THE GEOGRAPHIC CLUSTERING
OF HIGH TECH INDUSTRY,
SCIENCE AND INNOVATION IN APPALACHIA

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Abstract

We use a triangulation strategy and a series of complementary indicators and measures of spatial association for varying geographic units to identify and document sub-regional concentrations of technology-related employment, research, and applied innovation within and immediately adjacent to the 406 county service area of the Appalachian Regional Commission (ARC). The analysis reveals a set of technology clusters—defined as joint spatial concentrations of high-tech employment and innovative activity—within and adjacent to the ARC region. The clusters, which span eight general technology areas, vary significantly in size, depth, and overall competitive strength. Analysis of the characteristics of the clusters offers a detailed picture of the intra-regional distribution and depth of technology-related activity in Appalachia.

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1 Introduction

Over the last 40 years, economic development progress has been substantial in many parts of Appalachia, the 406 county region that is the focus of the Appalachian Regional Commission (ARC). A recent study by Wood and Bischak (1999) shows that the number of ARC counties identified as distressed declined from 214 to 106 between 1960 and 1990.[1] Wood and Bischak attribute those gains to the growth of the manufacturing sector in predominantly southern rural counties, while also noting that they have come partly at the expense of traditional northern manufacturing centers. They also cite the significance of positive spillovers from high growth metropolitan areas that border the Appalachian region, particularly in the South (with Atlanta as the premier example). Reviewing evidence of strong job growth in modern, high wage industries, Isserman (1996, p. 23) concludes: "Appalachia remains unable to shed its image as a stagnating, underdeveloped, lagging region, but the image is wrong."

At the same time, about one-quarter of ARC counties that were distressed four decades ago remain distressed today. Furthermore, the prospects for the continued economic progress of Appalachia are uncertain, even in many of its currently non-distressed sub-regions. Much of Appalachia remains heavily dependent on unstable and cost-sensitive manufacturing, agriculture, and mining. Just as inexpensive labor and a more permissive regulatory environment initially brought manufacturing to southern Appalachia, foreign locations are now using similar advantages to lure those jobs away. As U.S.-based businesses substitute capital for labor to minimize costs, they are displacing workers, spurring out-migration from smaller communities with few alternative job opportunities, and increasing demands on workforce education and re-training programs. Labor saving technologies also continue to spur productivity gains in agriculture while reducing farm employment.

In this context, it is no surprise that ARC officials, as well as state and local leaders in Appalachia itself, increasingly view technology and innovation as central to the region's economic future. It is now received wisdom that building a strong base of science and innovation will be one of surest routes to sustained prosperity for many U.S. regions in the 21st century. The view rests on three major premises. First is simply that technology-oriented businesses are projected to post the most favorable combination of wage and employment gains over the next several decades (Rausch 1998; Hecker 1999). Second is that trade liberalization is forcing U.S.-based businesses to seek competitive advantage in America's innovative capacity, including its world-leading private and public R&D institutions, educated workforce, tradition of risk-taking and entrepreneurship, advanced physical infrastructure, and stable and transparent social and political institutions. Many features of that capacity are unique to the United States, even in comparison to other industrialized nations, while basic infrastructure and cheap factors of production are not. Third, and perhaps most importantly, is that the spatial clustering of technology-related sectors—and the cumulative dynamic behind that clustering—implies that regions must move quickly to capture such activity or risk lagging behind.

The case for the geographic clustering of innovation and technology is now well known and need only be summarized briefly here. Theoretically, innovation-intensive activities cluster in specific regions because knowledge spillovers are *localized* (Glaeser 2000). Knowledge spillovers are the ability of economic agents to utilize a new technology or innovation without fully compensating its original source or owner (Grossman and Helpman 1991). Innovations initially occur in companies, universities, and laboratories located in specific places. The subsequent spread (or diffusion) of such innovations, as well as the spillovers they generate, may occur more readily among economic actors located in close proximity, either because the innovation is tacit in nature or because its successful utilization requires an element of hands-on learning-by-doing. Increasing returns to innovation, coupled with a localized diffusion effect, imply that technology-oriented activity and R&D are likely to concentrate geographically. Technology

[1] See also Feser and Sweeney (2002) who use an alternative methodology to compare 25-30 year trends in economic distress for all commuter zones in the contiguous U.S. Using distress thresholds based on long run trends, that study identified eight Appalachian commuter zones as unemployment distressed in 1999 (the share of Appalachian population in those zones stood at 1.2 percent). Forty-two zones, accounting for 12.9 percent of Appalachian residents, were found to be income-distressed in 1998.

businesses locate near other high tech companies and R&D performers in order to share in the spillovers, further enhancing the attractiveness of the growing cluster for still more high tech enterprises. The cluster expands through a process of cumulative advance. The growing body of empirical work on industry clusters lends credence to this view (Enright 2000; Baptista 2001; Cooke 2001; Enright 2001; Hertog, Bergman *et al.* 2001; Isaksen and Hauge 2002; Porter 2002).

This paper reports the results of an effort to better understand Appalachia's technology sector by systematically investigating the extent of clustering of high technology activities within and immediately adjacent to the region. By one definition there were roughly 1.07 million workers employed in the region's high-tech industries in 1998, up from 959,000 in 1989, an increase of 11.2 percent.[2] Most of the employment gains during the 1990s occurred in sectors such as chemicals, electronics, transportation equipment, instruments, and hospitals and health-related labs. Other components of Appalachia's technology base include its major research universities, network of teaching universities and community colleges, and non-university laboratories. We evaluate the extent of functional and spatial "fit" between the high tech industry base on the one hand and the knowledge/innovation base on the other. Our results help characterize the evolving spatio-economic structure of Appalachia while also serving as a useful guide for cluster-based economic development activities in the region.

Sections 2, 3 and 4 discuss the study methodology, findings, and implications, respectively. Our research involved extensive investigation of three issues—the clustering of high tech industry, the clustering of the innovation and knowledge base, and the geographic and functional overlap between the two—as well as use of some measures that are general in nature and others that could be disaggregated to specific technology areas or disciplines. Given space constraints, we focus on the third set of findings here and only those indicators that can be disaggregated to specific technology categories or sectors. Readers are referred to Feser, Goldstein *et al.* (2002) for the full analysis, including extensive documentation of all data sources and classification schemes.

2 Methodology

Figure 1 summarizes our conceptual framework. We examined technology-related assets within and near Appalachia from two perspectives: the industrial base (technology-related goods and services production) and the knowledge base (knowledge creating institutions and programs). Our objective in both cases was to identify functional and spatial clusters of activity that are legitimate existing or potential strengths in the region vis-à-vis the broader U.S. economy.[3] We define the areas of *overlap* between the industry and the knowledge/innovation strengths as Appalachia's unique *technology clusters*. The clusters are places where a moderately to highly sophisticated knowledge infrastructure is joined with a substantial related industrial base. While the clusters represent potential targets for development initiatives, they can also be used to characterize broader intra-regional differences in clustering of technology activity in Appalachia, such as between the region's core and periphery, its main sub-regions (north, central, south), and its metro and non-metro areas. Consistent with geographic information systems (GIS) terminology, in the discussion that follows we describe each geo-referenced set of measures as a *layer* representing a single possible geographic snapshot of the region's technology base. The goal is to use multiple such layers to filter out those locations with the strongest complement of technology-related activity.

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[2] The high tech estimates are based on a classification of technology sectors developed by the North Carolina Employment Security Commission, which based its scheme on U.S. Bureau of Labor Statistics and National Science Foundation studies of the share of science and engineering workers by sector.

[3] There is a significant difference between an analysis of the region's relative strengths of the kind we undertake here, and an absolute analysis. In the context of university R&D strengths, the relative approach implies an explicit assessment of Appalachian universities against an outside referent (e.g., a U.S. benchmark). An absolute approach would simply identify the key R&D strengths within and around Appalachia itself. In the case of the former, it is possible that no strengths would be identified. In the case of the latter, the top disciplines in the region—irrespective of their position in a national ranking—would be highlighted. A relative analysis is superior to an absolute one from a policy perspective since Appalachian businesses, universities, colleges, and labs are not competing solely with each other, but also with entities elsewhere in the United States.

The methodology is based on an explicit strategy of triangulation. Given the myriad plausible ways that high tech activity might be defined, measured (in terms of quantity), and assessed (in terms of quality), we opted to use multiple data sources, classification schemes, competitiveness criteria, and indicators to screen locations. The logic is that we can be more confident of the strength and depth of the science and technology base of a given area if it stands out along multiple (rather than simply one or two) science and technology dimensions.

Any quantitative exercise of this kind is analytically and empirically messy. We do not claim that the classification schemes we adopted are without weaknesses or that the measures or criteria we used are beyond dispute. Moreover, we do not claim to have evaluated all salient dimensions of the technology sector. The findings we generate must be scrutinized closely given potential aggregation biases (according to industry, geography, and discipline or technology area) and the absence of information on important features of clusters in general (such as the presence of informal networks, the extent of real knowledge spillovers, etc.). Nevertheless, we argue that this kind of systematic quantitative characterization of clustering, despite the attendant limitations, is useful for highlighting trends, weaknesses, and strengths in Appalachia's economy that warrant further investigation.

Study area

Because the impacts of neither technology-oriented industries nor knowledge infrastructure respect jurisdictional boundaries, the study area includes the 406 counties under the policy jurisdiction of the Appalachian Regional Commission along with a border territory of counties and metropolitan areas roughly adjacent to the ARC region.[4] Figure 2 depicts both the ARC and broader study boundaries as well all included metropolitan areas. Metro areas with at least one county either immediately adjacent to or within the ARC region are included. All 62 metropolitan areas in the study area are listed in Appendix Table 1 along with a code that identifies their location on the map in Figure 2.

The high-tech industrial base

Rather than utilize a single definition and measure of high-technology industrial activity, we characterized Appalachia's industrial base by synthesizing findings generated with two kinds of related information: 1) the location of employment in eight high-tech value chains; and 2) the location of science and engineering workers in thirteen occupational categories that concord to the eight value chains. In the case of value chain employment, we used county-level data and two measures of spatial concentration to identify unique multi-county areas where technology-related activity is disproportionately clustered. We could not use the same approach for the occupation analysis since data on science and engineering workers are available only for metropolitan areas. Thus an exact screening of individual areal units based on value chain and occupational employment is impossible. Nevertheless, we produced graphic overlays of the results to aid identification of those sub-regions within and along the border of Appalachia where technology-related activity is especially pronounced. Concepts, measures, and data sources utilized in the analysis of the region's industrial base are summarized in Table 1.

We recognize that even with the use of varying industry and occupational classification schemes, our approach may obscure some important underlying industrial strengths in advanced technology. Our approach is a compromise between the obvious desirability of a highly detailed county-by-county investigation and the practical need for a methodology that is manageable for a large and diverse multi-county region. Our objective was to simply shed light on the broader spatial pattern of technology-oriented activity in Appalachia, to identify focus areas for strategic policy design, and to derive a set of sub-regions that can be subjected to more detailed investigation.

Value chain employment layer. To identify nominally linked technology industries, we sorted a set of SIC sectors commonly identified as technology intensive into eight individual value chains based on a detailed analysis of national input-output patterns (see Table 2). The value chains therefore represent the core technology-intensive buyer-supplier chains in the U.S. economy. The details of their derivation are summarized in Feser, Goldstein *et al.* (2002). Each of the eight chains listed in Table 2 is comprised of

[4] Also included are eight independent cities in Virginia. The Census Bureau gives a separate county level FIPS code to these cities and thus they are treated as independent entities in our spatial analysis. Note that in some cases, counties wedged between two adjacent counties were also included in the border region.

between eight and thirty diverse four-digit SIC codes. The chains are not mutually exclusive since some sectors are linked to multiple industries, a feature that reinforces their characterization of interdependence in the economy. The high tech value chains are a good starting point for assessing unique industrial specializations in Appalachia since they go beyond simple sectoral definitions to include groups of industries that share similar competitive pressures and, in some cases, utilize similar production technologies.

The value chains serve as the common reference classification of functional high technology areas. In other words, we established concordances between the value chains and all other variable classifications (e.g., university disciplines, science and engineering occupations, utility patents, etc.) in order to come up with a single consistent set of functional technology overlays.We used simple county-level location quotients and the Getis/Ord *G* statistic to identify localized concentrations of the value chains (Getis and Ord 1992; Ord and Getis 1995). While a location quotient indicates a concentration of activity within a single county that is relatively high compared to a national baseline, the *G* statistic helps reveal broader multi-county areas where technology-related activity is especially pronounced. The *G* works by analyzing the full multi-county spatial distribution of values of a given indicator to detect where high and low values of the indicator are proximate.

The *G* measure for areal unit *i* for a given industry cluster is calculated as:

$$G_i^* = \frac{\sum_j w_{ij} x_j - W_i \bar{x}}{s\sqrt{(nS_{1i} - W_i^2)/(n-1)}}, all\ j$$

where x is the variable of interest (e.g. employment or patents), $\{w_{ij}\}$ is a spatial weights matrix that defines neighboring areas j to areal unit i, W_i is the sum of weights in $\{w_{ij}\}$, and

$$\bar{x} = \sum_j x_j \Big/ (n-1)$$

$$S_{1i} = \sum_j w_{ij}^2$$

$$s^2 = \left(\sum_j x_j^2 \Big/ n-1\right) - (\bar{x})^2.$$

Although the normality of *G* depends partially on the number of neighbors, we make the common simplifying assumption that it follows a normal distribution for each county. Significant counties are identified as those posting values of 1.96 or greater, the 95 percent significance level from a two-tailed normal distribution.

To implement *G*, we developed a spatial weights matrix $\{w_{ij}\}$ with adjacency defined by immediate neighbor counties inclusive of the county itself. Non-neighboring areal units are given a weight of zero. The value x of neighboring county j to county i is weighted by the degree of expected interaction between counties j and i

$$w_j = \frac{X_i X_j}{\sum_j X_i X_j}$$

where upper-case X is total exportable (or basic sector) employment and the denominator is the sum of interactions between county i and all its neighboring counties j. Dividing by the sum of interactions row-standardizes the matrix, turning each cell's weight into a percentage of the total interactions between adjacent counties. The weighting scheme embeds a gravity-based logic where larger counties exert a heavier influence on neighboring counties than do smaller counties. There is also an implicit assumption of no interaction between non-neighboring counties.

To detect unique clusters of activity in and around Appalachia, we needed a means of controlling for the general tendency of industry to concentrate. To the extent that much commerce in a given area serves a local population or industry base, we should expect more employment in urban centers simply because those centers boast larger populations and industry employment (Feser and Sweeney 2000). In this study, we sought to find local concentrations of activity beyond those that might be expected by the general distribution of employment and population. To do that, we used a procedure outlined in Feser, Sweeney *et al.* (2001) that involves regressing sectoral employment on total export-base employment, where counties are the units of analysis. The residual from the regression, the difference between the predicted and actual employment, is an estimate of local activity beyond that expected by the overall size of the place. The *G* is then calculated using residuals.

Although not infallible, the residual-based *G* approach tends to successfully screen out very small and overly specialized places since those places are likely to have small residuals. A downside is that the approach sometimes misses concentrations that are entirely confined within the borders of a single county. Thus the reason for comparing results using the *G* with findings generated with county-level location quotients. Note that when overlaying the results in the figures below, we highlight only significant values for each measure. In the case of the *G*, highlighted values were those that were statistically significant at the 95 percent level. In the case of the location quotient, highlighted values were those in excess of 1.1.

Data for the *G* and the location quotients are from the confidential unsuppressed Unemployment Insurance Data Base (UDB) of the U.S. Bureau of Labor Statistics, obtained with special permission.[5] The UDB data, which contain employment and wage figures by establishment for all fifty states, permit us to take a fine-grained look at employment patterns even in very small counties. Publicly available sources of employment data, such as *County Business Patterns*, contain significant data suppression for detailed industries in small counties, either limiting the analysis to aggregated industries or requiring data estimation schemes that introduce error.[6]

Occupational employment layer. Occupational employment statistics provide a second means of characterizing the location of technology intensive activity, where the latter is broadened to include both the private and public sectors. Sub-state occupational employment data are available from the U.S. Bureau of Labor Statistics' Occupational Employment Statistics (OES) series.[7] The OES data are available only for metropolitan areas however, forcing us to ignore rural areas and to use only the location quotient measure of concentration. Nevertheless, the metro-level analysis of the region's scientific, engineering and technician workforce is a useful supplement to our analyses of the geography of industry employment.

From the 709 occupations reported in the 1999 OES data, we identified 56 specific science, engineering, and engineering technician occupations. We organized the 56 occupations into thirteen substantive groups that roughly parallel, though are more detailed, than the eight value chain categories. We then established a concordance between the thirteen categories and the eight value chains. For example, we matched the chemists/chemical engineers and materials engineers/scientists occupations to the chemicals and plastics value-chain. The concordances between the occupations and value chains are reported in the first and fourth columns of Table 3.

A few of the remaining 653 occupations in the 1999 OES data bear mentioning since the reasons for excluding them from our classification of scientists and engineers helps clarify our objectives. For example, we did not include civil engineers/technicians and opthamalic and dental lab technicians among the 56 science and engineering occupations. The vast majority of individuals employed as civil engineers or health

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[5] The ES-202 file reports employment and wage data for all firms subject to federal and state employment security law, with only the very smallest enterprises and sole proprietorships excluded. At the time of study, 1998 was the most recent year available, with reliable data stretching back to 1989. The UDB data, along with the BLS' new Longitudinal Establishment Microdata (or LDB), are described in Pivetz, Searson *et al.* (2000). Strengths and limitations of BLS ES-202 data are discussed generally in White, Zipp *et al.* 1990 and Davis, Haltiwanger *et al.* 1996.

[6] Geographic identifiers in the UDB also permit the use of alternative spatial units of analysis. In early tests, we compared results using both counties and zip codes in order to minimize the potential bias that can result from examining geographical patterns using arbitrarily shaped areal units.

[7] The 1999 OES survey is described in BLS 2001. OES data are accessible directly via the Internet at http://www.bls.gov/oes.

lab technicians are not engaged in science or innovation. We also did not include teachers in the various science and engineering fields in the set of 56 study occupations. Because there are such a large number of teachers in a broad array of fields (a significant share of whom are engaged primarily in instruction rather than research), they tend to dominate other occupational categories. As an indicator of science and engineering activity, occupational employment loses much of its precision when teachers are added to the mix. We evaluated the role of post-secondary educational institutions in both teaching and research with other measures.

As survey-based data, BLS occupation statistics must be used cautiously. The data for many metro areas, particularly smaller ones, are often incomplete due to inadequate sample sizes and data confidentiality regulations that necessitate suppression or non-reporting. BLS also does not report data for occupations with fewer than fifty workers. The publicly available metro level data therefore often constitute undercounts for smaller MSAs when they are aggregated up from detailed occupational categories. Yet because data are generally reported for occupations with a substantial number of workers and employing companies, they can still be useful for highlighting significant industrial specializations in various technology areas.

Knowledge infrastructure

Appalachia's knowledge infrastructure is comprised of two major components: organizations conducting scientific research and applied innovation and the network of universities and colleges engaged in developing the region's human capital base. (In the case of major research universities, the two components come together.) Appalachia's science and innovation assets are based in eighteen research universities and a limited number of other research institutions (such as federal government laboratories), non-profit R&D organizations, state-sponsored technology agencies, and private sector businesses engaged in innovation. The region's higher education network consists of over 250 universities, colleges, and community colleges offering degree programs and specialized training in fifteen science and engineering-related fields. In 1997/8, four-year institutions in the region conferred over 23,600 science and engineering degrees while two-year colleges and institutes granted an additional 12,200 degrees. Many more students obtained relevant training at Appalachian community colleges without earning degrees. Concepts, measures, and data sources for all knowledge infrastructure layers are summarized in Table 4.

University research strengths layer. There are eleven research universities located in ARC territory: Carnegie-Mellon, Clemson, Cornell, Mississippi State, Ohio University (consolidated in the available data, but dominated by Ohio State), Penn State, the University of Alabama at Birmingham, the University of Pittsburgh, the University of Tennessee, Virginia Tech, and West Virginia University. There are an additional six research universities situated adjacent to or very nearby the ARC boundary: Auburn University, Georgia Tech, Emory University, the University of Georgia, and the University of Mississippi. We included the six adjacent schools in the analysis on the assumption that their close spatial proximity yields a high potential spillover effect into the ARC region. We also added one additional institution not classified as a doctoral university (extensive) by the Carnegie Foundation—the University of Alabama at Huntsville—because of its uncommonly strong technology focus.[8] The locations of the eighteen research universities in the study are plotted in Figure 3.

We developed three measures of university competitiveness or strength *by discipline*: 1) perceived faculty quality as judged by peers in 1995; 2) external research funding receipts in 1991 and 1999; and 3) the number of full-time graduate students enrolled in 1991 and 1999.[9] To establish a common scale for combining the disparate dimensions of research strength, we converted the measures into national rankings and established a concordance between the set of value chain categories and the disciplines (see Table 3

[8] We assembled our list of doctoral-research universities inside and nearby the ARC region from the Carnegie Foundation's recently revised classification of institutions of higher education McCormick (2001).

[9] The faculty quality ratings are from the National Research Council's 1995 *National Survey of Graduate Faculty* (Goldberger, Maher *et al.* 1995). The survey asks peer faculty to rate doctoral programs within their respective disciplines on a scale of zero (lowest) to five (highest). The ranks are based on mean scores for each university. Research expenditures (external funding) and the number of full-time graduate students enrolled by academic discipline are from the National Science Foundation's Internet-based *webCASPAR* data base (http://caspar.nsf.gov). Two additional measures of competitiveness–the number of patents issued to universities and gross license income in 1991, 1995, and 1999–could not be disaggregated by discipline.

above).[10] We then averaged the rankings across the disciplines *within* each technology area. For example, Cornell University's rank for sponsored research relevant to the chemicals and plastics industry is the arithmetic average of its ranks for chemical engineering, materials engineering, and chemistry.[11]

Given the rankings on the three indicators, we identified Tier 1 universities as those with an average rank in the U.S. top twenty for at least two out of the three measures. Tier 2 schools are those with: a) an average rank in the U.S. top twenty for research funding or faculty quality; b) an average rank in the U.S. top forty for all three measures; or c) an average rank in the U.S. top twenty for number of graduate students and a rank in the U.S. top forty for either (or both) faculty quality or research funding (see Table 5). Our criteria effectively consider sponsored research and faculty quality as the leading barometers of a university's research capacity and output.

Federally funded non-university research organizations layer. The second major category of R&D performer in the Appalachian region is non-university-based research organizations. We used National Science Foundation data on federal funds provided to non-university R&D performers, federal agency web sites, and information from state development officials and other individuals familiar with the science and technology base of each state to identify eighteen major research institutions located in six Appalachian states (see Table 6). We were able to document funding levels only for defense-related labs.[12]

Patents layer. A third and extremely important element of Appalachia's science and innovation base are the many private sector businesses actively engaged in research, applied innovation, and development. Unfortunately data on private sector R&D activity are very limited. The National Science Foundation's industry surveys are based on very small samples and cannot be disaggregated to the sub-state level. While counts of both patents and federal innovation grants (under the Small Business Innovation Research program, Small Business Technology Transfer Research program, and Advanced Technology Program) cannot be regarded as direct proxies of private sector R&D generally, they can provide a partial picture of the geographical distribution of private sector science and innovation in the region.

A patent is an attempt by an inventor to appropriate fully and exclusively any returns derived from her innovation, at least for a limited period. Utility patent grants by sector are thus a partial indicator of applied innovative activity. While some patents are granted to universities and non-profit R&D performers, the vast majority is secured by private industry.

We used 1990-99 county level utility patent data from the U.S. Patent and Trademark Office (USPTO) to calculate G statistics and location quotients for the study region.[13] The USPTO assigns patents to counties based upon residence of the inventor.[14] Utility patents are initially classified by invention or

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[10] In the case of faculty quality, patents, and license income, the classification of disciplines is from the National Research Council. The discipline classification for research funding and enrollments is from the National Science Foundation. While there is a close match between the NRC and NSF categories in engineering and the physical sciences, the NSF classification is more aggregated in the biological sciences than the NRC scheme.

[11] Each measure indicates a different but complimentary dimension of university research competitiveness. In the absence of a compelling rationale favoring one dimension over the other, we elected to weight each indicator equally.

[12] The funding data are from Department of Defense budget documents.

[13] The G statistic for patents is calculated on the residuals of a linear regression with the number of county patents in a technology sector as the dependent variable, and the average county population between 1990 and 1999 as the independent variable. The residuals correspond to the expected county patenting activity beyond that explained by the population of the county. Because patents are coded to the residence of the inventor, population is a better control than employment.

[14] At best, this is only a rough approximation of the location of innovation. It assumes that the county of residence is an accurate representation the individual or institution that took a primary role in creating the invention. Many inventions are developed in multiple places while others are developed in one particular place before another person or institution in a different location subsequently patents them. Furthermore, it is unclear whether an inventor's place of work or residence is the more accurate way to identify innovative places. It may make more sense to think of innovative regions rather than try to pinpoint the site of innovation. Under typical metropolitan commuting patterns, residential areas are peripheral to work sites in the urban core. But these patterns are changing and suburb-to-suburb commuting has become the norm in many regions. The conduit for the spread of innovation and ideas is a complex web of economic and social interactions that might be limited by geography, but is not necessarily subject to imaginary boundaries

product, which the USPTO then re-classifies into industries using the 1972 SIC definitions. Using the USPTO SICs, we organized patents into ten technology sectors that roughly correspond to the value chain categories. The USPTO commonly assigns a single patent to multiple SICs and therefore a patent may be included in more than one technology sector.

Federal innovation program layer. To assemble a data set of SBIR/STTR/ATP winners in the ARC region, we reviewed program competition announcements for fiscal year 2000 to identify winners with zip codes in the ARC area. As with all other measures, each grant was mapped to a set of technology areas that roughly are consistent with the value chain industry classification. We then calculated the total number of SBIR/STTR/ATP grants by location for each technology category.

Higher education layer. The higher education and training component of Appalachia's knowledge infrastructure in the sciences and engineering fields is comprised of all universities, colleges, and institutes that offer degree programs in fifteen technology-related disciplines. The literature on technology-related regional growth has long emphasized the important role major research universities play in conducting R&D, transferring technology, and generating spin-off companies (Bozeman and Crow 1991; Coursey and Bozeman 1993; Lee and Gaertner 1994; Chrisman, Hynes *et al.* 1995). However, four-year teaching universities and colleges and two-year community colleges and institutes are also critical suppliers of necessary human capital and common sites for publicly funded business modernization programs (Luger and Goldstein 1997). Community colleges, in particular, play a key role both in preparing and upgrading technology workers in a wide range of applied fields and in supplying focused training and modernization assistance to technology-intensive firms.

We evaluated the human capital dimension of the Appalachia's colleges and universities using 1997/98 data on degrees granted by program from the U.S. Department of Education's Integrated Postsecondary Education Data System (IPEDS).[15] IPEDS data ultimately derive from the Department of Education's surveys of all postsecondary institutions that participate in federal financial aid programs. The surveys essentially cover every conventional university, college, and community college in the U.S., as well as many specialized trade schools and technical institutes.[16] The IPEDS degree completions data are reported at a very high level of program detail. We aggregated the figures into fifteen disciplinary/program areas that parallel, as much as possible, the National Science Foundation discipline classification. Table 3 reports the concordance between those categories and the eight core technology areas represented by the industry value chains.[17]

Our initial analysis indicated that heavy spatial concentrations of degree completions for four-year colleges and universities tend to coincide with the locations of major research universities. That is unsurprising given that the research universities are some of the largest educators in the region. Therefore, in the overlay maps below we depict only degree completions for two-year higher education institutions. That has the advantage of emphasizing synergies between the universities and the key applied education and training role of community colleges.

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between work and home. Note that patents with multiple inventors living in different counties are weighted by the total number of inventors. Because the *G* statistic is designed to reveal spatial association among counties, it helps offset the discrepancy caused by differences in inventor residency and work locations.

[15] The Integrated Postsecondary Education Data System (IPEDS), along with all technical documentation, is accessible via the Internet at http://nces.ed.gov/ipeds/index.html.

[16] The Department of Education's universe for its completions surveys are all institutions with which it has Program Participation Agreements (PPAs) regarding Title IV federal financial aid programs, or some 9,519 schools in the fifty states and District of Columbia. The 1997/98 overall response rate for the survey (actually two separate instruments) was 74 percent. Four-year institutions responded at 89 percent, two-year schools at 88 percent, and less than two-year institutions at 53 percent. Although responding institutions account for the vast majority of degrees granted, the IPEDS completions data must be regarded as slight undercounts of total degree completions.

[17] Degree completions in the IPEDS data are disaggregated by over 550 Classification of Instructional Programs (CIP) codes (see http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=91396). We used judgment and the National Science Foundation science and engineering disciplines as guides to first identify 190 CIP codes as technology-related programs, and then aggregate the 190 selected codes to fifteen substantive categories. The included CIP codes along with their classification to the fifteen aggregate categories are reported in Appendix Table 5.

Identifying technology clusters

To identify Appalachia's core *technology clusters* we used GIS to overlay the multiple variables specifying joint industrial and innovative strengths for each of the eight technology areas: technology intensive value chain employment by county (*G* statistics and location quotients), science and engineering occupational employment by metro area (location quotients), Tier 1 and 2 research universities by location (ranking), technology-related utility patent grants by county (*G* statistic and location quotients), SBIR/STTR/STC award winners by county, and degree completions. We then visually inspected the maps, as well as applied more formal screening criteria, to identify a set of sub-regions where both high tech industry and related R&D and innovation activity are in evidence.

3 Findings

The results of the analysis are summarized graphically in Figures 4-11. They should be interpreted with care and especially with a mind toward the study's specific objectives. We adopted a fairly liberal standard for designating clusters: that there be at least some evidence of joint industrial and innovative activity in the same vicinity. Given the less-developed nature of much of the Appalachian region, we sought to avoid overlooking sub-regions with potential for expansion in various technology areas. Certainly, some identified clusters are much stronger than others. An understanding of differences in the relative depth of clusters in various areas can be derived from Table 7, which indicates the types of technology activity found in each sub-region.

The specific geography of the clusters is inexact. Modifiable areal unit problems and limitations in individual measures limit our capacity to isolate the exact boundaries of concentrated activity. That is why we include multiple measures (location quotients, *G* statistics) and units of analyses (metropolitan areas, counties). We have focused on locations where results from these different indicators and units of analysis tend to overlap. It follows that our areal labels in Table 7 and in Figures 4-11 describe only the general vicinity of given clusters and should not be interpreted narrowly or exclusively (e.g., most of the clusters labeled as "Pittsburgh" extend across the greater Pittsburgh region). Ultimately, the maps offer the most accurate means of interpreting the geographic pattern of technology activity.

While there is no need to discuss every cluster in Table 7 individually, there are several general findings that emerge from the analysis. First, Appalachia's principal localized technology-related strengths at the present time are in three major areas: chemicals/plastics, industrial machinery, and motor vehicles and related industries. Those three traditional "sectors" account for 58 of the 100 clusters identified. Only four to eleven localized clusters could be found for each of the remaining six technology areas. Moreover, in the remaining six technology areas, the Washington, DC, Huntsville, Pittsburgh, Atlanta, and Ithaca/Binghamton regions account for eighteen of the 42 clusters identified.

Second, the distribution of clusters throughout Appalachia is highly uneven. Nearly half (45 in total) of the region's technology clusters are located in the northern third of the region (New York, Pennsylvania, and northern Ohio). Only nineteen clusters were identified for central Appalachia (an area that includes southern Ohio, West Virginia, Virginia, and Kentucky), with Cincinnati and Washington, DC accounting for nine of those nineteen. In the southern third of the region, Atlanta, Greenville-Spartanburg, and Huntsville account for sixteen of 29 clusters identified. The geography of clustering in the region is a function of both the general historical distribution of industrial activity as well as the limited presence of leading universities in central and southern Appalachia. The distribution of federal grants (e.g., SBIR/STTR/ATP) also tends to favor the north, especially if grants in the Huntsville area (originating from organizations linked to large area federal labs and defense installations) are excluded

Third, the uneven geography of the clusters in the region varies substantially by technology area. The chemicals/plastics and information technology/instruments clusters are relatively evenly distributed amongst the northern, central, and southern thirds of the region. Industrial machinery, on the other hand, is nearly exclusively a northern and southern strength. Indeed, there are two large-scale dominant concentrations of industrial machinery activity in the region: along the northern ARC border in the states of Ohio and New York and extending over much of Pennsylvania, and along the Interstate 85 corridor of North Carolina, South Carolina, and Georgia. Other clusters are most common in the north: communications services and software, aerospace, and pharmaceuticals and medical technologies.

Fourth, just over half of the technology clusters in the region are located on the periphery and are anchored in core metropolitan centers outside the region (such as Cincinnati, Atlanta, and Washington, DC). There are few predominantly rural clusters, as is expected given a methodology that essentially considers both relative and *absolute* size as barometers of a cluster's strength. The following is a summary of findings for each technology area, with an emphasis on identifying the clusters of greatest competitive strength:

- *Chemicals and plastics:* Particularly strong clusters in the areas of Binghamton and Ithaca, Newburgh, Reading/Allentown, Cleveland and Akron, Charleston, Greenville-Spartanburg, and Auburn, AL. State College, anchored by R&D activity at Penn State, is another significant area of chemicals and related activity;
- *Motor vehicles and related:* Strongest clusters are Rochester, Binghamton, Cleveland and Akron, and Greenville-Spartanburg. Most industrial employment in motor vehicles and related supplier industries is situated along the border of the region and tracks Interstates 71 and 75 through Ohio, Kentucky, and Tennessee. In this cluster, the location of industry activity is coincident with innovative activity only infrequently;
- *Industrial machinery:* Strongest clusters in Buffalo and Rochester, northeastern Ohio, Mansfield, and Greenville-Spartanburg. Lynchburg and Cincinnati only two clusters identified in central Appalachia;
- *Information technology and instruments:* Strongest clusters in Binghamton (home of IBM), State College, Washington, Atlanta, and Huntsville. Community colleges provide substantial training in related fields, particularly in Washington, DC, eastern Pennsylvania, northern and central Ohio, and Pittsburgh. Overall, the region's knowledge infrastructure in information technology is considerably stronger than its industrial base;
- *Communications services and software:* Strongest clusters in Washington, DC, Atlanta, and Huntsville. As in the case of information technology, the industrial component of the cluster is much weaker than the knowledge and innovation component;
- *Aerospace:* Strongest clusters Pittsburgh, Atlanta, and Huntsville. Washington, DC boasts heavy complement of scientists and engineers in related occupations but a comparatively modest industry concentration, perhaps reflecting the dominance of federal government activity (e.g., defense) in the area;
- *Household appliances:* Very little evidence of clustering in Appalachia; leading concentrations in Cleveland and Akron, Huntsville, and Greenville-Spartanburg;
- *Pharmaceuticals and medical technologies:* Dominant clusters near Ithaca and Chenango County, NY, Pittsburgh, Washington, DC, and Birmingham. There is a substantial concentration of related industry employment in Huntsville but a weak supporting knowledge infrastructure.

Summary measures of spatial coincidence

Although the maps presented as Figures 4-11 aid in identifying the location and spatial distribution of local technology clusters, the wealth of data presented make it difficult to generalize findings for the entire study area and make comparisons across technology areas. To help characterize broader trends in clustering in the region, we developed a simple spatial coincidence ratio (SCR) to summarize the incidence of overlap between industry and innovation-oriented strengths by location. For any two indicators,

$$SCR = \frac{\sum_i x_i y_i}{\left(\sum_i x_i + \sum_i y_i\right) - \sum_i x_i y_i}$$

where x and y indicate significant technology strengths in county i. The SCR can be easily expanded to evaluate any number of indicators. The spatial coincidence ratio is simply the number of counties with significant strengths in two (or more) indicators, divided by the number of counties with strength under either indicator. Since our county indicators are binary, the SCR measures the geographic intersection of our indicator sets, divided by the union of those sets. SCR ranges from 0 to 1, with 1 indicating perfect spatial coincidence. In other words, when SCR=1, for every county where indicator *x* is significant, indicator *y* is also significant.

We use the SCR to compare the location of value chain employment concentrations to innovation base concentrations, for each technology category. Counties with significant value chain employment and patent concentrations are identified as previously described. Counties with significant university research strengths are identified as either the home county of a Tier 1 or Tier 2 research university, or a county immediately adjacent to a home county. The knowledge indicator identifies counties with significant strength in *either* patents or university research. We limit our analysis value chain employment, patent, and university indicators of technology strength because they are the richest geographic measures available. We calculated the SCR for all study counties as well as various sub-regional classifications (northern, central and southern Appalachia, border versus interior counties, and rural versus metro counties). The results are summarized in Table 8.

The figures in Table 8 are consistent findings derived from a visual inspection of mapped overlays. However the SCR also reveals some additional findings. The degree of coincidence between the industrial base and innovation base is strongest for industrial machinery, communications services and software, and information technology and hardware. There are a significant number of chemicals and plastics and motor vehicle manufacturing employment clusters in and adjacent to the region, but they are only rarely juxtaposed with related innovation activities.

The level of industry/innovation spatial coincidence is highest in northern Appalachia and the lowest in the south. This is particularly true for industrial machinery, chemicals and plastics, and motor vehicle manufacturing. Historically, those sectors have been concentrated in the northern manufacturing belt, which remains a center of both employment and innovation. Co-location of innovative and employment activity is also heavily confined to border counties of the study area (counties outside the ARC boundaries) as well as urbanized counties. This further emphasizes the importance of including adjacent areas in studies where geographic spillovers are a likely possibility. There is very little spatial coincident activity to speak of in rural counties; clustering is largely an urban phenomenon.

Table 9 reports additional variations of the SCR index. The first set of results in Table 9 includes different permutations of the three core measures. The indices that include only university research strengths as the innovation side measure are almost universally weak or zero, namely because so few areas have significant research university strengths. To offset this weakness, we calculated a second set of comparisons that only includes counties that contain, or are adjacent to, at least one of the eighteen major research universities in the study area. Even within this limited subset, the spatial coincidence of value-chain employment and knowledge activity still largely follows the same pattern across technology sectors as the study region as a whole. The single exception is for communications services and software.

In general, university strengths are only weakly proximate to employment concentrations in the ARC region in most sectors, a useful finding to bear in mind when evaluating empirical studies that link research universities to innovation and employment outcomes (Jaffe 1989; Bania, Eberts *et al.* 1993; Anselin, Varga *et al.* 1997; Anselin, Varga *et al.* 2000). There is a somewhat stronger, but still modest, spatial coincidence between patent clustering and university research strength, especially in the most knowledge intensive sectors: aerospace, information technology and instruments, and communications services and software. Those sectors may be much more dependent upon university research and/or faculty as either a direct or indirect source behind local innovative activity that results in patents.

The final set of indices in Table 9 adds a science and technology occupation concentration measure as a fourth "core" indicator to our analyses. As mentioned before, the OES survey that generates the employment by occupation data is only available for aggregated metro areas. Therefore, we can make occupation-based comparisons only for metropolitan counties. We combined value-chain employment and S&T occupation employment into a composite measure and compared it to the composite knowledge base measure. The results are largely consistent with the value chain employment/knowledge comparison for MSA counties presented in Table 8. The two exceptions are in aerospace, where the spatial coincidence is somewhat larger when occupations are included, and in communications services and software where the spatial coincidence is somewhat smaller. In general, we find a strong spatial association between occupations and the other cluster indicators for metro areas, which is not surprising considering the predominantly metropolitan character of most technology clusters in the study region. There is a fairly high coincidence between metro value-chain clustering and S&T occupation employment as well as between S&T occupations and knowledge base clustering, especially in communications services and software, information technology, and chemicals and plastics. The results are weaker when S&T occupations, value chain employment and the knowledge base are compared as separate indicators, although communications services/software and information technology still show modest co-location tendencies under the more stringent test.

4 Implications and further research

This study identified sub-regional concentrations of technology-related economic activity and innovation within and immediately adjacent to the 406 county ARC region. Many of the clusters are in traditional manufacturing (chemicals, motor vehicles, and industrial machinery). Overall, we found that Appalachia's industrial base is oriented toward high tech industries of moderate technology intensity. The joint spatial clustering of business and innovation/R&D in some very high-tech sectors such as information technology, software, and aerospace is limited. While some Appalachian universities boast significant existing or emerging R&D strengths in science and engineering disciplines, often those universities are not located nearby significant concentrations of industrial employment in related sectors. Likewise, while Appalachia has its share of federal laboratories and other non-university R&D institutions, they are not always spatially coincident with the technology-oriented industrial base.

Furthermore, a great many of the region's clusters are located on its periphery. The ARC region's current high-tech prospects are therefore heavily dependent on spillover (or "spread") effects from neighboring cities and metropolitan areas. Unfortunately, those spillover effects are neither certain nor necessarily positive. High-tech concentrations in border metro areas such as Washington, DC, Cincinnati, Columbus, and Atlanta may draw away talented graduates from Appalachia's colleges and universities, leaving the region without the human capital base necessary to fuel technology-related growth. Given the power of first mover advantages and subsequent agglomeration economies common to technology-based industries, the prospect of negative geographic spillover (or "backwash") effects from larger neighboring jurisdictions is a very real one.

What can regional policymakers do with extensive information on Appalachia's technology clusters? How can technology clusters in Appalachia be nurtured and expanded? The concept of a technology cluster–a joint concentration of industrial production and innovative activity–suggests three principal avenues of intervention: targeting cluster sectors for growth and expansion by entrepreneurship and recruitment programs (addressing the business component of clusters); improving research and education capabilities in scientific and technical fields (the knowledge infrastructure component of clusters); and leveraging productivity-enhancing agglomeration economies and knowledge spillovers shared by cluster firms and supporting institutions (usually by maximizing opportunities for collaboration, learning, networking, joint problem-solving, and the like).

Industrial targeting

One of the most common and direct applications of the cluster concept is the application of conventional economic development strategies (especially recruitment and entrepreneurship programs) to under-developed elements of industry clusters. Cities and states in the ARC region can subject each individual technology cluster identified here to further detailed analysis to determine that cluster's underlying industry mix, its recent pattern of growth and decline by sector, and the growth prospects of related industries that are under-represented or entirely absent. Promising sectors can then be evaluated for feasibility as development targets based on their typical location requirements (in terms of infrastructure, workforce, market, input supply, amenities, and environmental impact). The idea is to implement a business development strategy that plays to–and expands–the region's demonstrated strengths in production and R&D, thereby increasing the complement of higher wage, technology-oriented activity.

Knowledge infrastructure

Another area of public sector intervention is the development of a high quality knowledge infrastructure. What characterizes technology clusters is not only high-tech businesses, but also the presence of important supporting institutions such as research universities, teaching universities and community colleges, and non-profit and private-sector contract research houses and laboratories. DeVol (2000 p. 34) argues that "research centers and institutions are indisputably the most important factor in incubating high-tech industries." The concept of clusters has piqued the interest of state, regional, and federal development agencies because it implies clear avenues for policy in areas in which the public sector has traditionally, and often very successfully, engaged. The finest research and teaching universities in the country–whether private or public–owe a good part of their success to federal and/or state funding, the federal government has long been a major supporter of basic research, and many states are becoming direct players in the technology arena by establishing centers for biotechnology, information technology, electronics, and other areas of applied research (Jankowski 1999; Schacht 2002). Given the limited success of efforts to recruit relocating businesses (high-tech or otherwise), governments are increasingly attempting to aid the growth of technology clusters by doing what they have traditionally done well: support basic research, education, and training.

That is not to argue that government support for research and technology-oriented education and training in a specific region is guaranteed to generate or expand a technology cluster with dynamic high-tech, high wage companies at its core. Exactly how to implement such a strategy is still unclear and much research remains to be done both on the link between research and education and job creation and on the rationale for government support for business R&D (e.g., see Tassey 1999; Wallsten 2000b; Wallsten 2000a). Most states are currently in various stages of policy experimentation, with some focusing on university technology transfer, others establishing "centers of excellence" in specific areas of research, and still others funneling resources into applied science and engineering training at the community college level. But the attractiveness of such strategies, even in the face of uncertainty with regard to efficacy, is explained by their potential to yield a broad range of benefits with different degrees of certainty. The establishment of a leading research focus area (or "center of excellence") within a university or non-profit organization, for example, is a benefit aside from its potential to attract companies or spin off new business ventures. Likewise, education and training yield civic, social, and quality of life benefits apart from the immediate connection between quality human capital and business investment. Thus the pursuit of technology clusters offers the prospect of a more diverse portfolio of social outcomes and benefits than conventional business recruitment and marketing strategies.[18]

Cities and states in the ARC region could use our findings to identify investments in knowledge infrastructure that will do two things: first, ensure that there is a sufficiently skilled labor force for technology-related industrial growth; and, second, maximize complementarities between innovation and industrial competencies. The workforce skills question can be addressed by determining whether university and community college programs are meeting the needs of technology sectors in identified clusters within specific Appalachian sub-regions. Given the narrow requirements of many technology businesses, a case-by-case analysis is necessary as a follow on to our general assessment. Strengthening university or non-profit R&D strengths in disciplines that dovetail with growing technology sectors can foster synergies between the industrial and innovation components of the clusters. Again, the first step is to take the technology clusters identified here and break them down further into much narrower areas of industrial and R&D strength.

Leveraging spillovers and agglomeration economies

A third area of development policy intervention implied by the cluster concept is the promotion or leveraging of productivity-enhancing spillovers and economies shared by the technology businesses at the core of each cluster. Aside from promoting the growth of the cluster to encourage external economies of scale, appropriate policy options are limited to establishing venues or mechanisms for business collaboration and information exchange. Cities or states can encourage the creation of a trade association or other private sector organization charged with defending and promoting the shared interests of firms in a given cluster. Typically, such organizations also help market the region as a location for related businesses, hold networking events and conferences, and provide a natural standing venue for businesses to bring infrastructure, workforce development, regulation, and taxation concerns to the attention of public agencies, universities, and community colleges. Absolutely essential to the success and efficacy of such organizations is a clear articulation of the benefits firms can gain–even if they are direct competitors–by collaboration on at

[18] The logic presumes that the given investment, in this case an engineering school, is pursued based on criteria apart from–or at least in conjunction with–business creation objectives. There is a very real risk that government will over-supply research and education in its effort to create technology jobs. A partial example of this pitfall is documented by Luger and Goldstein 1991 in an analysis of the university research park craze of the 1980s.

least some issues (e.g., regulatory reform, public infrastructure, etc; see Dalsgaard 2001). A common thread in the research literature to date is that firms rarely know they are part of clusters, let alone that they benefit from efforts to further develop the same.

Further research

This study provides only the broadest picture of the regional distribution and orientation of Appalachia's technology-related assets and activities. A number of important issues with respect to the proper formulation of economic development policy in Appalachia remain unaddressed. There are several possible avenues for further research. First there is the question of whether Appalachian sub-regions with a strong joint complement of industrial and innovative activity are growing faster–in income, employment, output, and/or productivity terms–than those without a strong knowledge infrastructure component. Some studies (e.g., O'Malley and Van Egeraat 2000) have found little evidence of a strong positive relationship between clustering and manufacturing growth, implying that public policies aiming to develop clusters will not yield significant growth impacts.

Second, the net spillovers (positive or negative) of border technology clusters that are anchored outside the ARC region are little understood. Information on the migration trends of graduates from ARC universities, the location patterns of spin-offs from technology businesses and universities in the region, and cross-border linkages among firms in border clusters, while difficult to assemble, would provide a critical understanding of the likely influence of border cluster development on the economic prospects of Appalachia itself.

Third, it would be useful to explore the functional and organizational differences among otherwise similar technology clusters in Appalachia and the implications of those differences for the net economic impact of technology clusters in general. Some clusters may be dominated by multi-locational firms headquartered outside the region while others may be indigenously based. Similarly, foreign-owned companies may dominate some clusters, e.g., the automotive cluster emerging in Greenville-Spartanburg. Locally-based cluster companies may be more likely to generate spin-offs within the region, as well as link more closely with the research efforts of Appalachian universities and labs, therefore generating more significant economic impacts in the long-run.

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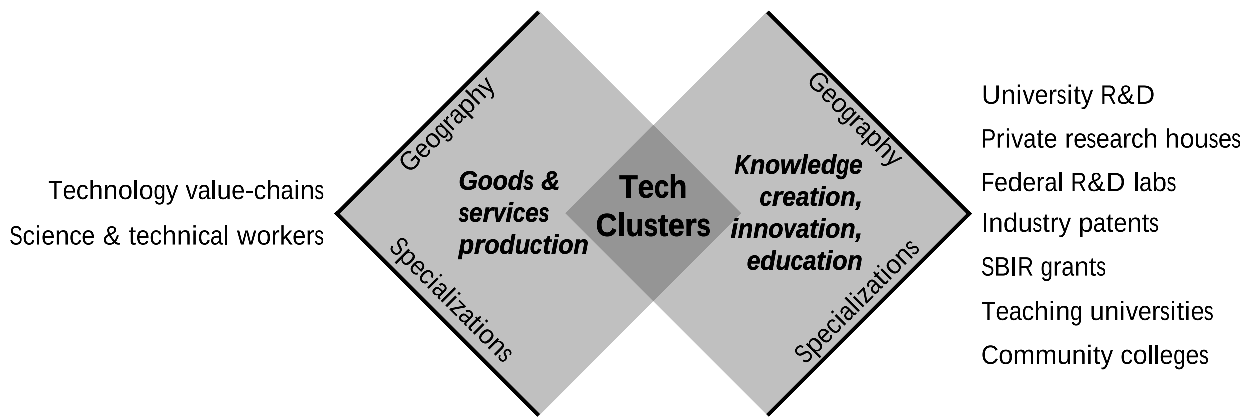


Figure 1. Study conceptual framework & report organization

Figure 2
Study area, Appalachia & border region

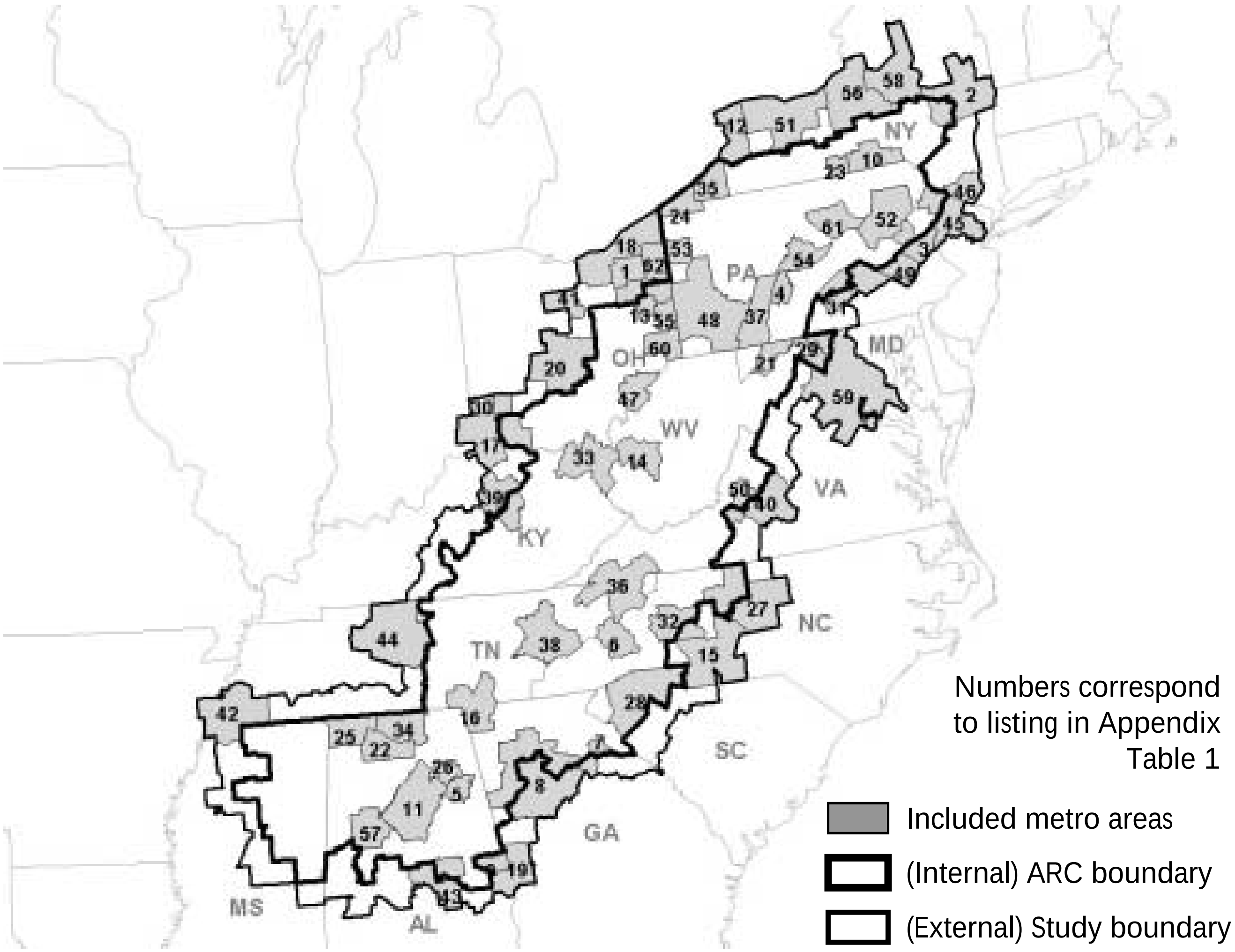


Figure 3

Technology clusters: Chemicals & plastics

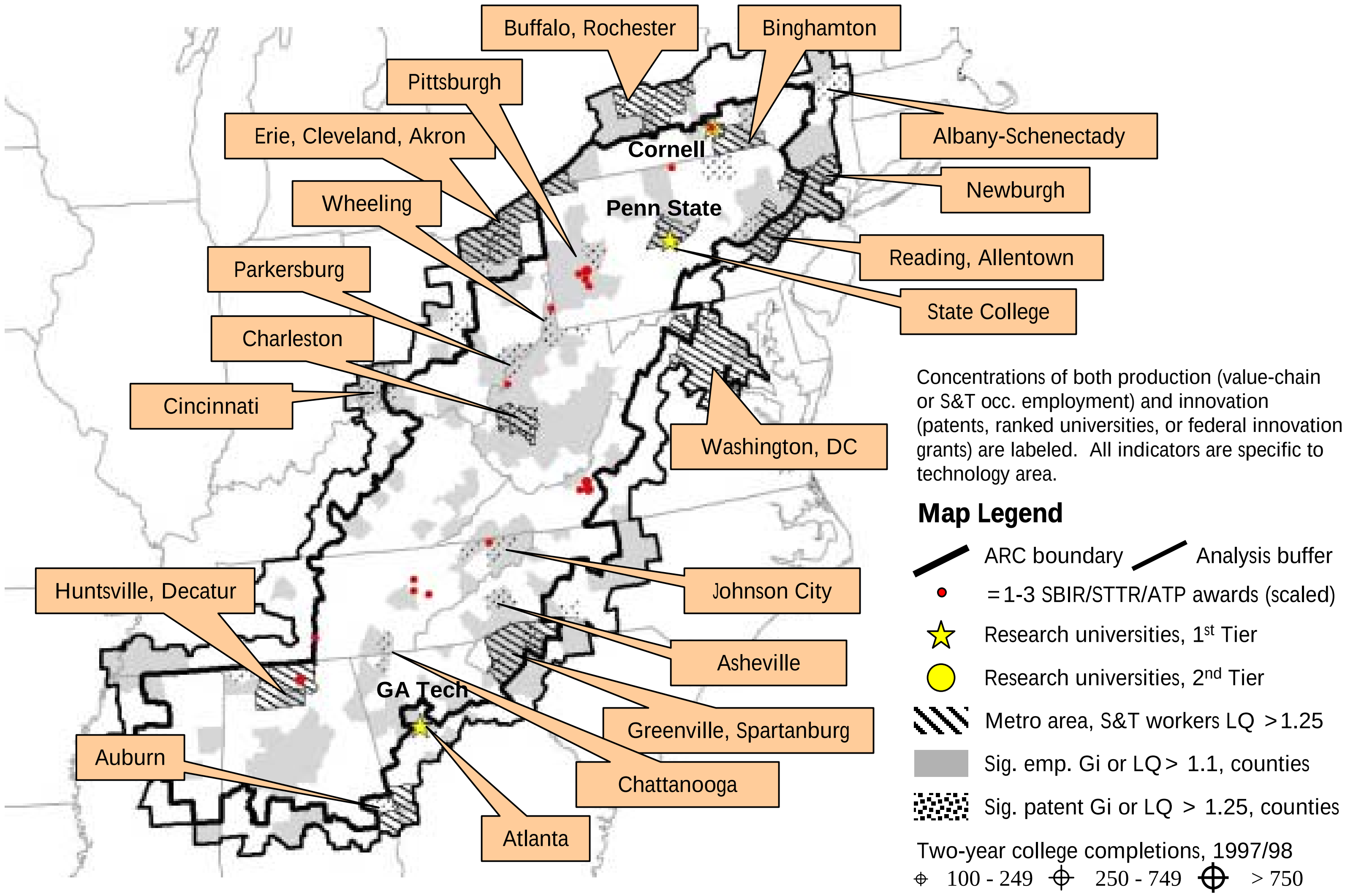


Figure 4

Technology clusters: Motor vehicles & related

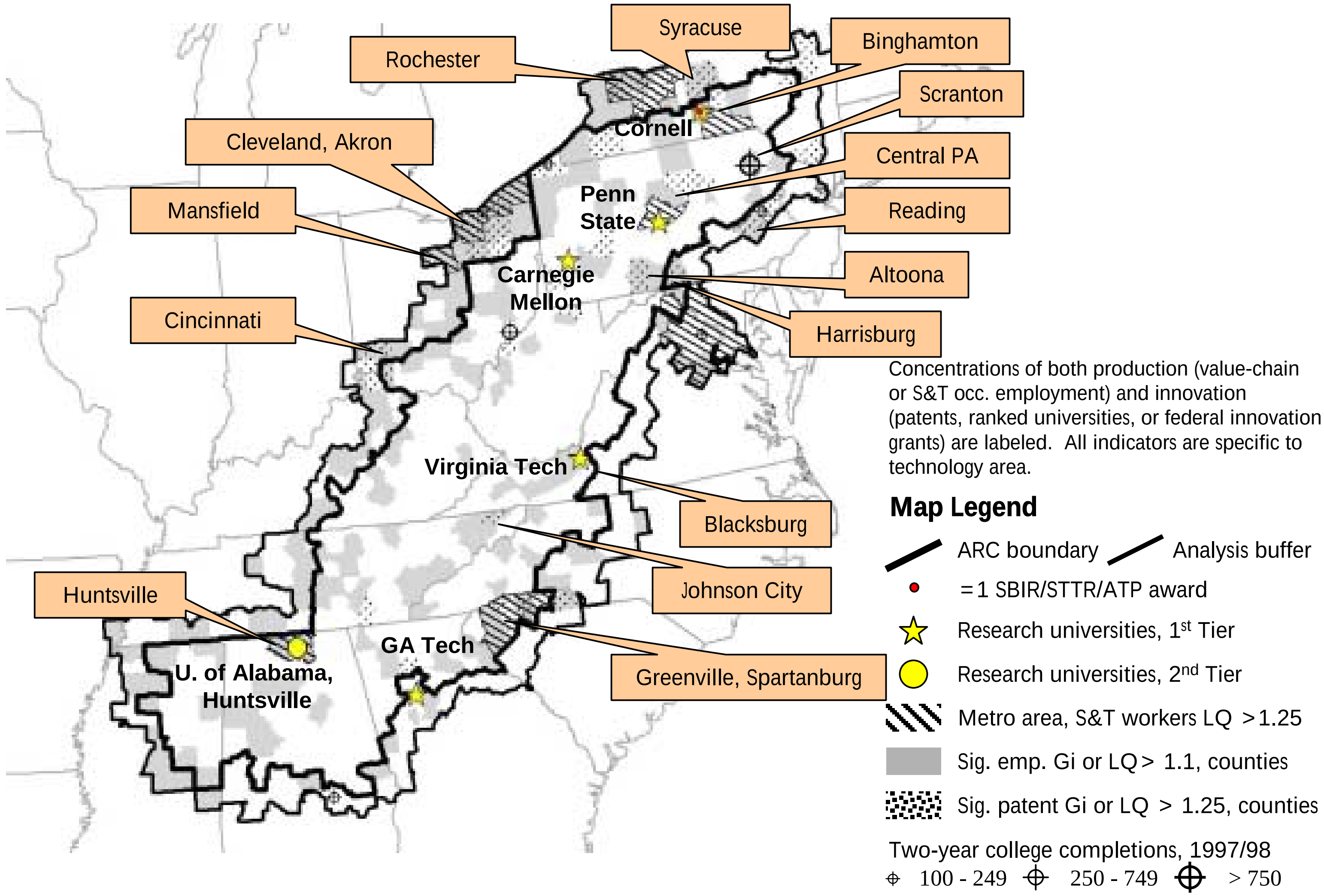


Figure 5

Technology clusters: Industrial machinery

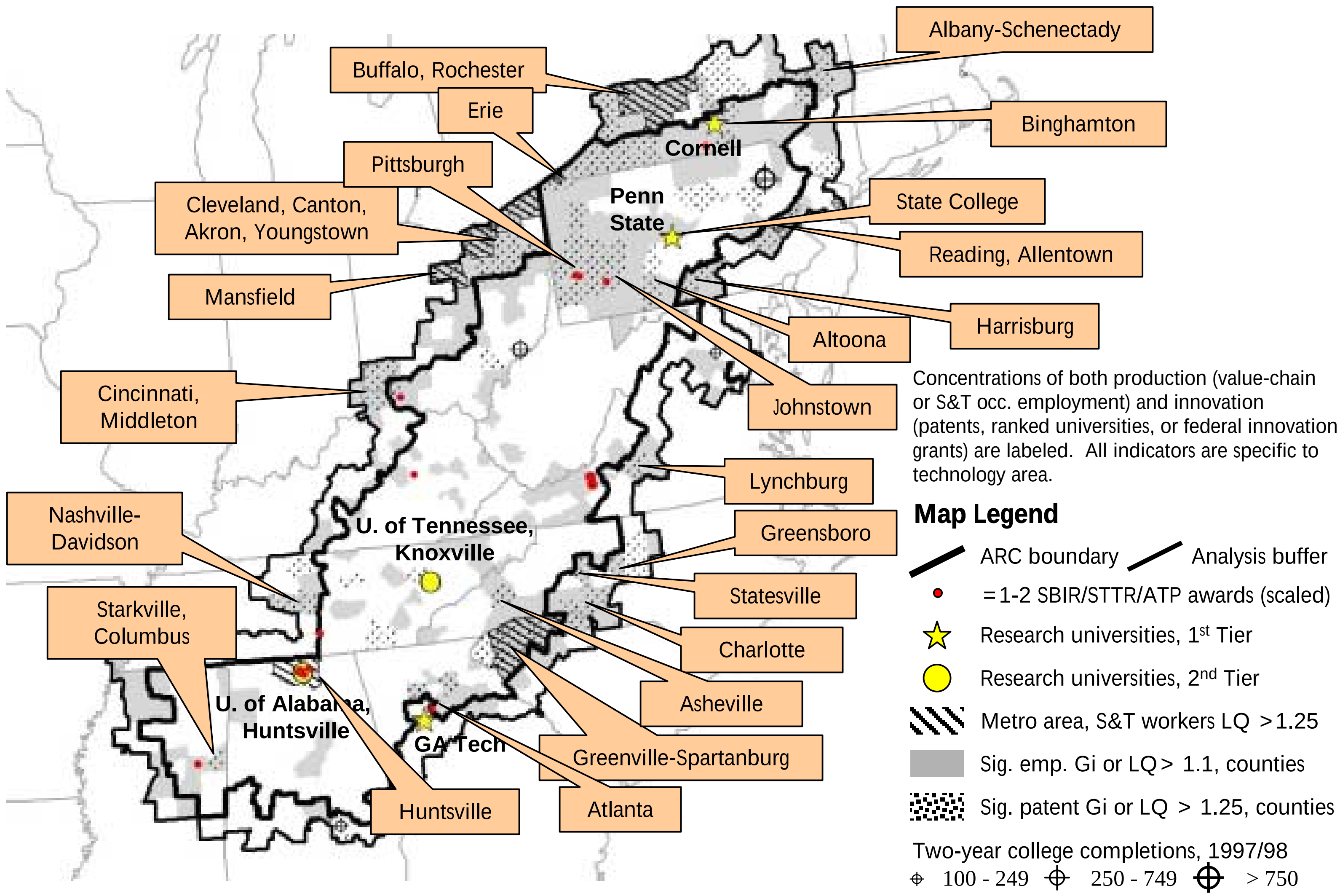


Figure 6

Technology clusters: Information technology & instruments

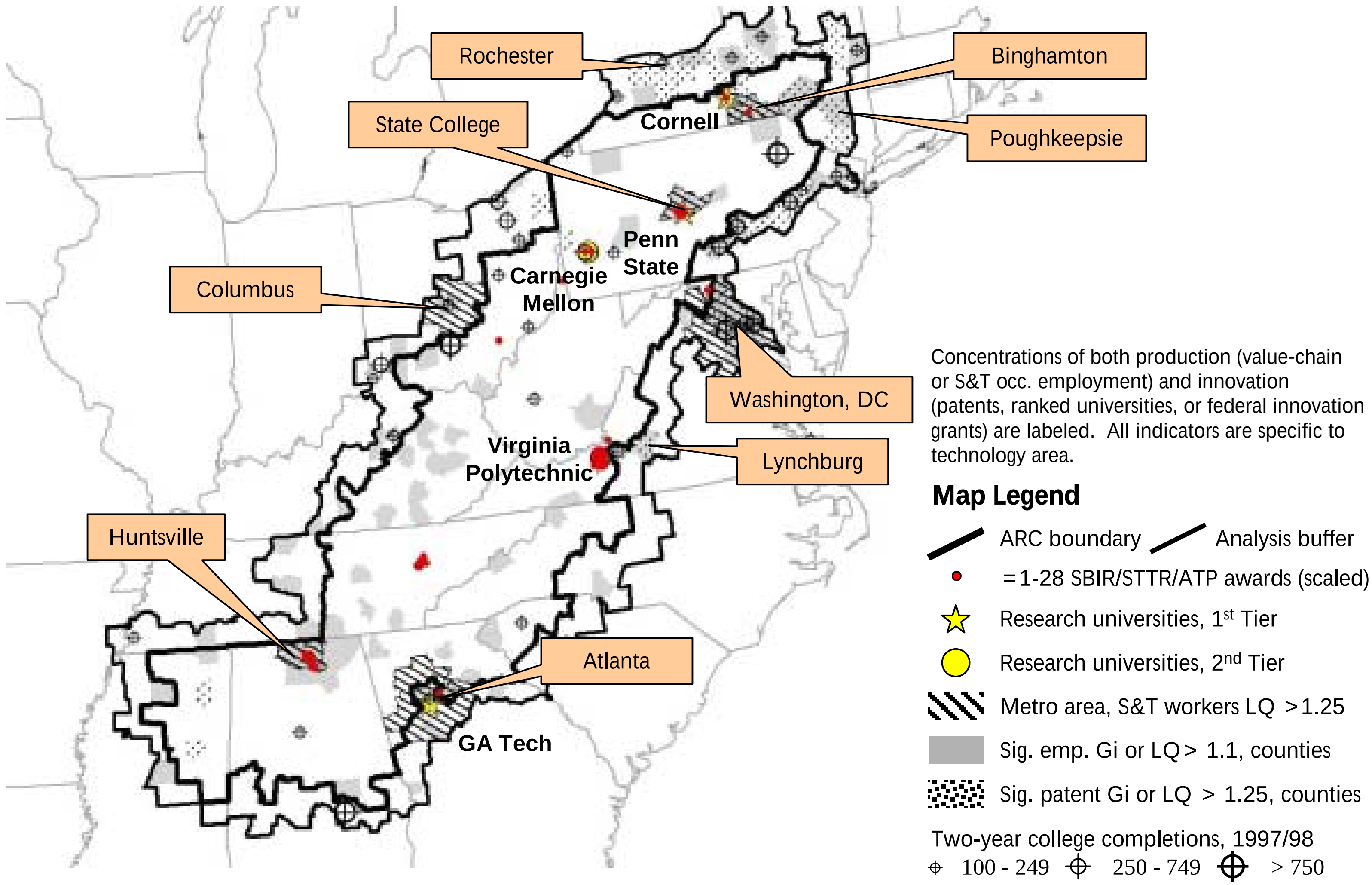


Figure 7

Technology clusters: Communications services & software

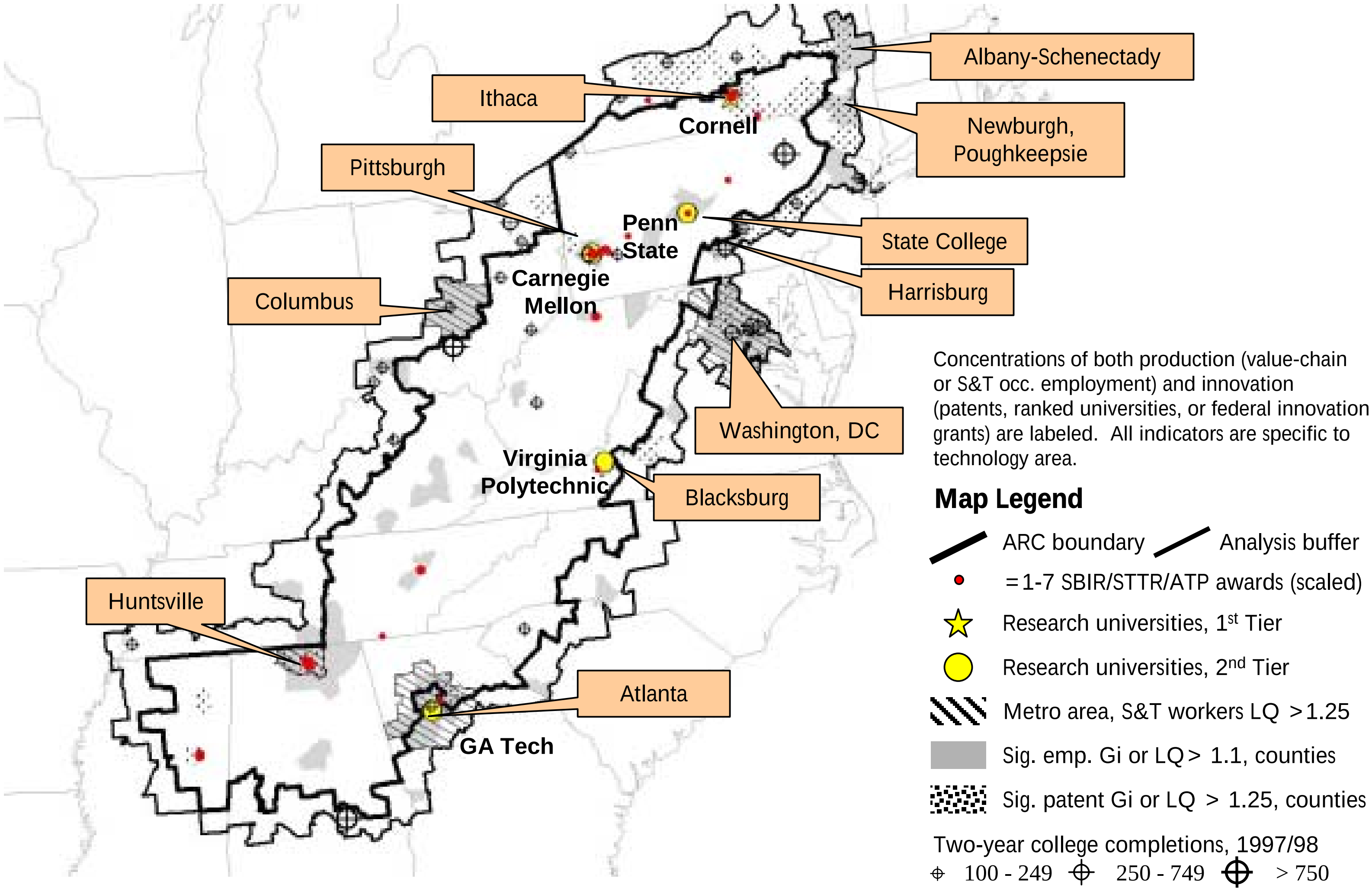


Figure 8

Technology clusters: Aerospace

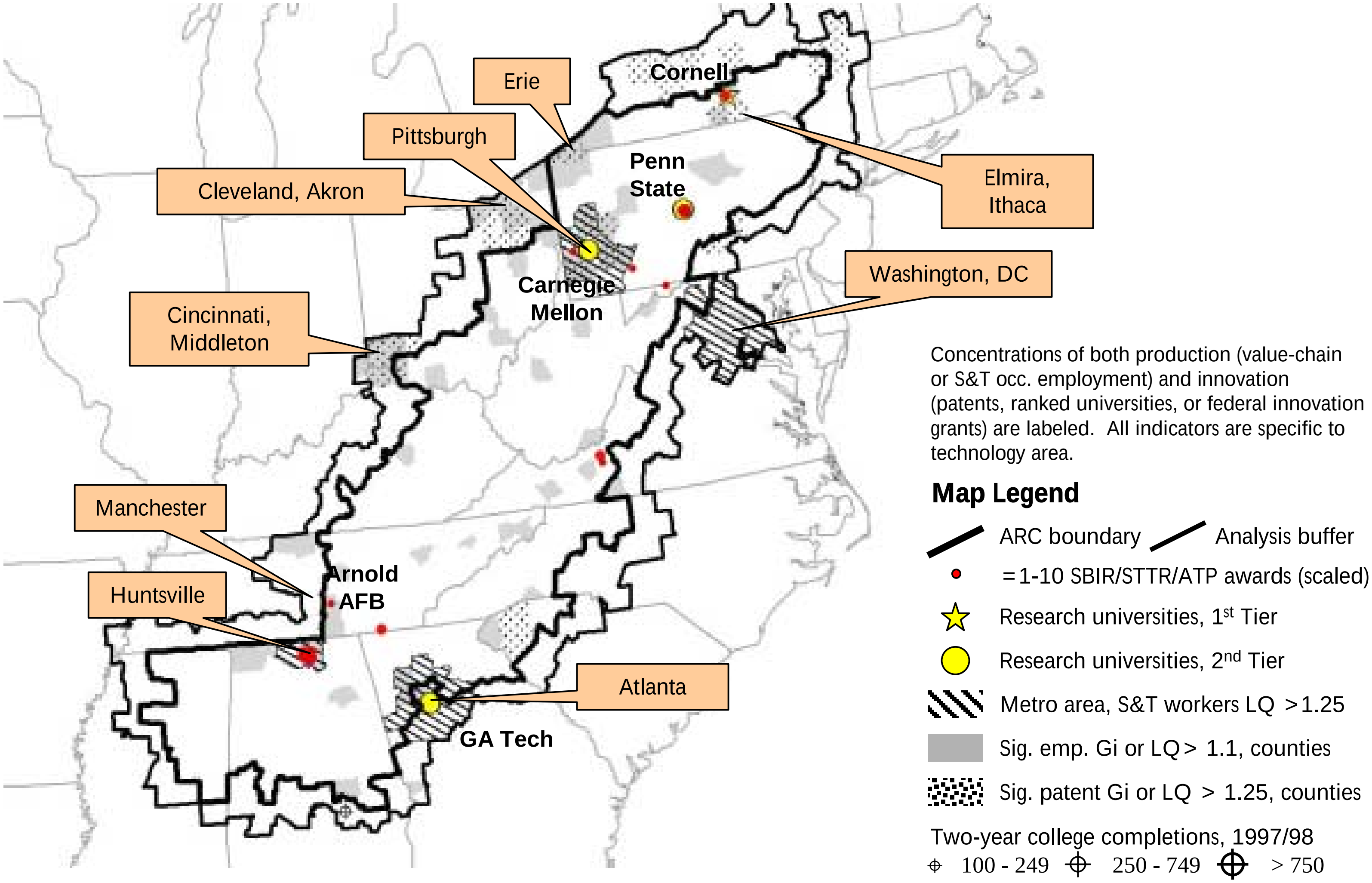


Figure 9

Technology clusters: Household appliances

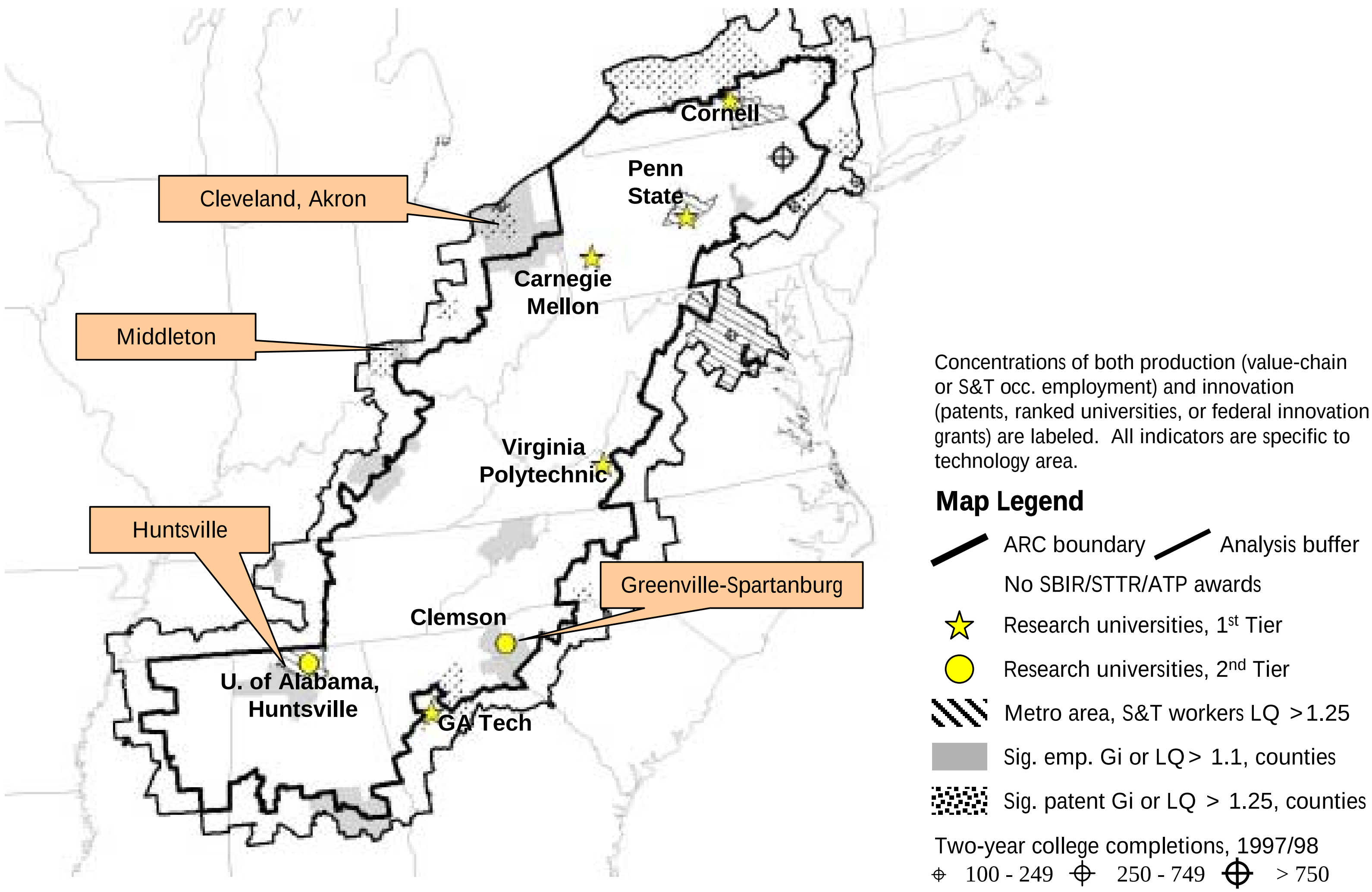
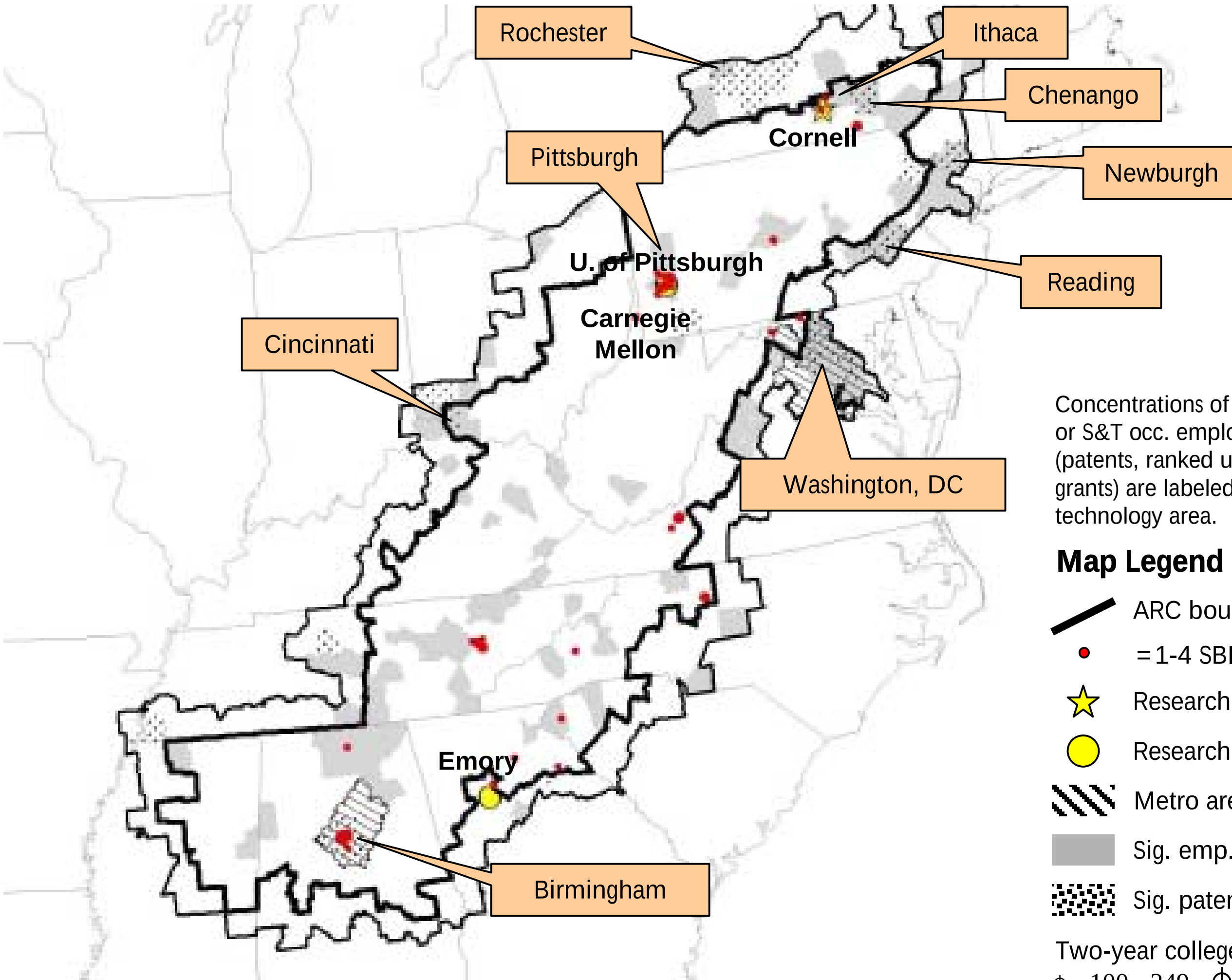


Figure 10

Technology clusters: Pharmaceuticals & medical technologies



Concentrations of both production (value-chain or S&T occ. employment) and innovation (patents, ranked universities, or federal innovation grants) are labeled. All indicators are specific to technology area.

Map Legend

ARC boundary — Analysis buffer
= 1-4 SBIR/STTR/ATP awards (scaled)
Research universities, 1st Tier
Research universities, 2nd Tier
Metro area, S&T workers LQ > 1.25
Sig. emp. Gi or LQ > 1.1, counties
Sig. patent Gi or LQ > 1.25, counties

Two-year college completions, 1997/98
100 - 249 250 - 749 > 750

Table 1

Study measurement of high-tech industrial activity

Concept	Classification	Variable	Year(s)	Concentration measure	Areal unit	Data source
Value chain clusters	Eight value chains developed via an input-output analysis of buyer-supplier patterns among high-technology sectors	Industry employment	1989, 1998	Location quotient, G statistic	Counties, zip codes	Confidential ES-202 series, US Bureau of Labor Statistics; 1992 benchmark input-output accounts, U.S. Bureau of Economic Analysis
Scientists & engineers	Scientific, engineering, and engineering technician ccupations	Occupational employment	1999	Location quotient	Metro areas	US BLS Occupational Employment Survey

Table 2

Technology-intensive value-chain employment & wages, 1989, 1998

United States*

Value-chains	Employment 1989 (000's)	Employment 1998 (000's)	% private sector '98	% Change '89-'98	Payroll 1998 (Millions $)	% private sector '98	Average wage $
Chemicals and plastics	1,218.7	1,384.8	1.3	13.6	59,213	1.8	42,760
Information technology & instruments	2,887.5	3,573.0	3.4	23.7	202,588	6.1	56,700
Industrial machinery	550.1	568.0	0.5	3.3	23,040	0.7	40,564
Motor vehicles	1,375.8	1,523.3	1.5	10.7	70,242	2.1	46,111
Aerospace	1,097.2	848.8	0.8	-22.6	42,557	1.3	50,136
Household appliances	94.6	91.5	0.1	-3.2	3,233	0.1	35,330
Communications services & software	1,877.2	2,918.6	2.8	55.5	163,049	4.9	55,866
Pharmaceuticals & medical technologies	840.9	982.7	0.9	16.9	49,930	1.5	50,807
Total private sector	96,029.3	104,258.3	100.0	8.6	3,310,187	100.0	31,750

Appalachia

Value-chains	Employment 1989 (000's)	Employment 1998 (000's)	% private sector '98	% Change '89-'98	Payroll 1998 (Millions $)	% private sector '98	Average wage $
Chemicals and plastics	119.0	129.7	1.5	9.0	5,107	2.3	39,377
Information technology & instruments	151.0	167.2	2.0	10.7	6,494	3.0	38,852
Industrial machinery	65.7	60.0	0.7	-8.6	2,276	1.0	37,926
Motor vehicles	90.7	121.4	1.4	33.9	4,356	2.0	35,884
Aerospace	40.7	40.1	0.5	-1.4	1,572	0.7	39,222
Household appliances	5.2	5.7	0.1	10.7	171	0.1	29,965
Communications services & software	98.2	132.4	1.6	34.8	5,845	2.7	44,140
Pharmaceuticals & medical technologies	54.1	56.9	0.7	5.1	2,286	1.0	40,194
Total private sector	7,292.4	8,443.1	100.0	15.8	219,867	100.0	26,041

Source: U.S. Bureau of Labor Statistics, ES-202 files. *U.S. figures exclude Alaska, Hawaii, and Wyoming. Appalachia includes only the 406-county ARC region. Value-chains are not mututally exclusive.

Table 3
Technology area concordances

Technology area	University Disciplines	Degree Completions Disciplines	S&T Occupation Categories
Chemicals and plastics	Chemical engineering, materials engineering, chemistry	Chemical engineering & technology; materials engineering and science	Chemists & chemical engineers; materials engineers & scientists
IT and instruments	Electrical engineering, mechanical engineering, materials engineering, physics, mathematics and statistics	Communications & computer sciences/technology; mechanical engineering, engineering physics & science, systems engineering	IT scientists, engineers, and programmers; electrical engineers & technicians
Industrial machinery	Mechanical engineering, industrial engineering, physics	Mechanical engineering, engineering physics & science, systems engineering; Industrial engineering & technology	Industrial & mechanical engineers & technicians
Motor vehicles	Electrical engineering, mechanical engineering, industrial engineering	Mechanical engineering, engineering physics & science, systems engineering; Industrial engineering & technology	Electrical engineers & technicians; industrial & mechanical engineers & technicians
Household appliances	Electrical engineering, mechanical engineering, industrial engineering	Mechanical engineering, engineering physics & science, systems engineering	Electrical engineers & technicians
Aerospace	Aerospace engineering, astronomy, geosciences, mathematics and statistics, computer science, physics	Aerospace engineering, aviation science & astrophysics; mathematics	Mathematicians, statisticians, and physicists
Communications services & software	Computer science, mathematics and statistics, geosciences	Communications & computer sciences/technology; mathematics	IT scientists, engineers, and programmers
Pharmaceuticals, medical technologies	Biological sciences, medical sciences, computer science	Biochemistry & biomedical engineering; botony, biology, bacteriology, & biotechnology; basic medical science	Biological scientists & technicians; medical scientists & engineers

Note: National Research Council discipline categories for faculty quality differed slightly from NSF categories, particularly in the medical and biological sciences. The NRC categories were aggregated to match the NSF classification to derive a uniform set of university disciplines.

Table 4

Study measurement of innovative activity/knowledge infrastructure

Rating of faculty quality, research universities, by academic discipline	1995	National Research Council
Research expenditures (all sources), research universities by academic discipline	1991, 1999	NSF CASPAR database
Enrolled graduate students, research universities, by academic discipline	1991, 1999	NSF CASPAR database
Non-university research organizations receiving federal funds in the ARC region, by location and technology area	1999, 2000	NSF, various
Utility patent grants by county, measured as location quotients and *G* statistics	1990-1999	US Patent and Trademark Office
SBIR, STTR, and ATP award winners in ARC region, FY 2000, by location and technology area	2000	Federal government agency databases

Table 5

University R&D strengths by technology area

1st and 2nd tier strengths based on U.S. rank

University	Chemicals & plastics	IT & instruments	Industrial machinery	Motor vehicles	Aerospace	Household appliances	Comm services & software	Pharm & med tech
U of Alabama at Birmingham								
U of Alabama at Huntsville			2	2		2		
Auburn U								
Carnegie Mellon U		2		1	2	1	2	2
Clemson U						2		
Cornell U	1	1	1	1	1	1	1	1
Emory U								2
GA Institute of Technology	1	1	1	1	2	1	2	
U of Georgia								
U of Kentucky								
Mississippi State U								
U of Mississippi								
Ohio U								
Pennsylvania State	1	1	1	1	2	1	2	
U of Pittsburgh								2
U of Tennessee at Knoxville			2					
Virginia Polytechnic Institute		2		1		1	2	
West Virginia U								

Note: Based on evaluation of national rank on three measures: research funding, faculty quality (based on peer rankings), and number of gradute students. Universities were ranked on sixteen disciplines. Each discipline was assigned to one or more of the eight technology categories (see Appendix Table 8). Average rankings across the disciplines in the given technology area were then used to determine the institution's overall rank on the given measure. Tier 1 schools are those with an average rank in the U.S. top 20 for at least two out of the three measures. Tier 2 schools are those with: a) an average rank in the U.S. top 20 for research expenditures or faculty quality; or b) an average rank in the U.S. top 40 for all three measures; or c) an average rank in the U.S. top 20 for number of graduate students and a rank in the U.S. top 40 for either (or both) faculty quality or research expenditures.

Table 6

Appalachian non-university research organizations

Name	City/Town	State	Technology	Funding 1997	Source
Southern Research Institute	Birmingham	AL	Other		
Army Space and Missile Defense Command	Huntsville	AL	Aerospace		
Marshall Space Flight Center	Huntsville	AL	Aerospace		
Army Aviation and Missile Command RD&E	Redstone Arsenal	AL	Aerospace		
Army Redstone Technical Test Center	Redstone Arsenal	AL	Aerospace		
Army Missile Research Dev and Engineering Ctr	Redstone Arsenal	AL	Aerospace		
Army Benet Laboratories	Watervliet	NY	Aerospace	$697,986,000	3
NSF Data Storage Center	Pittsburgh	PA	Comm services & software		
Software Engineering Institute	Pittsburgh	PA	Comm services & software		
SC Research Institute		SC	Other		
Air Force Arnold Engineering Development Ctr	Arnold AFB	TN	Aerospace		
Oak Ridge Institute for Science and Education	Oak Ridge	TN	Other		
Oak Ridge National Laboratory	Oak Ridge	TN	Industrial machinery	$233,785,000	1
National Radio Astronomy Observatory	Green Bank	WV	Aerospace	$532,000	2
National Energy Technology Laboratory	Morgantown	WV	Industrial machinery	$16,395,000	1
NASA Independent Validation and Verification Facility	Fairmont	WV	Comm services & software	$21,659,000	2
WV High Tech Consortium	Fairmont	WV	Other	$202,000	2
WV Research Corp		WV	Other	$5,540,000	2

1: NSF, Federal Funds for Research and Development: Fiscal Years 1997, 1998 and 1999, NSF 99-333.

2: NSF, Federal Science and Engineering Support to Universities, Colleges and Nonprofit Institutions, Fiscal Year 1998, NSF-00-315.

3: NSF, State Science and Engineering Profiles and R&D Patterns: 1997-98, NSF 00-329

Table 7

Technology clusters in Appalachia

Chemicals & plastics						Notes
Buffalo, Rochester, NY	T	T	T			
Ithaca and Binghamton, NY	T	T	T	T	T	Cornell ranked as 1st tier in disciplines related to chemicals and plastics
Pittsburgh, PA	T	T			T	
Albany-Schenectady, NY	T	T				
Newburgh, NY, PA	T	T	T			
Cleveland-Canton, OH corridor	T	T	T			
State College, PA	T		T	T		
Reading/Allentown PA	T	T	T			
Wheeling, WV	T	T			T	
Charleston, WV	T	T	T			Not a major strength of West Virginia University; Ohio University (all campuses) ranked 16th in research dollars in chemical engineering
Parkersburg, WV	T	T			T	
Cincinnati, OH	T	T				
Washington, DC	T	T	T			
Johnson City, TN	T	T			T	
Asheville, NC	T	T				
Greenville-Spartanburg, SC	T	T	T			
Chattanooga, TN	T	T				
Atlanta, GA	T			T		
Auburn, AL	T	T	T			
Huntsville, Decatur, AL	T		T		T	Chemical engineering an emergent strength at UA-Huntsville; UA-Huntsville ranked 6th in number of graduate students in industrial engineering

Motor vehicles & related						Notes
Rochester, NY	T	T	T			
Syracuse, NY	T	T				
Binghamton, NY	T	T	T	T		
Scranton, PA	T	T				Large two-year college programs in related fields
Central Pennsylvania	T	T	T	T		
Reading, PA	T	T				Large two-year college programs in related fields
Altoona, PA	T	T				
Cleveland, Akron, OH	T	T	T			
Mansfield, OH	T		T			
Cincinnati, OH	T	T				

Table 7

Technology clusters in Appalachia

Harrisburg, PA	T	T		T		
Blacksburg, VA	T					
Johnson City, TN	T	T				
Greenville-Spartanburg, SC	T	T	T	T		UA-Huntsville ranked 6th in number of graduate students in industrial engineering; also a
Huntsville, AL	T					2nd tier strength in disciplines related to motor vehicles

Industrial Machinery						Notes
Buffalo, Rochester, NY	T	T	T			
Erie, PA	T	T				
Albany-Schenectady, NY	T	T				
Binghamton, NY	T	T		T		Cornell a 1st tier university in related disciplines
State College, PA	T			T		Penn State a 1st tier university in related disciplines
Reading, Allentown, PA	T	T				
Harrisburg, PA	T	T				
Pittsburgh, PA	T	T			T	Carnegie-Mellon an emerging strength in mechanical and materials engineering
Northeastern Ohio	T	T	T			
Mansfield, OH	T	T	T			
Altoona, PA	T	T				
Johnstown, PA	T	T			T	
Lynchburg, VA	T	T				Virginia Tech an emerging strength in electrical engineering
Cincinnati, Middleton, OH	T	T			T	
Greensboro, NC	T	T				
Statesville, NC	T	T				
Charlotte, NC	T	T				
Nashville-Davidson, TN	T	T				
Asheville, NC	T	T				
Greenville-Spartanburg, SC	T	T	T			
Atlanta	T	T		T		Georgia Tech a 1st tier university in related disciplines
Huntsville, AL			T	T	T	Weak industry employment but concentrated related occupations and 2nd tier university
Starkville, Columbus, MS	T	T			T	

Information technology & instruments						Notes
Rochester, NY	T	T				Weak industry employment; large community college programs in related fields
Binghamton, NY	T	T	T	T	T	Cornell ranked as 1st tier university in related disciplines
Poughkeepsie, NY	T	T				

Table 7

Technology clusters in Appalachia

State College, PA	T	T	T	T		
Washington, DC	T		T			Very large community college programs in related fields
Columbus, OH	T	T	T		T	Community college programs in related fields
Lynchburg-Blacksburg, VA	T			T	T	Weak industry employment in Blacksburg; community college programs in related fields
Atlanta, GA	T	T	T	T	T	Georgia Tech a first-tier university in related disciplines
Huntsville, AL	T		T			University of Alabama-Huntsville an emerging strength in computer science
Communications services & software						**Notes**
Ithaca, NY	T	T		T	T	Cornell a 1st tier strength in related disciplines
Albany-Schenectady, NY	T	T				
Newburgh-Poughkeepsie, NY	T	T				
State College, PA	T			T	T	Penn State a 2nd tier strength
Harrisburg, PA	T	T				
Pittsburgh, PA	T			T	T	CMU a 2nd tier strength; NSF Data Storage Center; Software Engineering Institute
Columbus, OH	T		T			Large two-year college programs in related fields
Washington, DC	T	T	T			Large two-year college programs in related fields
Blacksburg, VA	T			T	T	
Atlanta, GA	T		T	T	T	Georgia Tech a 2nd tier strength in related discipline; two-year college programs
Huntsville, AL	T	T	T		T	University of Alabama-Huntsville an emerging strength in computer science
Aerospace						**Notes**
Erie, PA	T	T				
Elmira, Ithaca, NY	T	T		T		Cornell a 1st tier strength in related disciplines
Cleveland, Akron, OH	T	T				
Pittsburgh, PA	T	T	T	T	T	CMU a 2nd tier strength in related disciplines
Washington, DC	T		T			
Cincinnati, Middleton, OH	T	T				
Atlanta, GA	T		T	T		Georgia Tech a 2nd tier strength in related disciplines
Manchester, TN	T				T	Nearby Arnold Air Force Base
Huntsville, AL	T		T	T		University of Alabama-Huntsville an emerging strength in geosciences; Army Space and Missile Defense Command, Marshall Space Flight Center, Army Aviation and Missile Command, Army Redstone Technical Test Center, Army Redstone Missile Research Development and Engineering Center

Table 7

Technology clusters in Appalachia

Household appliances						Notes
Cleveland, Akron, OH	T	T				
Middleton, OH	T	T				
Greenville-Spartanburg, SC	T			T		
Huntsville, AL	T		T	T		University of Alabama-Huntsville a 2nd tier strength in related disciplines

Pharmaceuticals & med technologies						Notes
Rochester, NY	T	T				
Ithaca, NY	T			T	T	Cornell a 1st tier strength in related disciplines
Chenango County, NY	T	T				
Newburgh, NY	T	T				
Reading, PA	T	T				
Pittsburgh, PA	T			T	T	CMU and Pitt 2nd tier strengths; Pitt an emerging strength biological sciences
Washington, DC	T	T	T			
Cincinnati, OH	T					
Birmingham, AL	T	T	T		T	

Legend and Notes. Concentration of employment in pertinent value-chain (either significant *G* or location quotient > 1.1, 1998). Concentration of patenting activity in related technology areas (either significant *G* or location quotient > 1.25, 1999). Concentration of scientists, engineers, and technicians in related fields (location quotient > 1.25; data available for metro areas only, 1999). Presence of a research university with related programs in 1st or 2nd tier based on national ranks (various years; see text for ranking criteria). One or more SBIR/STTR/ATP award winners in Fiscal Year 2000. Locations indicate general vicinity only. See text for data sources and general methodology.

Table 8

Spatial coincidence

Value-chain employment v. Knowledge Base (Patents & University Research Strength)

Technology	Entire Study Area	North	Central	South	Border	Interior	MSA	Rural
Chemicals and plastics	0.19	0.28	0.20	0.12	0.25	0.15	0.25	0.10
Information technology & instruments	0.22	0.21	0.29	0.13	0.30	0.13	0.32	0.07
Industrial machinery	0.30	0.56	0.16	0.17	0.39	0.22	0.42	0.13
Motor vehicles	0.14	0.26	0.11	0.07	0.19	0.09	0.21	0.06
Aerospace	0.19	0.24	0.30	0.03	0.27	0.13	0.24	0.07
Household appliances	0.06	0.06	0.04	0.07	0.08	0.05	0.08	0.02
Communications services & software	0.27	0.17	0.25	0.45	0.32	0.20	0.34	0.08
Pharmaceuticals & medical technologies	0.12	0.20	0.17	0.00	0.14	0.10	0.15	0.07
Average	*0.18*	*0.25*	*0.19*	*0.13*	*0.24*	*0.13*	*0.25*	*0.08*

Table 9

Spatial coincidence, additional comparisons

	Chemicals and plastics	Infotech & instruments	Industrial machinery	Motor vehicles	Aerospace	Household appliances	Comm svcs & softwware	Pharma & med techs	***Average***
Entire Study Area									
Value-chain employment v. patents	.18	.22	.30	.12	.21	.05	.20	.10	*.17*
Value-chain employment v. University research strength	.00	.02	.02	.01	.06	.00	.03	.00	*.02*
Patents v. University research strength	.00	.09	.05	.05	.12	.07	.09	.00	*.06*
Value-chain emp v. Patents v. University research strength	.00	.02	.02	.01	.05	.00	.02	.00	*.01*
Research University Counties Only									
Value-chain employment v. Knowledge base	.18	.20	.26	.15	.16	.06	.32	.10	*.18*
Value-chain employment v. University research strength	.00	.06	.05	.03	.13	.00	.06	.00	*.04*
Patents v. University research strength	.00	.17	.11	.10	.24	.12	.17	.00	*.11*
VC emp v. Patents v. University research strength	.00	.06	.05	.03	.12	.00	.06	.00	*.04*
MSA Counties only									
Industry (VC emp & S&T Occupations) v. Knowledge Base	.25	.32	.44	.22	.28	.10	.29	.15	*.26*
Value-chain emp v. S&T Occupations	.25	.30	.16	.18	.09	.00	.52	.18	*.21*
S&T Occupations v. Knowledge base	.22	.31	.20	.17	.18	.05	.27	.12	*.19*
VC emp v. S&T Occupations v. Knowledge Base	.10	.18	.11	.07	.04	.00	.24	.05	*.10*

Appendix Table 1

Metropolitan areas within & bordering Appalachia

ID	Metropolitan area	Location	ID	Metropolitan area	Location
1	Akron, OH PMSA	O	32	Hickory-Morganton-Lenoir, NC MSA	B
2	Albany-Schenectady-Troy, NY MSA	B	33	Huntington-Ashland, WV-KY-OH MSA	I
3	Allentown-Bethlehem-Easton, PA MSA	B	34	Huntsville, AL MSA	I
4	Altoona, PA MSA	I	35	Jamestown, NY MSA	I
5	Anniston, AL MSA	I	36	Johnson City-Kingsport-Bristol, TN-VA MSA	I
6	Asheville, NC MSA	I	37	Johnstown, PA MSA	I
7	Athens, GA MSA	B	38	Knoxville, TN MSA	I
8	Atlanta, GA MSA	B	39	Lexington, KY MSA	B
9	Auburn-Opelika, AL MSA	O	40	Lynchburg, VA MSA	O
10	Binghamton, NY MSA	I	41	Mansfield, OH MSA	O
11	Birmingham, AL MSA	I	42	Memphis, TN-AR-MS MSA	O
12	Buffalo-Niagara Falls, NY MSA	O	43	Montgomery, AL MSA	B
13	Canton-Massillon, OH MSA	B	44	Nashville, TN MSA	O
14	Charleston, WV MSA	I	45	Newark, NJ PMSA	O
15	Charlotte-Gastonia-Rock Hill, NC-SC	O	46	Newburgh, NY-PA PMSA	O
16	Chattanooga, TN-GA MSA	I	47	Parkersburg-Marietta, WV-OH MSA	I
17	Cincinnati, OH-KY-IN PMSA	B	48	Pittsburgh, PA MSA	I
18	Cleveland-Lorain-Elyria, OH PMSA	O	49	Reading, PA MSA	O
19	Columbus, GA-AL MSA	O	50	Roanoke, VA MSA	B
20	Columbus, OH MSA	O	51	Rochester, NY MSA	O
21	Cumberland, MD-WV MSA	I	52	Scranton--Wilkes-Barre--Hazleton, PA MSA	I
22	Decatur, AL MSA	I	53	Sharon, PA MSA	I
23	Elmira, NY MSA	I	54	State College, PA MSA	I
24	Erie, PA MSA	I	55	Steubenville-Weirton, OH-WV MSA	I
25	Florence, AL MSA	I	56	Syracuse, NY MSA	O
26	Gadsden, AL MSA	I	57	Tuscaloosa, AL MSA	B
27	Greensboro, Winston-Salem, High Point MSA	B	58	Utica-Rome, NY MSA	O
28	Greenville-Spartanburg-Anderson MSA	I	59	Washington, DC-MD-VA-WV PMSA	B
29	Hagerstown, MD PMSA	I	60	Wheeling, WV-OH MSA	I
30	Hamilton-Middleton, OH PMSA	O	61	Williamsport, PA MSA	I
31	Harrisburg-Lebanon-Carlisle, PA MSA	B	62	Youngstown-Warren, OH MSA	B

Note: I: MSA entirely contained within the Appalachian region; B: MSA spans Appalachian border; O: MSA completely outside Appalachia, with borders at least 10 miles from region boundary. MSA boundaries correspond to the 1999 definitions released by the Office of Management and Budget.