities. A recent estimate suggests that 65% of U.S. business leaders consider clusters as one of the key sources of economic strength. Our effort provides a more nuanced understanding of cluster evolution by tracing its trajectory over time and space. A cluster that fails to evolve will eventually die. However, the mere existence of specific evolutionary characteristics is no guarantee of cluster success.

Our model of Table 1 may be used to provide a contextual view of Akron by comparing it to other U.S. clusters like Silicon Valley and Detroit. In the case of Silicon Valley, there is evidence of both orchestration and spawning generated by locally headquartered MNE giants (e.g., Apple, Google, Intel, Cisco). We also see significant cluster success along a range of dimensions including global innovation leadership and the local urban outcomes of employment, value creation and quality of life. In Detroit, there is evidence of orchestration that is traced to the Big Three auto assemblers (GM, Ford and Chrysler, even though the last of these has been in foreign ownership for much of the current century). However, there is very limited evidence of spawning in the Motor City, perhaps due to the fact that these firms are rooted in the twentieth century "managerial economy" rather than the twenty-first century "entrepreneurial economy" (Audretsch & Thurik, 2001). The cluster has continued to be at the center of the global automotive industry's innovation system, but local employment, wealth creation and quality of life all leave much to be desired (Hannigan et al., 2015). In the case of Akron, we see evidence of both orchestration (traced mainly to Goodyear, the sole surviving local MNE giant) and spawning (centered more on the efforts of UA). However, neither of these processes has achieved significant scale. Overall, it would be fair to say that the cluster has transformed itself and survived, but it has not achieved notable success along any one dimension of cluster performance.

It is important to note that this evolution cannot be fully understood without highlighting the importance of the key institutions of this cluster. We emphasize the roles played by anchor firms and UA in providing a common platform for knowledge creation and diffusion, not least by attracting distant human talent to the cluster. Moreover, we also document how a close and interactive relationship between cluster firms, universities and entrepreneurs accentuates new business formation in a cluster and promotes the economic health of a region. From an industrial marketing perspective, this finding represents a shift from viewing changes in industrial networks from an emergent mode to an 'intentional' mode (Matthyssens et al., 2013). In other words, cluster evolution can be governed from within to create network-wide value, and drive evolution. This is a shift from a deterministic, external environment-based model to a more internally driven explanation of industrial cluster evolution (Rampersad, Quester, & Troshani, 2010; Ritvala & Salmi, 2010).

This research also offers relevant implications for managers and policy makers. First, as pointed out by Shih and Chai (2015), healthy clusters leverage core institutions, which may be both private and public organizations. The survival of the Akron cluster is an illustration of the critical role played by collaboration between anchor private companies, such as Goodyear, and universities in determining and fostering the technical evolution of the cluster. The creation of these linkages generated the technical breadth to support and facilitate the transition. Second, our analysis suggests that managers of companies located in a cluster should invest in creating knowledge networks that are locally anchored but with strong international linkages. International connectivity enables the access to global hubs of specialized and complementary knowledge, which should be coupled to the critical mass of competencies embedded within the cluster's boundaries (Hannigan et al., 2015). Third, the Akron cluster provides an example of the necessity for companies located in traditional advanced economy clusters to redeploy their technical competences to move from laboratory-science-based innovation toward more design-driven processes.

7. Limitations and future research

As with all studies, this research has limitations that are worth noting. First, this study tracks the evolution of the Akron cluster over time using patent data as proxy of innovative capabilities and performance. Future studies may complement this analysis using different typologies of data, such as new products. Second, our data suggest a growing pattern of design-driven innovation as a direction of evolution of the Akron cluster. However, it would be interesting to assess how general this trend is. In other words, whether it is limited to specific industries or technologies, or it is applicable to all major traditional clusters located in advanced economies. We leave that to future studies. Finally, we study the international connectivity linked to the Akron cluster using knowledge collaboration derived from patent data. Therefore, we do not attempt to further explain the underlying mechanisms of these collaborations, and more interestingly how they evolve over time. Future studies may delve deeper and analyze the genesis and organization of these international linkages and collaborations.

References

Audretsch, D. B., & Thurik, A. R. (2001). What's new about the new economy? Sources of growth in the managed and entrepreneurial economies. *Industrial and Corporate Change*, *10*(1), 267–315.

Awate, S., Larsen, M., & Mudambi, R. (2012). EMNE catch-up strategies in the wind turbine industry: Is there a trade-off between output and innovation capabilities? *Global Strategy Journal*, *2*(3), 205–223.

Ball, E. N., & Preston, K. G. (2014). University commercialization models: The University of Akron. *Computer*, *8*, 28–36.

Breschi, S., & Lenzi, C. (2015). The role of external linkages and gatekeepers for the renewal and expansion of US cities' knowledge base, 1990–2004. *Regional Studies*, *49*(5), 782–797.

Breschi, S., & Lenzi, C. (2016). Co-invention networks and inventive productivity in US cities. *Journal of Urban Economics*, *92*, 66–75.

Bruce, M., & Bessant, J. R. (2002). *Design in business: Strategic innovation through design*. Essex: Pearson Education.

Buenstorf, G., & Klepper, S. (2009). Heritage and agglomeration: The Akron tyre cluster revisited. *The Economic Journal*, *119*(537), 705–733.

Beunstorf, G., & Klepper, S. (2010). Why does entry cluster geographically? Evidence from the U.S. tire industry. *Journal of Urban Economics*, *68*(2), 103–114.

Cabanelas, P., Omil, J. C., & Vázquez, X. H. (2013). A methodology for the construction of dynamic capabilities in industrial networks: The role of border agents. *Industrial Marketing Management*, *42*(6), 992–1003.

Cano-Kollmann, M., Cantwell, J., Hannigan, T. J., Mudambi, R., & Song, J. (2016). Knowledge connectivity: An agenda for innovation research in international business. *Journal of International Business Studies*, *47*(3), 255–262.

Cantwell, J. (1989). *Technological innovation and multinational corporations*. London: Basil Blackwell.

Cantwell, J., & Mudambi, R. (2005). MNE competence-creating subsidiary mandates. *Strategic Management Journal*, *26*(12), 1109–1128.

Cantwell, J., & Mudambi, R. (2011). Physical attraction and the geography of knowledge sourcing in multinational enterprises. *Global Strategy Journal*, *1*(3–4), 206–232.

Carlsson, B., & Mudambi, R. (2003). Globalization, entrepreneurship and public policy: A systems view. *Industry and Innovation*, *10*(1), 103–116.

Casper, S. (2007). How do technology clusters emerge and become sustainable? Social network formation and inter-firm mobility within the San Diego biotechnology cluster. *Research Policy*, *36*(4), 438–455.

Corsaro, D., Cantù, C., & Tunisini, A. (2012). Actors' heterogeneity in innovation networks. *Industrial Marketing Management*, *41*(5), 780–789.

Datta, A., Mukherjee, D., & Jessup, L. (2015). Understanding commercialization of technological innovation: Taking stock and moving forward. *R&D Management*, *45*(3), 215–249.

Delgado, M., Porter, M., & Stern, S. (2016). Defining clusters of related industries. *Journal of Economic Geography*, *16*(1), 1–38.

Engel, J. S. (2015). Global clusters of innovation: Lessons from Silicon Valley. *California Management Review*, *57*(2), 36–65.

Felzensztein, C., Gimmon, E., & Aqueveque, C. (2012). Entrepreneurship at the periphery: Exploring framework conditions in core and peripheral locations. *Entrepreneurship: Theory and Practice*, *37*(4), 815–835.

Felzensztein, C., Stringer, C., Benson-Rea, M., & Freeman, S. (2014). International marketing strategies in industrial clusters: Insights from the southern hemisphere. *Journal of Business Research*, *67*(5), 837–846.

Fleming, L., & Sorenson, O. (2001). Technology as a complex adaptive system: Evidence from patent data. *Research Policy*, *30*(7), 1019–1039.

Fleming, L., King, C., III, & Juda, A. I. (2007). Small worlds and regional innovation. *Organization Science*, *18*(6), 938–954.

Fornahl, D., Hassink, R., Klaerding, C., Mossig, I., & Schröder, H. (2012). From the old path of shipbuilding onto the new path of offshore wind energy? The case of northern Germany. *European Planning Studies*, *20*(5), 835–855.

Giuliani, E. (2013). Network dynamics in regional clusters: Evidence from Chile. *Research Policy*, *42*(8), 1406–1419.

Hall, B., Jaffe, A. B., & Trajtenberg, M. (2001). The NBER patent citation data file: Lessons, insights and methodological tools. *NBER working paper 8498*. Cambridge, MA: National Bureau of Economic Research.

Hannigan, T. J., Cano-Kollmann, M., & Mudambi, R. (2015). Thriving innovation amidst manufacturing decline: The Detroit auto cluster and the resilience of local knowledge production. *Industrial and Corporate Change*, *24*(3), 613–634.

Lester, R. (2005). Universities, innovation, and the competitiveness of local economies. *A summary report from the local innovation systems project: Phase I. Massachusetts Institute of Technology, industrial performance center, working paper series*.

Li, G. C., Lai, R., D'Amour, A., Doolin, D. M., Sun, Y., Torvik, V. I., ... Fleming, L. (2014). Disambiguation and co-authorship networks of the US patent inventor database (1975–2010). *Research Policy*, *43*(6), 941–955.

Lin, H. M., Huang, H. C., Lin, C. P., & Hsu, W. C. (2012). How to manage strategic alliances in OEM-based industrial clusters: Network embeddedness and formal governance mechanisms. *Industrial Marketing Management*, *41*(3), 449–459.

Lorenzen, M., & Mudambi, R. (2013). Clusters, connectivity and catch-up: Bollywood and Bangalore in the global economy. *Journal of Economic Geography*, *13*(3), 501–534.

Lundvall, B. (2007). National innovation systems: Analytical concept and development tool. *Industry and Innovation*, *14*(1), 95–119.

Marshall, A. (1920). *Principles of economics.* London: MacMillan.

Martin, R. (2010). Roepke lecture in economic geography—Rethinking regional path dependence: Beyond lock-in to evolution. *Economic Geography*, *86*(1), 1–27.

Martin, R., & Sunley, P. (2006). Path dependence and regional economic evolution. *Journal of Economic Geography*, *6*(4), 395–437.

Matthyssens, P., Vandenbempt, K., & Van Bockhaven, W. (2013). Structural antecedents of institutional entrepreneurship in industrial networks: A critical realist explanation. *Industrial Marketing Management*, *42*(3), 405–420.

McCann, P., & Mudambi, R. (2005). Analytical differences in the economics of geography: The case of the multinational firm. *Environment & Planning A*, *37*(10), 1857–1876.

Menzel, M., & Fornahl, D. (2010). Cluster lifecycles: Dimensions and rationales of cluster evolution. *Industrial and Corporate Change*, *19*(1), 205–238.

Meyer, K. E., Mudambi, R., & Narula, R. (2011). Multinational enterprises and local contexts: The opportunities and challenges of multiple embeddedness. *Journal of Management Studies*, *48*(2), 235–252.

Moodysson, J., & Sack, L. (2016). Institutional stability and industry renewal: Diverging trajectories in the Cognac beverage cluster. *Industry and Innovation*, *23*(5), 1–17.

Mudambi, R. (1998). Review of International financial management. *Journal of Finance*, *53*(3), 1194–1197.

Mudambi, R. (2008). Location, control and innovation in knowledge-intensive industries. *Journal of Economic Geography*, *8*(5), 699–725.

Mudambi, R., & Santangelo, G. (2016). From shallow resource pools to emerging clusters: The role of MNE subsidiaries in peripheral areas. *Regional Studies* (forthcoming).

Mudambi, S. M., Oliva, T. A., & Thomas, E. F. (2009). Industrial marketing firms and knowledge transfer: Toward a basic typology of community structures. *Industrial Marketing Management*, *38*(2), 181–190.

Narula, R. (2002). Innovations systems and "inertia" in R&D location: Norwegian firms and the role of systemic lock-in. *Research Policy*, *31*(5), 795–816.

Owen-Smith, J., & Powell, W. W. (2004). Knowledge networks as channels and conduits: The effects of spillovers in the Boston biotechnology community. *Organization Science*, *15*(1), 5–21.

Perez-Aleman, P. (2011). Collective learning in global diffusion: Spreading quality standards in a developing country cluster. *Organization Science*, *22*(1), 173–189.

Rampersad, G., Quester, P., & Troshani, I. (2010). Managing innovation networks: Exploratory evidence from ICT, biotechnology and nanotechnology networks. *Industrial Marketing Management*, *39*, 793–805.

Ritvala, T., & Salmi, A. (2010). Value-based network mobilization: A case study of modern environmental networkers. *Industrial Marketing Management*, *39*(6), 898–907.

Romanelli, E., & Khessina, O. (2005). Regional industrial identity: Cluster configurations and economic development. *Organization Science*, *16*(4), 344–358.

Safford, S. (2004). Searching for Silicon Valley in the Rust Belt: The evolution of knowledge networks in Akron and Rochester. *Industry Studies Working Paper, 2004–06*.

Scalera, V. G., Mukherjee, D., Perri, A., & Mudambi, R. (2014). A longitudinal study of MNE innovation: The case of Goodyear. *Multinational Business Review*, *22*(3), 270–293.

Shih, W. C., & Chai, S. (2015). What to know about locating in a cluster. *Sloan Management Review*, *57*(1), 8–11.

Simmie, J. (2004). Innovation and clustering in the globalized international economy. *Urban Studies*, *41*, 1095–1112.

Spencer, J. W. (2008). The impact of multinational enterprise strategy on indigenous enterprises: Horizontal spillovers and crowding out in developing countries. *Academy of Management Review*, *33*(2), 341–361.

Storper, M., & Venables, A. J. (2004). Buzz: Face-to-face contact and the urban economy. *Journal of Economic Geography*, *4*(4), 351–370.

Sull, D. N. (1999). The dynamics of standing still: Firestone Tire & Rubber and the radial revolution. *The Business History Review*, *73*(3), 430–464.

Sull, D. N., Tedlow, R. S., & Rosenbloom, R. S. (1997). Managerial commitments and technological change in the US tire industry. *Industrial and Corporate Change*, *6*(2), 461–500.

Tallman, S., & Phene, A. (2007). Leveraging knowledge across geographic boundaries. *Organization Science*, *18*(2), 252–260.

Tappi, D. (2005). Clusters, adaptation and extroversion: A cognitive and entrepreneurial analysis of the Marche music cluster. *European Urban and Regional Studies*, *12*(3), 289–307.

Uzzi, B. (1997). Social structure and competition in interfirm networks: The paradox of embeddedness. *Administrative Science Quarterly*, *42*, 35–67.

University of Akron (2015). *UARF: major roles of activities.*

Van Assche, A. (2008). Modularity and the organization of international production. *Japan and the World Economy*, *20*(3), 353–368.

Van Der Vegt, G. S., Essens, P., Wahlström, M., & George, G. (2015). Managing risk and resilience. *Academy of Management Journal*, *58*(4), 971–980.

Vernon, R. (1966). International investment and international trade in the product cycle. *Quarterly Journal of Economics*, *80*(2), 190–207.

Wolfe, D. A., & Gertler, M. S. (2004). Clusters from the inside and out: Local dynamics and global linkages. *Urban Studies*, *41*(5–6), 1071–1093.

Yang, H., Phelps, C., & Steensma, H. K. (2010). Learning from what others have learned from you: The effects of knowledge spillovers on originating firms. *Academy of Management Journal*, *53*(2), 371–389.

Zucchella, A. (2006). Local cluster dynamics: Trajectories of mature industrial districts between decline and multiple embeddedness. *Journal of Institutional Economics*, *2*(01), 21–44.