Paper to be presented at
the DRUID16 20th Anniversary Conference
Copenhagen, June 13-15, 2016

The Co-location of Innovation and Production in Clusters

Mercedes Delgado
MIT Sloan
TIES
delgadom@mit.edu

Abstract

An active debate has centered on the role of the co-location of innovation and production in the economic performance of regions and their firms. Prior studies find that innovation and employment creation is greater within regional clusters of related industries that have a large initial presence of both innovation activity and production. At the firm-level, studies of the spatial organization of firms have found evidence of co-location of same-firm R&D and manufacturing facilities that has been linked to improved firm performance. Taken together, these studies suggest that between-firms and within-firm co-location of innovation and production is associated with external and internal agglomerations. However, the extent and benefit of co-location may vary across different economic activities. Using a newly available set of cluster definitions and data from the U.S. Cluster Mapping Project, this paper examines for what types of clusters the co-location of innovation and production (employment) seems more important, and how these co-location patterns have changed from 1998 through 2011 in the United States. The findings suggest that there is a meaningful co-location of patenting and employment within regional clusters for most cluster categories, and especially for Information Technology and Analytical Instruments, Oil and Gas Production and Transportation, and Automotive. However, some cluster categories have experienced a large decline in co-location over time (e.g., Information Technology and Analytical Instruments). The paper discusses factors that may drive these changes and, in particular, the role that suppliers play in the co-location of innovation and production.

Jelcodes:R12,R11

The Co-location of Innovation and Production in Clusters[*]

Mercedes Delgado, MIT Sloan and Institute for Strategy and Competitiveness

06/09/2016

PRELIMINARY AND INCOMPLETE

An active debate has centered on the role of the co-location of innovation and production in the economic performance of regions and their firms. Prior studies find that innovation and employment creation is greater within regional clusters of related industries that have a large initial presence of both innovation activity and production. At the firm-level, studies of the spatial organization of firms have found evidence of co-location of same-firm R&D and manufacturing facilities that has been linked to improved firm performance. Taken together, these studies suggest that between-firms and within-firm co-location of innovation and production is associated with external and internal agglomerations. However, the extent and benefit of co-location may vary across different economic activities. Using a newly available set of cluster definitions and data from the U.S. Cluster Mapping Project, this paper examines for what types of clusters the co-location of innovation (patenting) and production (employment) seems more important, and how these co-location patterns have changed from 1998 through 2011 in the United States. The findings suggest that there is a meaningful co-location of patenting and employment within regional clusters for most cluster categories, and especially for Information Technology and Analytical Instruments, Oil and Gas Production and Transportation, and Automotive. However, some cluster categories have experienced a large decline in co-location over time (e.g., Information Technology and Analytical Instruments). The paper discusses factors that may drive these changes and, in particular, the role that suppliers play in the co-location of innovation and production.

[*] Juan Alcacer, Gordon Clark, and Maryann Feldman contributed helpful suggestions. I am particularly grateful for insightful comments by participants at the 4th Global Conference on Economic Geography at University of Oxford.
Author contact information: Mercedes Delgado (MIT Sloan, ISC; delgadom@mit.edu).

1. Introduction

An ongoing debate has focused on whether the co-location of innovation and production is important for the economic performance of a country and its regions (see e.g., Rosemberg, 1963; Dertouzos et al., 1989; Pisano, 1997; Pisano and Shih, 2012; Helper et al., 2012; Porter and Rivkin, 2012; Berger, 2013; Delgado, Porter, and Stern, 2014). This question has become even more important as the U.S. economy has shown an increasing decline in manufacturing employment in the last decades (Acemoglu et al., 2015). There is a concern that by reducing the production (manufacturing) capacity in a country, the subsequent innovation and entrepreneurial capacity of the country may be reduced because there are learning externalities from the production process that can improve the ability to innovate and the efficiency of the innovation process (see e.g., Rosemberg, 1963; Pisano, 1997). These externalities can be particularly important for knowledge intensive activities (Vernon, 1996; Duranton and Puga, 2001).

Motivated by this debate and building on prior work, this paper examines how the co-location of innovation and production varies across different cluster categories —groups of closely related industries—and over time in the United States. The goal is to inform the debate and offer some implications for future research on the innovation potential of regions and their firms.

Prior studies find that economies of agglomeration of various types may arise in regional clusters, including buyer-supplier linkages, access to demand, labor occupation linkages, and knowledge linkages (Marshall, 1920; Porter, 1990, 1998; Feldman, 1994; Glaeser and Kerr, 2009; Delgado, Porter, and Stern, 2014; among others). Firms and individuals' socioeconomic networks play an important role for these agglomeration economies to arise (Saxenian, 1994; Storper, 1995; Rosenthal and Strange, 2003; Bathelt, Malmberg, and Maskell, 2004; Feldman, Francis, and Bercovitz, 2005).

Recent studies find duality of innovation and employment performance within clusters (Delgado, Porter, and Stern, 2014). The innovation strength of the cluster positively relates to the employment growth of the industries in the cluster; and the employment strength of the cluster positively relates to the innovation growth of the industries in the cluster. This duality of innovation and employment within strong clusters suggests that various types of agglomeration are at work including input-output linkages and access to demand as well as knowledge spillovers. Hence, innovation in a region is better understood in the context of regional clusters of related industries (Porter, 1990, 1998, 2003; Feldman and Audretsch, 1999), rather than in the context of single industries or single technology classes. Measuring "innovation clusters" purely based on patenting activity, while important to measure knowledge linkages, could be limiting since it abstracts from the potential complementarities between the innovation and production strength of clusters.

While between-firm linkages in regional clusters are important for innovation outcomes, and may be facilitated by the co-location of production and innovation, within-firm linkages can also explain innovation outcomes in regions. Studies of the spatial organization of firms have found evidence of co-location of same-firm R&D and manufacturing facilities that has been linked to improved firm performance (Adams and Jaffe, 1996; Pisano, 1997; Van den Bulte and Moenaert, 1998; Chacar and Lieberman, 2003; Tecu, 2011; Alcacer and Delgado, 2016). There are recent examples of large firms that seem to have chosen to exploit internal agglomerations by co-locating a large part of the firm's value chain in a particular location (e.g., Facebook's new building in Menlo Park, California, which fits thousands of people (the largest open floor plan in the world); or electric carmaker Tesla Motors' plan to build a 5 billion "gigafactory" in Nevada to produce all its batteries). In some cases, firms exploit internal agglomerations in locations with strong clusters (e.g., Facebook in Silicon Valley), creating some complementarities between intra-firm and between-firm linkages (Cohen and Levinthal, 1990; Alcacer and Delgado, 2016).

Taken together, these studies suggest that the between-firm and within-firm co-location of innovation and production is associated with external and internal agglomerations that may result in better performance of regions. The goal of this paper is to shed light on the distinct factors that can facilitate the co-location of innovation and production in a location, and outline some questions for future research. This paper will examine these questions at the regional cluster level—where clusters are geographic concentrations of industries related by knowledge, skills, inputs, demand, and/or other linkages.

Using a newly available set of cluster definitions (Delgado, Porter, and Stern, 2016) and publicly available data from the U.S. Cluster Mapping Project, this paper will examine in which types of clusters the co-location of innovation and production is more prevalent (e.g., Information Technology versus Footwear), and how these co-location patterns have changed from 1998 through 2011 in the United States. Innovation is measured by patent activity, and "production" of goods and services is broadly measured by employment in both manufacturing and service activities in the cluster.

The paper develops new indicators of the co-location of innovation (patenting) and production (employment) in clusters. One indicator captures the dual specialization of clusters in patenting and employment (referred to as *Dual Specialization Correlation* (DSC)). The other indicator captures the concentration of patenting in the clusters with high employment specialization (referred to as *Strong Clusters Patenting* (SCP)). We find that there is meaningful co-location of employment and patenting in regional clusters, and it holds for many cluster categories. The clusters categories with the largest co-location as of 2011 are Information Technology (IT) and Analytical Instruments, Oil and Gas Production and Transportation, and Automotive. We find important changes over time in co-location patterns for specific clusters. For example, the dual specialization of the IT and Analytical Instruments clusters has declined significantly through 1998–2011.

The rest of the paper is organized as follows. Section 2 reviews the literature and examines the co-location of patenting and employment across U.S. clusters. Section 3 studies the evolution of the Information Technology and Analytical Instruments cluster (the top-1 cluster category in patenting), and the evolution of its top-1 regional cluster: San Jose-San Francisco-Oakland, CA. Similarly, Section 4 studies the evolution of Automotive and its top-1 region: Detroit-Warren-Flint, MI. Section 5 discusses the role of suppliers in the production and innovation capacity of a region and its clusters. Section 6 concludes and offers some areas for future research.

2. The Geography of Innovation and Production: Co-location in Clusters

An increasing concern among policymakers, practitioners, and business leaders is whether the geographical separation of manufacturing and innovation could limit the subsequent capacity of a location to innovate and create new businesses and/or could expose a region to greater import competition. This concern relates to the debate on whether the co-location of R&D and production is important for regional performance (Dertouzos et al., 1989; Pisano et al. 1997, 2012; Ketokivi and Ali-Yrkkö, 2009; Porter and Rivkin, 2012; Berger, 2013).

Prior studies have found that innovation and production are each geographically concentrated (Audretsch, 1998; Audretsch and Feldman, 1996; Alcacer, 2006; Helper, Krueger, and Wial, 2012), but the geographically bounded complementarities between these two activities are not fully understood. Economic geography theory predicts benefits from co-locating innovation and production in industries with high knowledge intensity where the manufacturing process is not standardized (Vernon, 1996; Duranton and Puga, 2001). The findings from some industry studies are consistent with this theory (e.g., Pisano (1997) and Alcacer and Delgado (2016) for Biopharmaceuticals, and Fuchs and Kirchain (2010) for Optoelectronics).

Relatedly, Delgado, Porter, and Stern (2014) find complementarities between the innovation and employment strength of a cluster that result in higher growth in innovation and employment of the industries located in the cluster. The dual strength of clusters also contributes to the creation of new industries within the cluster. This suggests that the co-location of innovation and production in clusters is important for regional performance. Drawing on this work, this paper will examine what clusters in the U.S. have greater dual specialization in patenting (innovation) and employment (production), and how these patterns have changed in 14 years (1998–2011 period).

We investigate this dual specialization within clusters using a publicly available dataset developed by the U.S. Cluster Mapping Project (USCMP). This database includes a set of U.S. Benchmark Cluster Definitions (BCD) developed in Delgado, Porter, and Stern (2016). They group related traded industries into clusters based on the strength of input-output links, shared labor occupations, and co-location patterns of industries.[1] The BCD delineates 51 clusters incorporating 778 traded industries (6-digit NAICS) covering services and manufacturing.[2] Data from the County Business Patterns (CBP) dataset is coded with the BCD to map the cluster specialization of 179 mutually exclusive Economic Areas (EAs) in the U.S. (as defined by the Bureau of Economic Analysis).

Since our main measure of innovativeness is patenting we focus the analysis on 35 U.S. cluster categories with more than 100 patents granted by the United States Patent and Trademark Office (USPTO) in 2011. This criterion excludes Financial Services, Insurance Services, and other clusters where the number of patents is very low, since their innovation capacity is likely not well captured by patenting. The clusters that are the focus of the analysis are listed in Table 1. They account for more than 90% of U.S. patents and over 85% of the traded employment as of 2011.

2.1 The Co-location of Employment and Patenting in Clusters

To develop indicators of the co-location of innovation and production in clusters we first need to assess the innovation and production strength of regional clusters. The innovation strength of a regional cluster is defined as the patent specialization of the region *r* in the cluster *c* ($Cluster\ Specialization_{Patent,cr}$) using a Location Quotient (LQ) (i.e., the share of EA *r* traded patents in the EA-cluster as compared to the share of U.S. traded patents in the U.S. cluster).

$$\text{Cluster Specialization}_{\text{Patent, c,r}} = (\text{Patent}_{c,r} / \text{Patent}_{r}) / (\text{Patent}_{c,US} / \text{Patent}_{US}) \qquad (1).$$

Similarly, the production strength of a regional cluster is measured by the employment specialization of the region *r* in the cluster *c* ($Cluster\ Specialization_{Emp,cr}$):

$$\text{Cluster Specialization}_{\text{Emp, c,r}} = (\text{Emp}_{c,r} / \text{Emp}_{r}) / (\text{Emp}_{c,US} / \text{Emp}_{US}) \qquad (2).$$

[1] A detailed literature review on how to empirically define clusters as well as detailed explanations of the BCD is offered in the paper. The set of BCD is available at the USCMP website (http://clustermapping.us/).

[2] Traded industries are those that concentrate in particular regions and sell products or services across regions and countries, in contrast to local industries serving primarily the local market (Porter, 2003; Delgado, Bryden and Zyontz, 2014).

While regional clusters could decline in response to shocks (see e.g., Porter, 1990, 1998; Swann, 1992; Bathelt and Boggs, 2003), the overall strength of regional clusters tends to be long lasting and reflects the comparative advantage of the region (Saxenian, 1994; Porter, 1990, 1998, 2003; Bresnahan and Gambardella, 2004 Delgado, Porter, Stern, 2010, 2014, among others). The persistence of the strength of regional clusters is illustrated in Table 2, which shows the cluster specialization of regions (Economic Areas in the U.S.) in terms of employment ($\textit{Cluster Specialization}_{Emp}$) and patenting ($\textit{Cluster Specialization}_{Patent}$) in 2011 and with a 10-year lag.

We find that regional cluster specialization in terms of employment is highly correlated over time (the correlation coefficient is 0.85). The innovation strength of clusters can also be persistent, as evidenced by the innovation resilience of Silicon Valley (Saxenian, 1994; Bresnahan and Gambardella, 2004). In our data, the innovation strength of a cluster in terms of patenting specialization is significantly correlated over time, but to a lower extent than the employment strength (the correlation coefficient is 0.33 vs. 0.85; Table 2). There are relevant differences across cluster categories in the persistence of patenting strength. For example, consider the IT and Analytical Instruments cluster (Table 1). This is the top-1 U.S. cluster in terms of count of granted patents (with 33% of all traded patents), patent intensity (31 patents per 1,000 employees) and STEM (Science, Technology, Engineering and Math) occupations (42% of the cluster employment is in STEM).[3] For this highly innovative and knowledge intensive cluster category, the innovation strength of the regional clusters is highly persistent (the correlation between patenting strength in a location in 2011 and 10 years earlier is 0.66, significantly greater than the 0.33 value across all 35 traded clusters).

If there are complementarities between the innovation and production in clusters (Delgado, Porter, and Stern, 2014), we will expect the employment and patenting strength of clusters to be somewhat correlated across regions. We use the correlation between regional cluster strength in employment and patenting to build a new measure of the extent of co-location of employment and innovation in clusters (referred to as *Dual Specialization Correlation* (DSC)):

$$DSC_{ct} = Corr(\text{Cluster Specialization}_{Emp,crt}, \text{ Cluster Specialization}_{Patent,crt}) \quad (3).$$

[3] We use Hecker's (2005) categorization of STEM occupations and the BLS data to compute the percent of the national cluster employment in STEM occupations.

Table 2 shows that *Cluster Specialization*$_{Emp}$ and *Cluster Specialization*$_{Patent}$ are indeed positively correlated contemporaneously (e.g., correlation coefficients of 0.25 across all existing regional clusters in all 35 cluster categories in 2011) and over time.

We compute the DSC for each of the 35 cluster categories *c* each year to examine differences in their patterns of colocation of employment and patenting. For example, for the IT and Analytical Instruments cluster, the DSC_{ct} in 2011 is the correlation between a regional cluster's employment and patenting specialization across all the existing clusters (i.e., 174 EAs with more than 10 employees in the cluster). Table 1 shows that for this cluster the dual specialization correlation in 2011 is 0.53 (versus 0.25 across all cluster categories).

We also develop an alternative measure that captures both the co-location of employment and patenting and the concentration of patenting. For any given cluster category *c*, we examine the share of the national cluster patents that are located in the strong clusters in terms of employment.[4] This measure is referred to as *Strong Clusters Patenting* (SCP):

$$\text{Strong Clusters Patenting (SCP)}_{ct} = \frac{\sum_{crt \in \text{Strong Cluster}} \text{Patents}_{crt}}{\text{Patents}_{cUSt}} \qquad (4).$$

To assess the concentration of employment in strong regional clusters, we also compute the percent of the given national cluster employment in the strong clusters. This measure is referred to as *Strong Clusters Employment* (SCE):

$$\text{Strong Clusters Employment (SCE)}_{ct} = \frac{\sum_{crt \in \text{Strong Cluster}} \text{Employment}_{crt}}{\text{Employment}_{cUSt}} \qquad (5).$$

For example, in 2011 the strong IT and Analytical regional clusters are listed in Table 5. These regional clusters accounted for 70% of the national cluster patents and 62% of the national cluster employment. These SCP and SCE scores are greater than the average SCP of 27% and SCE of 50% across clusters (Table 3). This suggests a significant co-location and concentration of patenting and employment in the strong IT and Analytical Instruments clusters.

[4] The strong clusters are defined as those in Economic Areas (EAs) with high employment specialization in the cluster in a particular year. They meet these criteria: Location Quotient (LQ) of cluster employment must be greater than the 75th percentile (measured across all EAs with non-zero employment in the cluster). To differentiate marginal cases in small EAs, the LQ must be greater than 1.0, the share of U.S. cluster employment greater than the 25th percentile, and the share of U.S. Cluster Establishments greater than the 25th percentile.

The DSC and SCP measures, while related (correlation coefficient of 0.4), can have different patterns. For example, if very few large regional clusters have high patenting and employment, the percent of patents in strong clusters could be high (SCP score), but the DSC score could be small if there are many regions with single strength in employment or patenting activity or no strength. For example, this seems to be the case for Biopharmaceuticals with a DSC score of 0.11 in 2011 (below the 0.22 average across clusters), but a very large patenting and employment concentration in the strongest clusters (SCP score of 66% and SCE score of 77%; Table 1). Thus, these variables when examined together can offer an informative picture of the co-location of innovation and employment across regions in the United States.

The U.S. clusters that have all DSC, SCP, and SCE above the median in 2011 are (ranked by patent count): Information Technology and Analytical Instruments, Communications Equipment and Services, Aerospace Vehicles and Defense, Automotive, Medical Devices, Oil and Gas Production and Transportation, Marketing, Design, and Publishing, and Water Transportation (Table 1). Most of these cluster categories have a high prevalence of STEM occupations (Column 3 in Table 1).[5] This suggests that the co-location of innovation and production can be particularly important for knowledge intensive clusters, as predicted by the theory (Vernon, 1996; Duranton and Puga, 2001).

2.2 The Dynamics of the Co-location of Employment and Patenting in Clusters

To examine the changes over time in co-location across U.S. clusters, we compute the DSC score annually and by cluster category (DSC_{ct}). Table 3 shows the average DSC_{ct} score across all the 35 traded clusters for each year. In the U.S. economy, the dual specialization in patenting and employment has remained significant during the whole period, with an annual average DSC_{ct} score of 0.20. The average DSC_{ct} declined slightly from 1998 to 2011 (from 0.24 to 0.22). This decline was accompanied by a small decrease in the average SCP_{ct} and SCE_{ct} (-1% decline in each indicator).

We also examine the percentage of total traded patents and employment accounted for all the employment-strong regional clusters in all 35 cluster categories. The findings suggest that

[5] All U.S. clusters, but Water Transportation, have a STEM content above the U.S. average (5%).

innovation has been increasingly concentrated in strong clusters (SCP_{All} increased by 4% from 1998 to 2011). The cluster categories that have contributed to this increase include IT and Analytical Instruments, Biopharmaceuticals, and Aerospace Vehicles and Defense. In contrast, employment has become less concentrated in strong clusters (SCE declined by 8% during the period), and is largely due to the decline in SCE of the Business Services cluster.

There are relevant differences across cluster categories in the evolution of their DSC. The clusters that have registered a larger decline in DSC in 2011 relative to 1998 are: Upstream Metal Manufacturing; Footwear; Textile Manufacturing; Paper and Packaging; Upstream and Downstream Chemical Products; Communications Equipment and Services; Information Technology and Analytical Instruments; and Biopharmaceuticals (Table 1). For most of these clusters, the SCP declined as well (e.g., -21% decline for Downstream Chemical Products). For two clusters, SCP is increasing despite the large decline in DSC. One is Biopharmaceuticals, which experienced a large increase in both SCP and SCE (12% and 8%, respectively). This suggests that employment and innovation in Biopharmaceuticals have become increasingly concentrated in a few (large) regions (including Boston, Los Angeles, and San Diego EAs), while in many other regions there is no such co-location (i.e., regions are specializing in either R&D or in manufacturing/marketing activities). The other cluster with a large decrease in DSC, but an increase is SCP, is the IT and Analytical Instruments cluster. We next examine this cluster in detail.

3. The Case of Information Technology and Analytical Instruments Clusters

In the set of U.S. Benchmark Cluster Definitions (BCD), the IT and Analytical Instruments cluster consists of products such as computers, software (including design, development, publishing, and reproduction), audio-visual equipment, laboratory instruments, and medical apparatus. The cluster also includes the standard and precision electronics used by these products (e.g., circuit boards and semiconductor devices).[6]

As mentioned earlier, this cluster category is the top-1 by patenting and prevalence of STEM occupations. For this cluster, the DSC score in 2011 is one of the largest (ranking 2nd among the 35 cluster categories; Table 1). The large DSC of this cluster can be illustrated by looking at

[6] See Delgado, Porter, and Stern (2016) for the set of industries included in the cluster.

the specialization in patenting of the strongest clusters in terms of employment (Table 5). For example, the top-5 regional clusters by employment strength all have high patenting strength as well (i.e. the Boise City-Nampa, ID; Seattle-Tacoma-Olympia, WA; San Jose-San Francisco-Oakland, CA; Burlington-South Burlington, VT and Austin-Round Rock, TX Economic Areas all have high LQ_{Emp} and LQ_{Patent} values).

While the DSC is high as of 2011, it has declined by 0.22 points during the period (from 0.74 in 1998 to 0.53 in 2011; Table 4). This large decline is due to an increase in the number of clusters with employment strength but low patenting strength.[7]

To better understand the decline in DSC, we examined the set of 33 regional clusters with the high employment strength in 2011 (reported in Table 5 and mapped in Figure 2). Most of these clusters were strong (based on employment) in both 1998 and 2011, but 8 were strong as of 2011 but not in 1998 (e.g., Madison-Baraboo, WI EA or Dayton-Springfield-Greenville, OH). Most of the new strong clusters have very low patenting strength (e.g., Madison-Baraboo, WI has a LQ_{Patent} of 0.6, below the median for the national cluster). The increase in the number of clusters with single employment strength helps explain the decline in the DSC for the IT and Analytical Instruments cluster. If strong clusters in terms of employment fail to improve their innovation strength in the future, they may experience lower employment and innovation growth (Delgado, Porter, and Stern, 2014). Similarly, IT and Analytical Instruments clusters with patenting strength but low employment strength (e.g., New York-Newark-Bridgeport, NY-NJ-CT-PA) may see their ability to grow limited.

While the DSC score declined sharply, the percent of national cluster patents in the strong regional clusters (SCP) has increased during the period, but the strongest regional cluster (located in the San Francisco EA) accounts for the increase. We examine this regional cluster next.

3.1 IT and Analytical Instruments in San Francisco EA

We cannot fully understand IT and Analytical Instruments without examining the evolution of its top-1 regional cluster: the one in San Jose-San Francisco-Oakland, CA (the EA that includes Silicon Valley). During the 1998–2011 period, this cluster had high dual specialization in

[7] The DSC score calculated among the sub-set of employment-strong clusters was 0.79 in 1998 and 0.50 in 2011.

employment and patenting (Table 6). In 2011, the employment and patent specialization were 3.4 and 1.5, respectively (above the 97th percentile value across all EAs with employment in the cluster). This regional cluster accounted for 11% of employment and 25% of patenting in the national cluster.

While it is clear that this region has a very strong cluster, the evolution during 1998–2011 shows a decline in the employment and patenting strengths of the cluster (i.e., LQ_{Emp} declined from 4 to 3.4, and LQ_{Patent} declined from 1.8 to 1.5). This could reflect that the region may be diversifying into other related clusters (such as, Lighting and Electronic Equipment; Distribution and eCommerce; and Medical Devices; Figure 1).

There is asymmetry in the employment and patenting performance of the regional cluster over time. Employment has been declining sharply: both in absolute level (almost 50% decline in employment from 1998–2011) and in the share of the national cluster (dropped from 14% to 11%). In terms of patenting the findings are the opposite: annual patenting increased during the whole period (133% growth rate with granted patents increasing from 3,258 to 7,602), and the share of the national cluster patents increased by 5% (from 20% to 25% of all IT & Analytical Instruments patents). Relatedly, the patent intensity of the cluster and wages have increased significantly over the period (patent intensity increased from 14 to 63 patents per 1,000 employees; and wages almost doubled).

The implications for the future growth of the cluster are unclear. If the reduction in employment reflects a reduction in the capacity to produce goods and services locally (e.g., a decline in the number of suppliers of inputs), this could limit the subsequent innovation capacity of the region. If the reduction in employment is the result of re-allocating production capacity to other related clusters, then the overall innovation potential of the regional cluster and the overall region may not be as greatly affected by the large decline in employment.

4. The Case of the Automotive Clusters

The Automotive cluster category includes establishments along the value chain that are necessary for manufacturing cars, trucks, and other motorized land-based transportation equipment (other than motorcycles). This includes metal mills and foundries, manufacturers of metal automotive parts, and manufacturers of completed automobiles.

This cluster has a high dual specialization in employment and patenting (ranking 6th in 2011 among the 35 national clusters) and high SCP score (ranking 9th). Table 4 shows that the DSC increased by 0.05 points during our period (from 0.32 in 1998 to 0.37 in 2011). The percent of national cluster patents in the strong regional clusters (SCP) has increased by 4% (from 37% to 41%), but the percent of national cluster employment has declined by 2% during the period (from 66% to 64%). To better understand the evolution, we next examine the top-1 regional Automotive cluster.

4.1 Automotive in Detroit EA

The Automotive cluster in the Detroit region is often cited as an example of a cluster in decline. However, as we discuss below, when we consider the Detroit Economic Area (not just Detroit city but also neighboring cities like Lansing and Ann Arbor that are part of the economic market), innovation and employment are highly co-located in this cluster and could contribute to explaining the innovation persistence of the cluster (Hannigan, Cano-Kollmann, and Mudambi, 2015).

During the whole period, this regional cluster had high dual specialization in employment and patenting. In 2011, the employment and patent cluster specialization were 6.2 and 7.1, respectively (above the 99th percentile value across all Automotive clusters). This regional cluster accounted for 12% of employment and 20% of patenting in the national cluster in 2011.

From 1998 to 2011, the strength in patenting increased significantly (from 4.7 to 7.1; from percentile 98th to 99th), and the employment strength remained high. Similar to the IT and Analytical Instruments cluster in the San Francisco EA, there is asymmetry in the employment and patenting performance of the cluster over time. Employment in Automotive in Detroit EA has been declining sharply: both in absolute level (56% decline in employment from 1998–2011) and in the share of the national cluster employment (dropped from 15% to 12%). In terms of patenting the findings are the opposite: annual patenting increased during the whole period (27% growth rate from 1998–2011), and the share of the national cluster patents increased by 3% (from 17% to 20%). Relatedly, the patent intensity of the cluster and wages have increased significantly over the period.

Note that both Automotive in Detroit EA and IT and Analytical Instruments in San Francisco EA have experienced an increase in their innovativeness (by count of patents and patent intensity). The magnitude of the improvement in innovativeness and wages is significantly larger in IT and Analytical Instruments. The concern regarding the decline in employment, which could be associated with lost suppliers and a decline in the production capacity of the regions, applies to both leading clusters. To better assess the growth potential of these clusters, we should also examine their industry and firm composition (e.g., presence of suppliers), and their connections with other related clusters in their regions.

5. Duality of Innovation and Production in Clusters: The Role of Suppliers

Prior work highlights the importance of suppliers for agglomeration economies to arise in a location, and in particular to foster innovation and entrepreneurship (Marshall, 1920; Chinitz, 1961; Porter 1990, 1998; Audretsch and Feldman, 1996; Feldman and Audretsch, 1999; Glaeser and Kerr, 2009; Delgado, Porter, and Stern, 2014; Feldman et al., 2014). When suppliers and their buyers are clustered together, they can be an important mechanism of duality of innovation and production capacity in a location. They can create externalities through shared pools of skills, technologies, knowledge, and specialized inputs. Prior work highlights the importance of nearby suppliers for fostering innovation and entrepreneurship in manufacturing industries (Helper, MacDuffie, and Sabel, 2000; Glaeser and Kerr, 2009). This suggests that the presence of suppliers can improve both the production and the innovation capacity of a region.

But, *who are the suppliers?* Most prior work defines suppliers as manufacturers (e.g., producers of semiconductors or automotive parts).This definition won't capture the suppliers of traded services (e.g., engineering and design services). In recent work, Delgado and Mills (2016) offer the first comprehensive attempt to quantify and characterize the suppliers in the U.S.

economy and examine their role in national performance. To do so, they define Supply Chain (SC) industries as those that primarily sell goods and services to businesses and government versus business-to-consumer (B2C) industries that focus on selling to personal consumption. Most of the firms operating in supply chain industries will be suppliers (i.e., sell mainly to other businesses or to the government). For example, Engineering Services and Biological Product Manufacturing are supply chain industries, and Computer Training and Pharmaceutical Preparation Manufacturing are B2C industries.[8]

Delgado and Mills (2016) find that SC industries compose a large and important segment of the traded economy (more than 20% of U.S. employment and 1million firms). There are many suppliers of traded services both in terms of employment and number of firms: four times as many firms in traded services than in manufacturing. This finding support that the production capacity of a country is broader than its manufacturing capacity of final goods, and includes both manufacturing and service suppliers. Furthermore, they find that much of the innovative activity happens in the suppliers. The segment of SC traded industries has a larger presence of STEM occupations than B2C traded industries (especially suppliers of services), and generates the majority of patents (especially manufacturing suppliers with more than 75% of U.S. patents). Taken together, these findings strongly suggest that suppliers contribute to the innovation and production capacity of a country.

Thus, studies of the co-location of innovation and production in regions should take into account the presence of suppliers of both goods and services. Future work can examine whether the decrease in the dual specialization in some U.S. clusters, such as Information Technology and Analytical instruments, may be the result of the loss of regional suppliers (e.g., substitution of suppliers with import competition and/or of locating suppliers in more distant regions in the United States and other countries). Furthermore, future work should assess the effects of losing regional suppliers in the subsequent innovation and employment growth of regions.

[8] Using the 2002 U.S. Benchmark Input-Output Account of the Bureau of Economic Analysis (BEA), they identify as SC industries those with small (less than one-third) supply of their output to personal consumption expenditures (PCE).

6. Conclusion

Prior studies find that co-location of innovation and production may be associated with economies of agglomeration that result in the better performance of regional clusters. Using data from the U.S. Cluster Mapping Project (USCMP), this paper has examined in which types of cluster categories the co-location of innovation and production (employment) seems more important, and how these co-location patterns changed during the 1998–2011 period in the United States. The paper develops a Dual Specialization Correlation (DSC) indicator that captures the patterns of specialization in employment and patenting of regional clusters that belong to the same cluster category.

The findings suggest that there is a meaningful co-location of patenting and employment within strong regional clusters for most cluster categories, and especially for Information Technology and Analytical Instruments, Oil and Gas Production and Transportation, and Automotive.

Some cluster categories have experienced a large decline in their dual specialization over time. This is the case of Information Technology and Analytical Instruments (the top-1 cluster by patenting in the United States). While this cluster category continues to have one of the largest DSC scores in 2011, the DSC declined significantly during the 1998–2011 period. The large decline is due in part to an increase in the number of clusters that are strong in terms of employment, but with weak patenting activity. If strong clusters in terms of employment fail to improve their innovation strength in the future, they may experience lower employment and innovation growth, and could be more vulnerable to shocks (e.g., import competition).

The Information Technology and Analytical Instruments cluster in the San Francisco EA (the top-1 regional cluster by patenting) has a high strength in both employment and patenting. It has outperformed other regional Information Technology and Analytical Instruments clusters in innovation and wages, but lost many jobs during the 1998–2011 period. The loss of employment may be associated with several factors: loss in production capacity (e.g., losing suppliers of services and goods), increased productivity, and/or re-allocation of some of the production capacity to related clusters (e.g., Medical Devices and Distribution and eCommerce clusters). The consequences for the growth potential of the regional cluster and the region will depend on what factors have driven the observed decline in employment and the increased patent intensity.

The declining co-location of innovation and production in Information Technology and Analytical Instruments, and the performance of its leading cluster in San Francisco EA, helps motivate some important questions for future research. First, to better understand the co-location of innovation and production in clusters, we need to take into account the presence in a region (and in nearby regions) of related clusters that could share production and innovation capacity. Relatedly, we could identify enabling industries in a region that may be shared by multiple industries within a cluster and in related clusters, facilitating inter-industry linkages and more efficient use of the innovation and production infrastructure of a location.

Second, the exclusion of low-patenting cluster categories in our analysis raises an old and ongoing challenge: how to better capture the innovativeness of economic activities with low patenting (e.g., many service-oriented activities). Surveys that measure the percent of a firm's sales that are due to new product introductions will be most meaningful to capture innovativeness (e.g., Feldman and Audretsch, 1999), but these surveys are not broadly available across firms, locations, and over time. Firms' applications for new trademarks could also proxy for new products (Guzman and Stern, 2015).

Another possibility is to indirectly measure the innovation strength in clusters with low patenting (e.g., Financial Services) by examining the strength of the location in patent-intensive clusters that are related to the focal cluster. For example, Financial Services is highly related to Business Services, Education and Knowledge Creation, and Communications Equipment, among others (Delgado, Porter, and Stern, 2016; Figure 1). Thus, locations that have a relative large patenting in these related clusters could be characterized as having the innovation capacity required to produce new financial services. Similarly, for national clusters with high presence of STEM occupations but low patenting (e.g., Insurance Services), we could examine the STEM content in the region to assess whether the required high-skill occupations are available.

More broadly, recent efforts have used attributes of firms at birth (such as their name or place of incorporation) and Big Data methods to predict the real-time innovation potential of firms at birth (Guzman and Stern, 2014, 2015). Using innovative data sources for measuring the real-time innovation potential of a location and its clusters is an important area for future research (Feldman et al., 2012).

Third, future work could assess the role of suppliers in the innovation capacity and economic performance of regions. These studies need to use a broader definition of suppliers that incorporate both manufacturing and service firms that focus on selling to other businesses (Delgado and Mills, 2016).

Another avenue of research is to examine whether the rate of startup activity, the quality of startups, and their entrepreneurial strategies will be different in locations that have dual strength in production and innovation versus locations that have single strength (in either innovation or in production) or no strength. Startups born in clusters with innovation strength but lacking production strength may have to define a different entrepreneurial strategy (Gans and Stern, 2013), which takes into account the potential trade-offs between breaking the value chain in different locations for R&D and production to exploit external agglomerations versus co-locating same-firm value chain activities to exploit internal agglomerations (Alcacer and Delgado, 2016).

Finally, as the value chains of regional clusters and their firms become more global, the consequences for the performance of regional clusters may depend on the complementarities between the regional and inter-regional linkages (Chacar and Lieberman, 2003; Bathelt, Malmberg, Maskell, 2004; Ketels and Memedovic, 2008; Beugelsdijk et al., 2010). A question that could be examined is whether regional clusters with dual strength in production and innovation develop different types of global (inter-regional) networks than regional clusters with a single strength (in R&D or production), and how these inter-regional linkages influence the growth of the focal regional cluster.

7. References

Acemoglu D., D. Autor, D. Dorn, G. Hanson, B. Prince, 2014, "Import Competition and the Great U.S. Employment Sag of the 2000s," MIT Working Paper.

Adams, J., A. Jaffe. 1996. "Bounding the effects of R&D: An investigation using matched establishment-firm data." *RAND Journal of Economics* 27(4), 700–721.

Alcacer, J. and M. Delgado, 2016, "Spatial Organization of Firms and Location Choices through the Value Chain," *Management Science*, forthcoming.

Audretsch, D.B. and M.P. Feldman, 1996. "R&D spillovers and the geography of innovation and production," *American Economic Review* 86(4), 253–273.

Audretsch, D.B., 1998, "Agglomeration and the Location of Innovative Activity," *Oxford Review of Economic Policy* 14 (2), 18–29.

Bathelt, H., A. Malmberg, and P. Maskell, 2004, "Clusters and Knowledge: Local Buzz, Global Pipelines, and the Process of Knowledge Creation," *Progress in Human Geography* 28 (1), 31–56.

Berger, S. (ed.), 2013, *Making in America*: *From Innovation to Market.* Cambridge, MA: MIT Press.

Beugelsdijk, S., P. McCann, R. Mudambi, 2010, "Place, Space, and Organization: Economic Geography and the Multinational Enterprise," *Journal of Economic Geography* 10(4), 485–493.

Chacar, A.S., M. Lieberman, 2003. "Organizing for technological innovation in the U.S. pharmaceutical industry." In Sorenson, O., and Baum, J. (Eds.) *Geography and Strategy—Advances in Strategic Management* 20, 299–322.

Delgado, M. and K. Mills, 2016, "A New Categorization of the U.S. Economy: The Role of Supply Chain Industries in Performance." Working Paper.

Delgado, M., M.E. Porter, and S. Stern, 2010, "Clusters and Entrepreneurship," *Journal of Economic Geography* 10 (4), 495–518.

Delgado, M., M.E. Porter, and S. Stern, 2014, "Clusters, Convergence, and Economic Performance," *Research Policy*, 43 (10), 1785–1799.

Delgado, M., M.E. Porter, and S. Stern, 2016, "Defining Clusters of Related Industries," *Journal of Economic Geography*, forthcoming.

Delgado, M., M.E. Porter, and S. Stern, 2015b, "Cluster Relatedness: A Roadmap for Regional Diversification." Working Paper.

Dertouzos, M.L., R.K. Lester, R.M. Solow, and the MIT Productivity Commission, 1989, *Made in America: Regaining the Productive Edge*. Cambridge, MA: MIT Press.

Duranton, G. and D. Puga, 2001, "Nursery Cities: Urban Diversity, Process Innovation, and the Life Cycle of Products," *American Economic Review* 91 (5), 1454–77.

Feldman, M.P., 1994, The Geography of Innovation, Kluwer Academic Publishers, Boston.

Feldman, M.P. and D. Audretsch, 1999, "Innovation in Cities: Science-based Diversity, Specialization, and Localized Competition," *European Economic Review*, 43, 409–29.

Feldman, M.P., J. Francis, and J. Bercovitz, 2005, "Creating a Cluster While Building a Firm: Entrepreneurs and the Formation of Industrial Clusters," *Regional Studies,* 39 (1), 129–41.

Feldman, M.P., A.G. Reed, L. Lanahan, G. McLaurin, K. Nelson, and A. Reamer, 2012, "Innovative Data Sources for Economic Analysis," e-book.

Fuchs, E. and R. Kirchain, 2010, "Design for Location? The Impact of Manufacturing Offshore on Technology Competitiveness in the Optoelectronics Industry," *Management Science* 56 (12), 2323–49.

Gans, J. and S. Stern, 2013, *Choosing an Entrepreneurial Strategy*. Mimeo.

Gibbons, R. and R. Henderson, 2012,"Relational Contracts and Organizational Capabilities," *Organization Science*, 23 (5).

Glaeser, E.L. and W.R. Kerr, 2009, "Local Industrial Conditions and Entrepreneurship: How Much of the Spatial Distribution Can We Explain?," *Journal of Economics and Management Strategy*, 18 (3), 623–63.

Guzman, J. and S. Stern, 2014, "Nowcasting and Placecasting Entrepreneurial Quality," NBER Working Paper.

Guzman, J. and S. Stern, 2015, "Where is Silicon Valley," *Science*, 347 (no. 6222), 606–609.

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

Hecker, D., 2005, High-technology Employment: a NAICS-based Update," Monthly Labor Review, 57–72.

Helper, S. and R. Henderson, 2014, "Management Practices, Relational Contracts, and the Decline of General Motors," *Journal of Economic Perspectives*, 28 (1).

Helper, S., T. Krueger, and H. Wial, 2012, *Locating American Manufacturing: Trends in the Geography of Production*. Washington, DC: Brookings Institution.

Helper, S., J. Nicholson, and R. Noonan, 2015, "The Economic Benefits of Reducing Supplier Working Capital Costs," available at: http://www.esa.doc.gov/sites/default/files/supplierpayv25.pdf (last accessed July 2015).

Helper, S., J.P. MacDuffie, and C.F. Sabel, 2000, "Pragmatic Collaborations: Advancing Knowledge While Controlling Opportunism," *Industrial and Corporate Change* 9(3), 443–483.

Johnson, K.P. and J.R. Kort, 2004, *2004 Redefinition of the BEA Economic Areas*, at http://www.bea.gov/scb/pdf/2004/11November/1104Econ-Areas.pdf.

Ketels, C and O. Memedovic, 2008, "From Clusters to Cluster-Based Economic Development," *Int. J. Technological Learning, Innovation and Development* 1 (3), 375–391.

Ketokivi, M. and Ali-Yrkkö, J, 2009, "Unbundling R&D and manufacturing: Postindustrial Myth or Economic Reality?," *Review of Policy Research* 26(1–2).

Klier, T. and Daniel P. McMillen, 2008, "Evolving Agglomeration in the U.S. Auto Supplier Industry," *Journal of Regional Science*, 48 (1), 245–267.

Marshall, A., 1920, *Principles of Economics; An Introductory Volume*. Macmillan and Co., London.

Pisano, G.P. and W.C. Shih, 2012, *Producing Prosperity: Why America Needs a Manufacturing Renaissance*, Harvard Business Review Press.

Pisano, G.P., 1997, *The Development Factory: Unlocking the Potential of Process Innovation*. Boston: Harvard Business School Press.

Porter, M.E., 1990, *The Competitive Advantage of Nations*, Free Press, New York.

Porter, M.E., 1996. "What is Strategy?," *Harvard Business Review* November, 61–78.

Porter, M.E., 1998. "Clusters and competition: New agendas for companies, governments, and institutions." In M.E. Porter (ed.), *On Competition*, 197–299. Harvard Business School Press, Boston, MA.

Porter, M.E., 2003, "The Economic Performance of Regions," *Regional Studies* 37, 549–78.

Porter, M.E. and J.W. Rivkin, 2012, "Choosing the United States," *Harvard Business Review* 90 (3), 80–91.

Rosenberg, N., 1963, "Capital Goods, Technology, and Economic Growth," *Oxford Economic Papers*, *New Series*, 15(3), 217–227.

Rosenthal, S.S., W.C. Strange, 2004. "Evidence on the nature and sources of agglomeration economies." In J.V. Henderson, J.F. Thisse (eds.), *Handbook of Regional and Urban Economics*, vol. 4. Elsevier North-Holland, Amsterdam.

Rosenthal, S.S., W.C. Strange, 2010, "Small Establishments/Big effects: Agglomeration, industrial organization, and entrepreneurship," in E. Glaeser (ed.), *Agglomeration Economics*. National Bureau of Economic Research, Inc., 277–302.

Saxenian, A., 1994, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, Cambridge, MA: Harvard University.

Storper M., 1995, "The Resurgence of Regional Economies, Ten Years Later: The Region as a Nexus of Untraded Interdependencies," *European Urban and Regional Studies,* 2, 191–221

Swann, P., 1992, *The Dynamics of Industrial Clusters*, Oxford: Oxford University Press.

Tecu, I., 2011, "Where do firms patent? Measuring intra-firm spillovers for R&D." Working Paper.

Van den Bulte, C., R.K. Moenaert, 1998, "The Effects of R&D Team Co-location on Communication Patterns among R&D, Marketing, and Manufacturing," *Management Science* 44(11), 1–18.

Vernon, R., 1966, "International Investment and International Trade in the Product Cycle," *Quarterly Journal of Economics* 80 (2), 190–207.

Table 1. Co-location of Employment and Patenting by U.S. Cluster: 1998-2011 Changes

Cluster	$Patents_{2011}$		Patents per 1k Jobs		% Jobs in STEM		Dual Specialization Corr (DSC_{2011})			Strong Clusters Patenting (SCP_{2011})			Strong Clusters Employment (SCE_{2011})		
	No.	Rank		Rank		Rank	Score	Rank	$Ch_{98\text{-}11}$	%	Rank	$Ch_{98\text{-}11}$	%	Rank	$Ch_{98\text{-}11}$
Information Technology & Analytical Instruments	30594	*1*	31	*1*	42	*1*	0.53	*2*	-0.22	70	*1*	4	62	*11*	-2
Communications Equipment & Services	11186	*2*	25	*2*	36	*2*	0.29	*12*	-0.22	41	*10*	-19	57	*15*	-4
Production Technology & Heavy Machinery	8579	*3*	10	*10*	11	*10*	0.24	*16*	0.04	15	*24*	-1	31	*30*	1
Aerospace Vehicles & Defense	7261	*4*	14	*5*	32	*3*	0.25	*15*	0.08	42	*8*	10	77	*2*	6
Biopharmaceuticals	3679	*5*	16	*3*	32	*4*	0.11	*26*	-0.18	66	*2*	12	77	*3*	8
Automotive	3605	*6*	5	*13*	6	*14*	0.37	*6*	0.05	41	*9*	4	64	*10*	-2
Plastics	3603	*7*	6	*12*	5	*17*	0.35	*8*	0.11	20	*18*	-13	36	*25*	-10
Lighting & Electrical Equipment	3305	*8*	12	*6*	11	*9*	0.41	*5*	0.07	13	*26*	-9	33	*27*	-14
Medical Devices	2667	*9*	10	*8*	10	*12*	0.24	*17*	0.00	55	*4*	6	59	*12*	2
Upstream Chemical Products	2623	*10*	16	*4*	16	*6*	0.28	*13*	-0.22	13	*25*	-1	51	*18*	-9
Downstream Chemical Products	2333	*11*	10	*9*	10	*11*	0.09	*27*	-0.19	19	*20*	-21	41	*23*	-15
Metalworking Technology	1508	*12*	3	*15*	5	*19*	0.14	*24*	-0.07	35	*11*	-10	57	*16*	-12
Recreational & Small Electric Goods	1304	*13*	8	*11*	4	*23*	0.21	*20*	0.16	33	*12*	8	44	*22*	0
Vulcanized & Fired Materials	1022	*14*	4	*14*	4	*24*	0.01	*32*	-0.09	15	*23*	-1	50	*19*	2
Downstream Metal Products	998	*15*	3	*17*	6	*16*	0.03	*29*	-0.02	10	*30*	-2	23	*33*	-3
Oil & Gas Production & Transportation	716	*16*	1	*23*	12	*8*	0.47	*3*	-0.13	45	*6*	14	81	*1*	8
Paper & Packaging	663	*17*	2	*19*	3	*25*	0.33	*9*	-0.24	12	*27*	-2	35	*26*	1
Construction Products & Services	646	*18*	1	*26*	5	*18*	0.18	*21*	0.10	11	*28*	1	32	*28*	6
Education & Knowledge Creation	502	*19*	0	*32*	8	*13*	0.02	*30*	0.00	50	*5*	4	59	*13*	2
Food Processing & Mfg	486	*20*	1	*29*	2	*28*	0.14	*25*	0.06	9	*32*	2	21	*35*	1
Furniture	436	*21*	1	*20*	2	*27*	0.31	*11*	-0.05	8	*33*	-3	36	*24*	-8
Upstream Metal Mfg	417	*22*	1	*24*	4	*22*	0.15	*23*	-0.27	26	*15*	-2	57	*14*	4
Textile Mfg	387	*23*	2	*18*	2	*26*	0.24	*18*	-0.27	26	*16*	-3	74	*4*	-2
Trailers, Motor Homes, & Appliances	315	*24*	3	*16*	4	*20*	0.42	*4*	0.38	17	*22*	3	68	*6*	12
Wood Products	301	*25*	1	*25*	2	*30*	0.00	*33*	-0.12	5	*34*	-1	31	*31*	-2
Marketing, Design, & Publishing	280	*26*	0	*31*	6	*15*	0.25	*14*	0.08	61	*3*	14	69	*5*	12
Printing Services	273	*27*	1	*28*	2	*29*	0.21	*19*	0.01	22	*17*	-3	45	*21*	-1
Water Transportation	211	*28*	1	*27*	4	*21*	0.67	*1*	0.39	30	*13*	3	67	*7*	0
Business Services	207	*29*	0	*35*	23	*5*	0.32	*10*	0.07	18	*21*	-36	22	*34*	-38
Distribution & Electronic Commerce	206	*30*	0	*34*	1	*31*	0.04	*28*	0.08	45	*7*	2	50	*20*	3
Hospitality & Tourism	188	*31*	0	*33*	1	*34*	0.35	*7*	0.17	19	*19*	6	30	*32*	3
Electric Power Generation & Transmission	180	*32*	1	*22*	14	*7*	-0.05	*34*	0.09	10	*31*	3	32	*29*	-7
Footwear	176	*33*	11	*7*	0	*35*	0.01	*31*	-0.27	5	*35*	-5	66	*8*	14
Apparel	165	*34*	1	*21*	1	*32*	-0.07	*35*	-0.09	28	*14*	-2	65	*9*	-1
Livestock Processing	133	*35*	0	*30*	1	*33*	0.17	*22*	0.06	11	*29*	4	52	*17*	5
Avg	2604		6		9		0.22		-0.02	27		-1	50		-1

Notes: Column 1 reports the patents granted to the national cluster. Column 3 reports the percentage of employment in STEM (Science, Technology, Engineering and Math) occupations (based on BLS 2009 data). $Ch_{98\text{-}11}$ is the change in the scores of DSC, SCP, or SCE.

Table 2. Correlation of Regional Cluster Strength Based on Employment and Patenting (179 Economic Areas (EAs), 35 Clusters, 2001, 2011)

		All (35 U.S. Clusters) 2011 N=5,838			IT & Analytical Instruments 2011 N=174		
		V_1	V_2	V_3	V_1	V_2	V_3
Cluster $Specialization_{Emp,2011}$	V_1	1.00			1.00		
Cluster $Specialization_{Emp,2001}$	V_2	0.85^*	1.00		0.80^*	1.00	
Cluster $Specialization_{Patent,2011}$	V_3	0.25^*	0.26^*	1.00	0.53^*	0.57^*	1.00
Cluster $Specialization_{Patent,2001}$	V_4	0.18^*	0.19^*	0.33^*	0.60^*	0.71^*	0.66^*

Notes: * Correlation coef. significant at 1% level. Conditioning on existing EA-clusters in year *t* (employment>10 in 2011). Cluster Specialization is measured by a Location Quotient (LQ).

Table 3. **Co-location of Employment and Patenting in U.S. Clusters, 1998–2011 (35 Clusters)**

Year	Dual Spec Correlation $DSC_{c,t}$ [1,-1]		Strong Clusters Patenting			Strong Clusters Employment		
			$SCP_{c,t}$ (%)		$SCP_{All,t}$ (%)	$SCE_{c,t}$ (%)		$SCE_{All,t}$ (%)
	Mean (N=35)	Sd	Mean (N=35)	Sd	Total	Mean (N=35)	Sd	Total
1998	0.24	0.20	28	17	40	51	15	50
1999	0.19	0.21	30	19	42	52	16	52
2000	0.21	0.20	29	18	42	52	16	52
2001	0.19	0.19	28	18	41	51	16	50
2002	0.20	0.19	29	18	44	51	16	47
2003	0.20	0.19	29	18	44	51	16	47
2004	0.22	0.16	29	19	46	51	16	47
2005	0.18	0.17	29	19	47	51	17	45
2006	0.17	0.16	29	19	49	51	17	44
2007	0.21	0.17	29	18	48	51	17	44
2008	0.21	0.16	28	19	48	51	17	43
2009	0.17	0.17	27	18	45	50	17	44
2010	0.23	0.19	28	18	46	50	17	43
2011	0.22	0.17	27	18	44	50	17	43
Avg_{98-11}	0.20	0.18	28	18	45	51	16	46
$Change_{98-11}$	-0.02		-1		4	-1		-8

Notes: Mean across the 35 national clusters.

Table 4. Co-location of Employment and Patenting for Selected Clusters

	IT & Analytical Instruments						Automotive					
	DSC_{ct}		SCP_{ct}		SCE_{ct}		DSC_{ct}		SCP_{ct}		SCE_{ct}	
	Score [1,-1]	Rank 1-35	Pat %	Rank 1-35	Emp %	Rank 1-35	Score [1,-1]	Rank 1-35	Pat %	Rank 1-35	Emp %	Rank 1-35
1998	0.74	*1*	66	*1*	64	*9*	0.32	*10*	37	*11*	66	*8*
1999	0.72	*1*	66	*2*	62	*11*	0.37	*6*	38	*12*	66	*9*
2000	0.73	*1*	67	*2*	63	*12*	0.45	*4*	41	*11*	67	*8*
2001	0.71	*1*	68	*1*	64	*9*	0.39	*4*	42	*10*	66	*7*
2002	0.71	*1*	68	*2*	61	*10*	0.50	*3*	42	*9*	66	*7*
2003	0.70	*1*	71	*1*	64	*9*	0.43	*5*	43	*8*	66	*5*
2004	0.69	*1*	71	*1*	63	*10*	0.44	*3*	42	*9*	67	*6*
2005	0.67	*1*	72	*1*	65	*9*	0.35	*5*	42	*10*	66	*8*
2006	0.70	*1*	72	*1*	66	*8*	0.43	*3*	42	*10*	66	*6*
2007	0.68	*1*	73	*1*	66	*9*	0.42	*5*	42	*8*	66	*8*
2008	0.71	*1*	73	*1*	64	*9*	0.37	*5*	42	*9*	64	*8*
2009	0.64	*1*	73	*1*	63	*10*	0.35	*4*	40	*9*	63	*11*
2010	0.62	*2*	74	*1*	65	*10*	0.36	*8*	41	*9*	64	*11*
2011	0.53	*2*	70	*1*	62	*11*	0.37	*6*	41	*9*	64	*10*
Avg_{98-11}	0.68		70		64		0.40		41		65	
$Change_{98-11}$	-0.22		4		-2		0.05		4		-2	

Table 5. Strongest IT and Analytical Instruments Clusters (33 EAs, 2011)

Economic Areas (N=33)	Employment			$\text{Specialization}_{\text{Employ}}$		Patents			$\text{Specialization}_{\text{Patent}}$		Strong Cluster
	in 1k	Shr	Pctile	LQ	LQ-Pctile	No.	Shr	Pctile	LQ	LQ-Pctile	in 1998
Boise City-Nampa, ID	12	1.1%	86	5.9	100	418	1%	90	1.4	96	1
Seattle-Tacoma-Olympia, WA	87	8.1%	99	4.7	99	2078	7%	98	1.7	98	1
San Jose-San Francisco-Oakland, CA	121	11.2%	100	3.4	98	7602	25%	100	1.5	97	1
Burlington-South Burlington, VT	6	0.5%	80	3.2	98	238	1%	87	1.5	98	1
Austin-Round Rock, TX	18	1.6%	91	3.0	97	1302	4%	97	1.7	99	1
Asheville-Brevard, NC	4	0.4%	76	2.5	97	9	0%	37	0.4	25	1
Portland-Vancouver-Beaverton, OR-WA	27	2.5%	95	2.5	96	773	3%	95	1.2	94	1
Madison-Baraboo, WI	12	1.1%	86	2.3	96	77	0%	75	0.6	45	0
Boston-Worcester-Manchester, MA-NH	77	7.1%	98	2.3	95	1750	6%	98	1.0	90	1
Lincoln, NE	4	0.3%	74	2.2	94	1	0%	7	0.2	2	0
State College, PA	5	0.5%	78	2.2	94	38	0%	65	0.7	69	1
San Diego-Carlsbad-San Marcos, CA	22	2.0%	93	2.1	93	757	2%	95	0.9	81	1
Minneapolis-St. Paul-St. Cloud, MN-WI	48	4.5%	97	2.0	93	1056	3%	96	1.0	91	1
Fargo-Wahpeton, ND-MN	3	0.2%	67	2.0	92	18	0%	51	0.8	75	0
Colorado Springs, CO	4	0.4%	74	2.0	92	82	0%	77	1.3	95	1
Salt Lake City-Ogden-Clearfield, UT	19	1.7%	92	1.9	91	223	1%	85	0.8	78	1
Syracuse-Auburn, NY	11	1.0%	85	1.8	90	160	1%	82	1.0	89	1
Albuquerque, NM	3	0.3%	72	1.7	90	61	0%	72	0.8	81	1
Dayton-Springfield-Greenville, OH	8	0.7%	82	1.6	89	46	0%	67	0.6	49	0
Tucson, AZ	4	0.4%	75	1.5	89	273	1%	87	1.5	97	1
Raleigh-Durham-Cary, NC	14	1.3%	88	1.5	88	702	2%	94	1.4	95	1
Spokane, WA	3	0.3%	68	1.4	88	32	0%	62	0.7	69	1
Eugene-Springfield, OR	3	0.2%	66	1.4	87	13	0%	44	0.6	51	1
Milwaukee-Racine-Waukesha, WI	15	1.4%	89	1.4	86	121	0%	80	0.6	58	0
Helena, MT	1	0.1%	49	1.3	86	7	0%	33	0.5	37	0
Huntsville-Decatur, AL	5	0.5%	77	1.3	85	29	0%	59	0.7	71	1
Denver-Aurora-Boulder, CO	20	1.8%	92	1.3	85	581	2%	92	1.1	92	1
Rochester-Batavia-Seneca Falls, NY	6	0.6%	81	1.2	84	436	1%	91	1.0	88	1
Missoula, MT	1	0.1%	47	1.2	84	3	0%	18	0.3	15	0
Los Angeles-Long Beach-Riverside, CA	71	6.5%	98	1.1	83	1609	5%	97	0.9	83	1
Pittsburgh-New Castle, PA	12	1.2%	87	1.1	82	222	1%	85	0.8	80	0
Sacramento--Arden-Arcade--Truckee, CA-NV	6	0.6%	81	1.1	82	194	1%	84	1.1	94	1
Phoenix-Mesa-Scottsdale, AZ	15	1.4%	89	1.0	81	397	1%	89	1.0	89	1
Total/Avg	665	62%		2.0		21308	70%		0.9		25

Table 6. IT and Analytical Instruments in San Francisco EA, 1998–2011

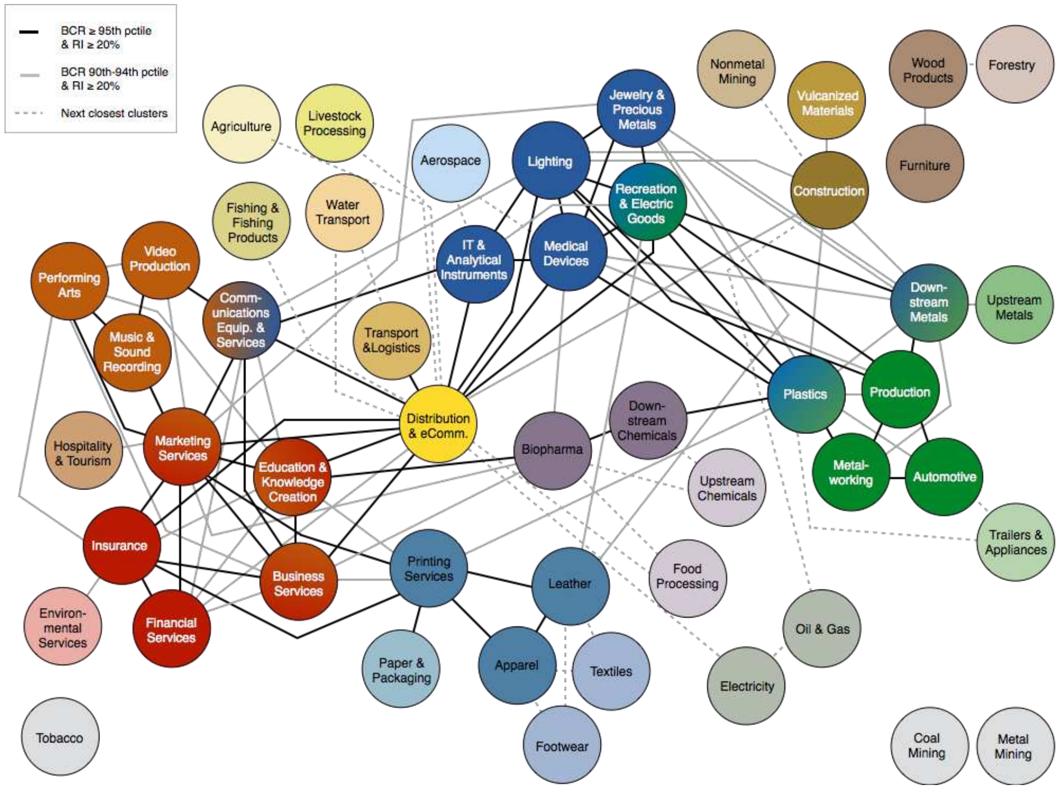
Year	Employment			$\text{Specialization}_{\text{Employ}}$		Patents			$\text{Specialization}_{\text{Patent}}$		Patents	Wages
	in 1k	Shr	Pctile	LQ	LQ-Pctile	No.	Shr	Pctile	LQ	LQ-Pctile	per 1k Employ	in 1k
1998	234	14%	100	4.0	98	3258	20%	100	1.8	97	14	$73
1999	224	14%	100	4.0	98	3571	21%	100	1.8	98	16	$90
2000	217	13%	100	3.8	97	3807	22%	100	1.7	98	18	$121
2001	226	14%	100	3.7	97	4169	22%	100	1.7	97	18	$98
2002	174	13%	100	3.7	97	3924	21%	100	1.7	97	23	$92
2003	165	12%	100	3.7	98	4238	21%	100	1.6	96	26	$102
2004	152	12%	100	3.6	97	4432	21%	100	1.6	98	29	$111
2005	142	12%	100	3.4	97	4272	22%	100	1.5	96	30	$113
2006	138	11%	100	3.4	97	5791	23%	100	1.5	97	42	$121
2007	135	11%	100	3.3	98	5146	24%	100	1.5	96	38	$129
2008	147	12%	100	3.5	98	5210	23%	100	1.4	97	35	$129
2009	134	12%	100	3.5	99	5805	24%	100	1.4	97	43	$122
2010	124	12%	100	3.4	98	7543	24%	100	1.5	97	61	$140
2011	121	11%	100	3.4	98	7602	25%	100	1.5	97	63	$144
$\text{Avg}_{98\text{-}11}$	167	12%	100	4	98	4912	22%	100	1.6	97	33	$113
$\text{EA Growth}_{98\text{-}11}$	-48%					133%					351%	97%
$\text{US Growth}_{98\text{-}11}$	-35%					90%					197%	84%

Table 7. Automotive Cluster in Detroit EA, 1998–2011

Year	Employment			Specialization$_{Emp}$		Patents			Specialization$_{Patent}$		Patents	Wages
	in 1k	Shr	Pctile	LQ	LQ-Pctile	No.	Shr	Pctile	LQ	LQ-Pctile	per 1k Emp	in 1k
1998	229	15%	100	6.1	100	570	17%	100	4.7	98	2	$54
1999	233	16%	100	6.2	100	618	18%	100	4.9	98	3	$57
2000	240	16%	100	6.3	100	689	18%	100	4.9	98	3	$56
2001	194	14%	100	6.0	100	785	20%	100	5.2	98	4	$52
2002	184	15%	100	6.2	100	789	20%	100	5.3	99	4	$53
2003	181	14%	100	5.8	99	798	21%	100	5.5	98	4	$57
2004	174	14%	100	5.6	100	783	22%	100	5.7	98	5	$59
2005	160	13%	100	5.5	98	741	22%	100	5.9	98	5	$60
2006	150	12%	100	5.3	98	728	20%	100	6.3	98	5	$57
2007	136	12%	100	5.5	98	643	20%	100	6.7	97	5	$65
2008	125	11%	100	5.5	98	610	20%	100	7.0	98	5	$62
2009	101	12%	100	6.0	99	559	19%	100	6.9	98	6	$60
2010	90	11%	100	5.9	98	765	20%	100	7.2	98	8	$68
2011	102	12%	100	6.2	99	725	20%	100	7.1	99	7	$65
Avg $_{98\text{-}11}$	164	13%	100	5.9	99	700	20%	100	5.9	98	5	$59
EA Growth$_{98\text{-}11}$	-56%					27%					186%	22%
US Growth$_{98\text{-}11}$	-43%					8%					88%	28%

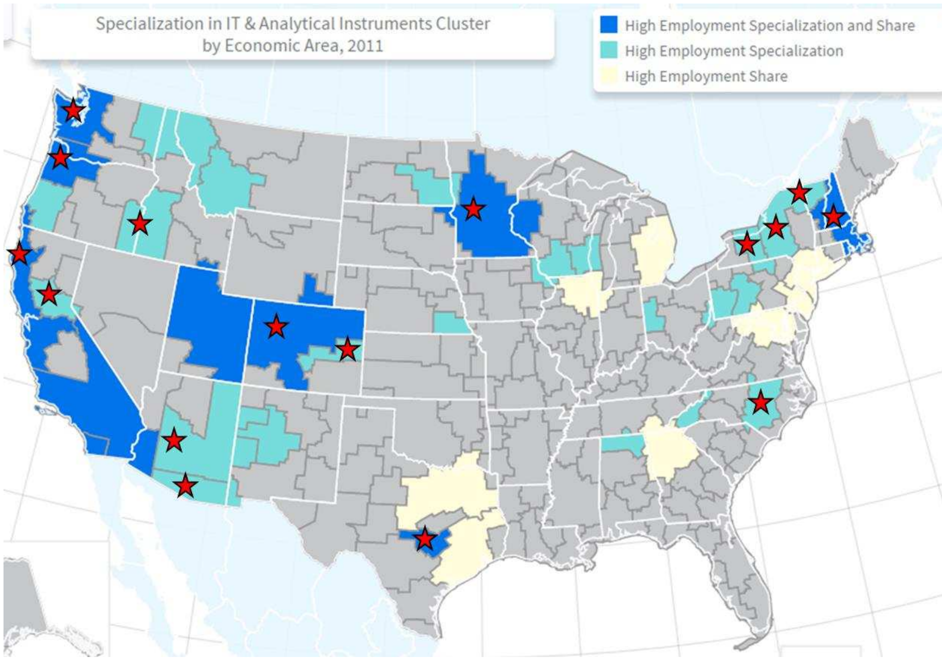
Notes: Detroit Economic Area includes, among others, the cities of Detroit, Ann Arbor, and Lansing.

Figure 1. Portfolio of 51 Traded Clusters and their Connections



Source: Delgado, Porter, and Stern (2016a,b). Clusters with solid connection lines are highly related.

Figure 2. Strong IT and Analytical Instruments Clusters across U.S. Economic Areas, 2011



Notes: EAs with a red star are clusters with dual strength in Employment and Patenting. Source: Interactive map available at USCMP (http://www.clustermapping.us/cluster/)