3 Appalachia's 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.[21] (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 R&D activities within universities span almost all academic disciplines in the sciences, applied sciences, and engineering, and also describe a large variety of technology-related specialties within non-university institutions. Although the research universities and other R&D institutions are located in twelve states in the ARC region, the most competitive disciplines and technology areas are concentrated in a fairly small number of nodes.

Appalachia'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 1997/98, four-year institutions conferred over 23,600 science and engineering degrees while two-year colleges and institutes granted an additional 12,200 degrees. Available programs and training are extensive in some technology areas (e.g., communications and computer sciences, aerospace engineering and aviation sciences, industrial engineering, agricultural sciences, and basic medical sciences) but comparatively sparse in others (e.g., biochemistry and biomedical engineering at the two-year level). An analysis of the mix of programs relative to U.S. averages provides an excellent picture of the education and training orientation of Appalachia's teaching colleges and universities in technology-related fields.

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21. A strong case could also be made for including primary education as a component of knowledge infrastructure. Indeed, the foundation for lifelong learning necessary to sustain a knowledge-intensive economy is laid in the primary and secondary schools. However, since this report's aim is to identify specific technology-oriented strengths, it focuses exclusively on institutions of higher education.

3.1 Appalachia's Science and Innovation Assets

The science and innovation component of Appalachia's knowledge infrastructure consists of performers of R&D (universities, labs, and private firms) and a support system of state-funded technology agencies and programs. The latter generally do not conduct R&D, but rather seek to diffuse best practice technologies through the provision of a variety of subsidized industrial extension services. The following sub-sections explore the innovation assets of the region using the set of complementary indicators summarized in Table 7.

3.1.1 R&D Performers

The major categories of R&D performer in Appalachia are research universities, non-university R&D organizations (including federal government labs), and private sector firms. The comparative strength of the universities is easiest to evaluate since data on faculty quality, R&D funding, enrollments, patents, and gross license income are available. The lack of reliable performance data for non-university laboratories and private sector R&D performers (i.e., private businesses) precludes systematic comparative evaluation of those sectors. However, proxy indicators (budget figures for federal labs and patents and federal grants participation for businesses) can provide at least limited information on the level and location of science and innovation activity in those sectors. Moreover, in the case of private business, science and innovation activity is partly indicated by the size, mix, and spatial distribution of technology-intensive industries analyzed in Section 2.

Research Universities. There are eleven research universities located in the 406-county ARC region: Carnegie-Mellon, Clemson, Cornell, Mississippi State, Ohio University (consolidated, but domi-

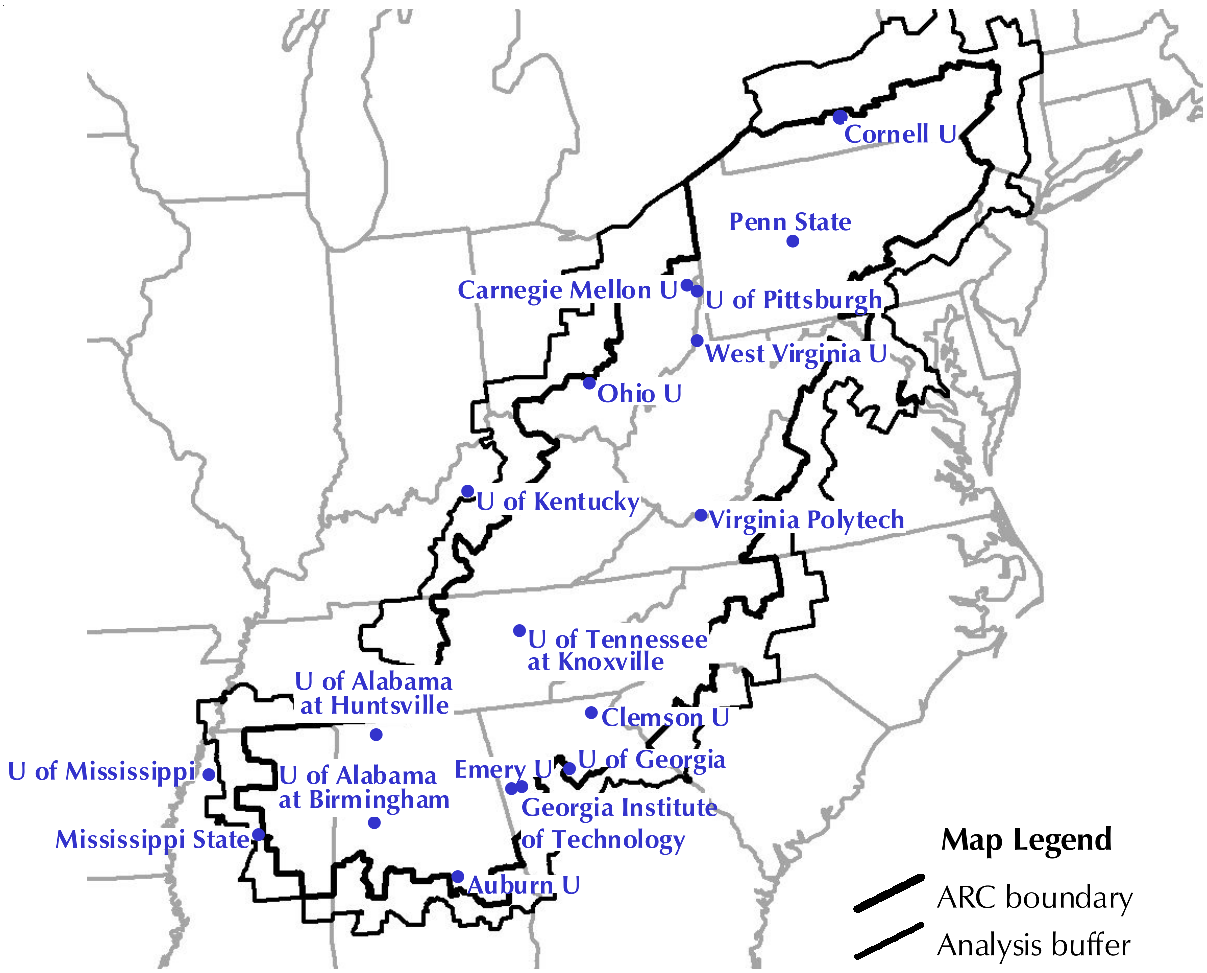
Table 7
Study measurement of innovative activity

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
Patents issued, research universities (all disciplines)	1999	AUTM Survey
Gross license income, research universities (all	1999	AUTM Survey
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

nated 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 strong technology focus.[22] The locations of the eighteen research universities in the study are plotted in Figure 20.

Figure 20

Major research universities within and adjacent to ARC boundary



22. 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). The newly revised classification system includes two categories of doctoral-research universities. Doctoral research

footnote continues next page

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. 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.[23] To establish a common scale for combining the disparate dimensions of research strength, we converted the measures of perceived faculty quality, research funding, and enrollment into national rankings.[24]

Based on ratings of faculty quality, there are six major nodes of highest competitive strength in Appalachia: Cornell (Ithaca, NY), Carnegie-Mellon (Pittsburgh, PA), Georgia Tech (Atlanta, GA), Emory University (Decatur, GA), Penn State (State College, PA), and Virginia Tech (Blacksburg, VA). Each of those universities ranks among the top-twenty universities in the U.S. in at least one science or engineering discipline and among the top-forty universities nationally in at least three other disciplines. Eight additional universities rank in the U.S. top forty in at least one discipline: University of Alabama at Birmingham, University of Alabama at Huntsville, Auburn, Clemson, University of Georgia, University of Kentucky, University of Pittsburgh, and the University of Tennessee.

By discipline, the faculty quality rankings indicate that the greatest competitive strengths among Appalachian research universities as a group are oriented toward the physical sciences and engineering rather than the biological and medical sciences (see Table 8). Overall, the disciplines of greatest strength are mechanical engineering, civil engineering, electrical engineering, industrial engineering, materials science, chemistry, statistics, and computer science. Among the biomedical disciplines, only five de-

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universities (extensive) are institutions that grant fifty or more doctoral degrees per year across at least fifteen disciplines; doctoral research universities (intensive) are institutions that grant ten or more doctoral degrees per year across three or more disciplines, or at least twenty doctorates per year overall. All of the universities included in this study but the University of Alabama-Huntsville are doctoral-research universities (extensive). We added the University of Alabama at Huntsville to the group of universities in the study because of National Science Foundation data indicating comparatively high rankings on research funding in several engineering and scientific disciplines.

23. 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* database (http://caspar.nsf.gov). Data on the number of patents issued to universities and gross license income are from the Association of University Technology Managers (AUTM 1991, 1995, 1999).

24. 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.

Table 8

Rankings of faculty quality: Appalachin research universities, 1995

Discipline	UA at Birmingham	UA at Hunstville	Auburn	Carnegie Mellon	Clemson	Cornell	Emory	Georgia Tech	U of Georgia	U of Kentucky	Mississippi State U	U of Mississippi	Ohio U	Penn State U	U of Pittsburgh	U of Tennessee at Knoxville	Virginia Tech	West Virginia U	Average*
Aerospace Engineering			32			6		9						17		31	15		18
Biomedical Engineering	25				33									19					26
Civil Engineering			54	12	62	6		17		53		86		32	50	65	19	66	44
Chemical Engineering			71	12	81	13		30		71		93	92	23	44	59	42	68	54
Electrical Engineering		95	59	12	73	7		13		97	102		85	28	63	66	27	88	58
Industrial Engineering		35	20		31			1						9	23		8		18
Materials Science	55	61	64	11		3		44		62				9	45		38		39
Mechanical Engineering		94	75	19	63	7		18		71				17	69	77	29	85	52
Astronomy						9								21					15
Chemistry	126		123	74	94	6	38	64	49	99	159	157	147	18	34	78	67	130	86
Computer Sciences	97	87		4		5		32		65	99			54	43		66		55
Physics	127	114	128	28		6		61	75	91		141	83	55	40	72	71		78
Ecology	119				80	4			16	72	112		107	26	92	40	70		67
Geo-Sciences						9		76	76	83				12	75	61	27	98	57
Math		130	93	40	92	15		44	58	71		136	124	37	61	77	66		75
Statistics	62			16		4	51			49				19	37		41		35
Biochemistry	49				175	22	76	112	66	93			185	45	89	165	130	128	103
Cellular Development	48		157		126	35	52	178	132	76			144	56	69	78		115	97
Molecular Genetics	45				91	23	32	90	40				100	32	46	95		81	61
Neurosciences						24	33						85	67	40				50
Pharmacology	77				110	65	15		88	31		107	125	75	44			50	72
Physiology	20		105		112	31	22		85	72			119	37	47		2	85	61
Average*	71	88	82	23	87	15	40	53	69	72	118	120	116	32	53	74	45	90	56

Source: National Research Council. Averages are only calculated on ranked values; missing values are not included.
Dark shading = Top 20; light shading = Top 40.

partments are among the top twenty nationally: Cornell and University of Georgia in ecology, Emory in pharmacology, and Virginia Tech and the University of Alabama at Birmingham in physiology. Physiology was the strongest biomedical discipline overall, with three universities boasting top-forty departments (Cornell, Emory, and Penn State).

A more objective indicator than faculty quality rankings is the national ranking of a university by its total garnered R&D funding, by discipline. An institution's R&D rank is an excellent quantity indicator of its relative contribution to the generation of new knowledge. The analysis of the rankings of the universities in the ARC region in 1999 reveals a surprising number of competitive strengths spread over a diverse number of disciplines and spatial nodes. Indeed, the pattern of R&D spending suggests that Appalachian universities are stronger in the life sciences disciplines than suggested by the faculty quality rankings.

Of the fifteen disciplines in the natural sciences and engineering for which data are available, there are eleven in which there is at least one Appalachian (or nearby) university with a top-ten ranking (see Table 9). In two of those disciplines (computer science and agricultural sciences), there are three universities with top-ten departments, and in five other disciplines (aerospace engineering, electrical engineering, mechanical engineering, materials engineering, and chemistry), there are two universities

Table 9
Rankings of R&D funding: Appalachin research universities, 1999
Research expenditures by academic discipline

Discipline	Auburn U, All Campuses	Carnegie Mellon U	Clemson U	Cornell U, All Campuses	Emory U	GA Tech, All Campuses	Mississippi State U	Ohio U, All Campuses	Penn State U, All Campuses	U of Alabama at Birmingham	U of Alabama at Huntsville	U of Georgia	U of Kentucky, All Campuses	U of Mississippi, All Campuses	U of Pittsburgh, All Campuses	U of Tennessee Univ-Wide	Virginia Tech	West Virginia U
ENGINEERING	56	29	37	17		2	36	85	4	93	60	94	43	109	89	42	16	55
Aerospace Engineering	32			12		4	30	16	22							9	18	
Chemical Engineering	28	30	77	42		13	61	67	22		47		55	99	35	36	39	73
Civil Engineering	61	55	32	37		7	73	69	13	97	89		100	99	98	20	12	30
Electrical Engineering	70	23	37	16		1	59	97	5	110	47		91	108	100	60	17	80
Mechanical Engineering	55	33	36	78		4	68	95	7		25		63	102	98		14	21
Materials Engineering	49	20		26		10		69	1	22	59			55	46	44	30	68
PHYSICAL SCIENCES	113	71	87	6	86	35	116	106	15	111	70	66	89	101	60	54	75	103
Astronomy	39			5				42	20						36			
Chemistry	118	80	79	8	57	29	95	120	7	110	105	51	86	123	49	70	52	106
Physics	103	51	77	6	112	25	119	73	14	99	41	70	74	69	71	35	100	82
GEOSCIENCES	104	83	92	65		30	74	101	13	120	61	33	99		105	39	18	73
MATH AND COMPUTER SCIENCES	110	3	68	11	100	7	76	125	53	111	40	39	84	124	57	38	52	113
Mathematics and Statistics	96	20	39	28	75	19	86	120	23	97	50	13	77	124	66	83	34	117
Computer Science	114	3	73	10	110	7	66	118	76	113	29	54	77	116	50	23	61	101
LIFE SCIENCES	80	111	79	13	22	107	72	120	50	17	128	26	38	115	18	59	68	92
Agricultural Sciences	24		32	15		51	8		33			3	12			27	5	45
Biological Sciences	85	106	59	29	40	110	122	102	22	16	126	15	115	125	96	64	89	88
Medical Sciences	94		98	17	21	76	83		63	13		64	38	81	7	51	89	69
S&E TOTAL	92	64	84	12	44	29	79	126	14	36	113	34	48	127	33	54	49	102

Source: National Science Foundation WebCASPAR Database System. Dark shading = Top 20; light shading = Top 40. National rankings for Research I & II universities (131 universities ranked). R&D data for the industrial engineering discipline were are not reported by NSF, though graduate enrollment data are reported

with top-ten departments. All fifteen disciplines have at least one university in or near Appalachia with a top-twenty ranking. Leading universities in the biological or medical life sciences include Cornell, the University of Alabama at Birmingham, the University of Georgia, the University of Pittsburgh, and Emory University.

The distribution of strengths among the universities is also noteworthy. Of the eighteen research universities within the ARC region, nine boast at least one top-ten department, and twelve have at least one top-twenty department. The leading schools are Georgia Tech, Cornell, Penn State, and Virginia Tech in terms of the number of highly ranked disciplines, but there are competitive strengths spread out among almost all of the other universities. Moreover, there are a number of programs whose funding rank improved substantially between 1991 and 1999, even if the rank in 1999 was still below the top-ten or twenty. Table 10 identifies 34 such programs in total. Among the leaders with at least three emergent disciplines apiece (based on funding rank) are Carnegie-Mellon, Georgia Tech, Ohio, Penn State, University of Kentucky, Virginia Tech, West Virginia University, and Mississippi State. Emory University and University of Alabama at Birmingham each boast two emergent disciplines.

Similar to R&D expenditures, the number of graduate students enrolled by academic discipline is a quantity indicator of a university's academic strength in a given field. Enrollments indicate universities' potential contribution of highly skilled human capital. Table 11 reports 1999 national graduate student enrollment rankings by discipline for the eighteen universities in or adjacent to the ARC region. There is an impressive distribution of strengths across a wide variety of disciplines and universities. Fourteen of the sixteen disciplinary areas are represented by top-ten university departments, and all sixteen have top-twenty representatives. Specifically, there are three top-ten university programs in industrial engineering in or adjacent to the region (Georgia Tech, Virginia Tech, and the University of Alabama at Huntsville), and two top-ten programs in civil engineering (Georgia Tech and Virginia Tech), materials engineering (Georgia Tech and Penn State), and computer science (Carnegie-Mellon and the University of Pittsburgh).

Table 10

Emergent strengths in Appalachian universities, 1991–1999
Ranking shifts based on R&D expenditures and enrollments, 1991–1999

Aerospace Engineering	Ohio University[a], West Virginia[b]
Chemical Engineering	Carnegie-Mellon[a], Georgia Tech[c], Penn State[a], University of Alabama-Huntsville[a], University of Kentucky[a]
Civil Engineering	Virginia Tech[c], West Virginia[c]
Electrical Engineering	Penn State[c], Virginia Tech[b]
Mechanical Engineering	Carnegie-Mellon[a], Mississippi State[a], West Virginia[a]
Materials Engineering	Carnegie-Mellon[a], Ohio University[a], University of Alabama-Birmingham[a], Penn State[b]
Astronomy	Auburn[a], Ohio University[a]
Chemistry	None
Physics	Georgia Tech[a], Penn State[c], University of Kentucky[a], West Virginia[a]
Geosciences	Georgia Tech[a], Virginia Tech[a], University of Georgia[b], University of Alabama-Huntsville[b]
Mathematics and Statistics	Carnegie-Mellon[a], Emory[a], Mississippi State[a], University of Georgia[c], Cornell[b], Georgia Tech[b], University of Kentucky[b]
Computer Science	Mississippi State[a], University of Alabama-Huntsville[a], University of Kentucky[a], University of Pittsburgh[a], Carnegie-Mellon[b], Virginia Tech[b], West Virginia[b]
Agricultural Sciences	Virginia Tech[a]
Biological Sciences	Emory[a], University of Alabama-Birmingham[b], Pittsburgh[b]
Medical Sciences	Georgia Tech[a], Emory[b]

Source: National Science Foundation and authors' calculations. [a]Substantial shift in national R&D funding rank between 1991 and 1999. [b]Substantial shift in graduate student enrollment rank between 1991 and 1999. [c]Substantial shift in both R&D funding and graduate student enrollment rank between 1991 and 1999.

Table 11

Graduate student enrollment rankings: Appalachian research universities, 1999

	Auburn U, All Campuses	Carnegie Mellon U	Clemson U	Cornell U, All Campuses	Emory U	Georgia Tech, All Campuses	Mississippi State U	Ohio U, All Campuses	Penn State, All Campuses	U of Alabama at Birmingham	U of Alabama at Huntsville	U of Georgia	U of Kentucky, All Campuses	U of Mississippi, All Campuses	U of Pittsburgh, All Campuses	U of Tennessee Univ-Wide	Virginia Tech	West Virginia U
ENGINEERING	67	40	44	30		1	73	87	14	99	100	116	71	104	39	38	8	46
Aerospace Engineering	25			31		1	30		20							29	11	35
Chemical Engineering	47	13	69	24		9	63	70	22		90		75	91	23	38	59	66
Civil Engineering	62	57	22	20		3	97	90	26	87	98		51	88	49	36	10	39
Electrical Engineering	95	30	51	34		3	44	64	26	105	54		70	101	37	81	11	69
Mechanical Engineering	61	42	30	31		3	91	54	11	99	55		82	100	53	43	21	34
Materials Engineering	28	25	29	17		7			6	45	51		56		36	46	35	
Industrial Engineering	41		39			1	56	54	21		6		63		28	19	3	36
PHYSICAL SCIENCES	102	92	55	17	87	38	117	91	4	120	106	59	66	119	34	52	73	97
Astronomy				17					23									
Chemistry	89	101	71	34	51	31	108	91	9	122	124	42	70	120	26	64	52	96
Physics	104	69	84	11	117	47	120	67	3	103	52	96	53	105	42	35	98	90
GEOSCIENCES	98		97	34		58	67	53	7		68	46	77	94	88	66	54	79
MATH AND COMPUTER SCIENCES	71	11	56	26	118	23	82	101	36	105	72	52	58	104	10	42	16	51
Mathematics and Statistics	71	48	67	4	98	51	97	49	23	119	103	43	28	122	34	37	30	56
Computer Science	67	6	50	45		16	66		41	93	54	56	84	83	8	43	14	48
LIFE SCIENCES	80	126	82	29	14	125	91	116	38	9	110	35	34	96	19	36	70	53
Agricultural Sciences	21		24	17			15		28			19	30			41	13	32
Biological Sciences	99	126	85	7	59	124	101	118	16	15	125	14	44	97	46	53	82	100
Medical Sciences	62			65	2		79		68	13		56	44	74	29	17	64	66
S&E TOTAL	85	60	78	25	67	21	101	110	17	58	111	64	50	118	26	46	32	61

SOURCE: NSF WebCASPAR Database System. Dark shading = Top 20; light shading = Top 40. National rankings for research I and II universities (131 universities ranked).

The principal spatial nodes of strength based on graduate student enrollments are similar to those for R&D funding. Georgia Tech, Penn State, Cornell, and Virginia Tech are the leading locations. Yet eight universities boast at least one top-ten program, and thirteen have at least one top-twenty department. There are also twenty university programs that can be classified as emergent based on improvements in their national enrollment rankings between 1991 and 1999 (see Table 10). They are distributed among twelve of the disciplines. There are three emergent programs apiece at Penn State, Virginia Tech, and West Virginia; two apiece at Georgia Tech and University of Georgia; and one apiece at Emory, Carnegie-Mellon, University of Alabama at Huntsville, University of Kentucky, Alabama-Birmingham, University of Pittsburgh, and Cornell.

Two final indicators of university strength are the number of patents issued and total gross license income (see Table 12). Both are measures of innovative activity that has the potential for application in the marketplace. According to data collected by the Association of University Technology Managers (AUTM), twelve research universities in or nearby the ARC region generated at least ten patents in 1999.[25]

25. Note that the AUTM data are reported only for university-wide systems in the case of Ohio University, the University of Tennessee, and the University of Pittsburgh.

The leading schools were Cornell (70 patents), Penn State (46 patents), Emory (44 patents), Virginia Tech (37 patents), and Carnegie-Mellon (30 patents). Appalachian and nearby universities garnered roughly $48.6 million in gross license income in 1999, with Emory University accounting for one-third of the total. Ten schools generated gross license income of at least $1 million in 1999.

Table 12
Patents issued and gross license income, 1999
(Sorted by gross license income)

Institution	Patents Issued	Gross License Income
Emory University	44	16,166,848
Cornell University	70	6,400,000
Carnegie Mellon University	30	5,892,284
Clemson University	2	4,648,141
University of Georgia	21	3,208,427
Pennsylvania State University	46	2,830,448
University of Kentucky	24	2,496,786
Georgia Institute of Technology	23	2,038,078
University of Alabama at Birmingham	24	1,562,778
Virginia Polytechnic Institute	37	1,328,343
*Ohio University	4	635,611
*University of Tennessee	17	620,903
*University of Pittsburgh	30	608,851
Auburn University	12	186,738
West Virginia University	2	41,800
Mississippi State University	NI	NI
University of Mississippi	NI	NI

Source: Association of University Technology Managers *Licensing Survey*, Fiscal Year 1999, Table 8. *Data available only for all campuses. NI: Institution was not included in the AUTM survey.

Federally Funded Non-University Research Organizations. The second major category of R&D performer in the Appalachian region is the non-university-based organization that receives federal research funds. 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 qualifying facilities located in six Appalachian states (see Table 13). We were able to document research-funding levels only for defense-related labs.[26]

There are several significant federal government research complexes in the ARC region. They are clustered in two principal locations: Huntsville, Alabama (aerospace and related activities) and Oak Ridge, Tennessee (energy-related research). Both are places without major research universities and outside the cores of large metropolitan areas. Another smaller complex is the NASA facility at Green Bank, West Virginia (astronomy research). There are additional, less-well-known federal government research operations in Pittsburgh (the NSF Data Storage Center), in Watervliet, New York (Army Benét Laboratories), and at Arnold Air Force Base, Tennessee (the Engineering Development Center). Several state government and non-profit research organizations, but which are primarily funded through the National Science Foundation, also operate in the ARC region.

Private Sector R&D. 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,

26. The funding data are from Department of Defense budget documents.

Table 13
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

and development. Unfortunately, data on private sector R&D activity are very limited. Even the National Science Foundation's industry surveys are based on very small samples and cannot be disaggregated to the sub-state level.[27] 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.

Utility Patents. 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.[28] While some patents are granted to universities and non-profit R&D performers, the vast majority are secured by private industry.

We use 1990 to 1999 county-level utility patent data provided by the U.S. Patent and Trademark Office (USPTO) to calculate *G* statistics and location quotients for the extended Appalachian study

27. One NSF official also noted that even the state-level industrial R&D estimates published by his agency are suspect, given very small samples and a strong bias toward large companies.

28. The difficulties of working with patent data and some of the caveats that must be considered in their use are discussed in Griliches (1990) and Feser, Goldstein *et al.* (1998).

region. The USPTO assigns patents to counties based upon residence of the inventor.[29] Utility patents are initially classified by invention or 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 high-tech value-chains (see Table 14). Appendix Table 9 lists the USPTO SIC components of each aggregated sector. The USPTO commonly assigns a single patent to multiple SICs and therefore a patent may be included in more than one technology sector. Figures 21–30 display the mapped overlays of the concentration indicators.[30]

Table 14
Utility patent grants over period, 1990–1999, U.S. & ARC region

	U.S.		13 ARC states			ARC counties		
Technology area	Total	Pct share	Total	Pct share	LQ	Total	Pct share	LQ
Chemicals and plastics	224,930	20.3	33,404	24.5	0.97	5,848	23.8	1.17
Information technology	363,069	32.8	34,617	25.4	0.93	5,767	23.5	0.72
Instruments	180,424	16.3	23,844	17.5	0.73	3,134	12.8	0.78
Industrial machinery	230,781	20.8	26,132	19.2	1.28	6,015	24.5	1.18
Motor vehicles	153,722	13.9	16,466	12.1	1.17	3,462	14.1	1.02
Aerospace	54,160	4.9	5,099	3.7	1.26	1,153	4.7	0.96
Household appliances	14,136	1.3	2,027	1.5	1.09	396	1.6	1.26
Pharmaceuticals	65,733	5.9	10,896	8.0	0.45	889	3.6	0.61
Metals	116,818	10.5	16,263	11.9	1.21	3,556	14.5	1.37
Other	72,272	6.5	11,353	8.3	1.21	2,463	10.0	1.54
Total (not sum)	1,108,391		136,425			24,562		

Source: U.S. Patent and Trademark Office (special data request). Categories are not mutually exclusive.

29. 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. Furthermore, 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 between work and home.

Note that patents with multiple inventors living in different counties are weighted by the total number of inventors. For example, if a single patent has two inventors that live in different counties, each county is assigned half of the patent. Because the G_i statistic is designed to reveal spatial association among counties, it helps offset the discrepancy caused by differences in inventor residency and work locations.

30. We adopted the slightly stricter standard of 1.25 for highlighting location quotient values in Figures 21–30 since the magnitude of patent grants is much lower than employment. The lower the magnitude of a given variable in the location quotient formula, the greater the variation in the indicator.

Our analysis of the spatial distribution of patenting activity by technology area using the *G* statistic indicates that localized concentrations of patent grants are almost always located in metropolitan areas, regardless of technology sector, a result that supports the conventional wisdom that cities, and the suburbs where their workers live, are the primary hotbeds of applied innovative activity. It is also noteworthy that many of those concentrations are in the same few metropolitan areas even across different technology sectors. Also, much of the localized activity is just outside the ARC boundary, and for the most part, is more likely to be adjacent to northern Appalachia than the central or southern parts of the region. It is important to note that these results are partly a function of the spatial unit of analysis (i.e., counties). The application of the *G* measure tends to favor metropolitan areas because an MSA is large enough to include several adjacent counties with significant patenting activity. Location quotients indicate more concentrations of patenting in Appalachia than the *G* measure, although, again, those concentrations are still often located in metropolitan areas.

As in the case of value-chain employment analyzed in Section 2, the incidence of localized patenting tends to fall into two groups: a set of sectors with evidence of concentration in the region and a set with only minimal concentration. Among the former are patents in the areas of industrial machinery, chemicals and plastics, and metals and metalworking. Industrial machinery patents accounted for most utility patents granted in the region between 1990 and 1999 (6,015 in total, one-quarter of all patent grants). Local concentrations are found in Jamestown, Binghamton, Pittsburgh, and Greenville-Spartanburg (Figure 21). Several counties in Pennsylvania, New York, North Carolina, Tennessee, and Georgia (near Atlanta) also post high location quotients.

Patent grants in chemicals and plastics accounted for slightly less of one-quarter of total patenting activity in Appalachia between 1990 and 1999 (with an overall regional location quotient of 1.2). Most of the significant spatial concentrations of chemicals and plastics patents as measured by the *G* analysis are in areas adjacent to northern Appalachia; there are no *G*-based concentrations in Appalachia itself. High location quotients, however, were found for Appalachian metro counties in Pennsylvania, West Virginia, Tennessee and Alabama (Figure 22). Concentrations of metals and metalworking patents are also located primarily in the north (New York and Pennsylvania, including Pittsburgh, Johnstown, and Jamestown); key border concentrations include Atlanta, Cincinnati, Akron, Reading, Newburgh, Rochester/Buffalo, and Albany (Figure 23).

Figure 21

Spatial concentration: Industrial machinery patent grants, 1990–1999

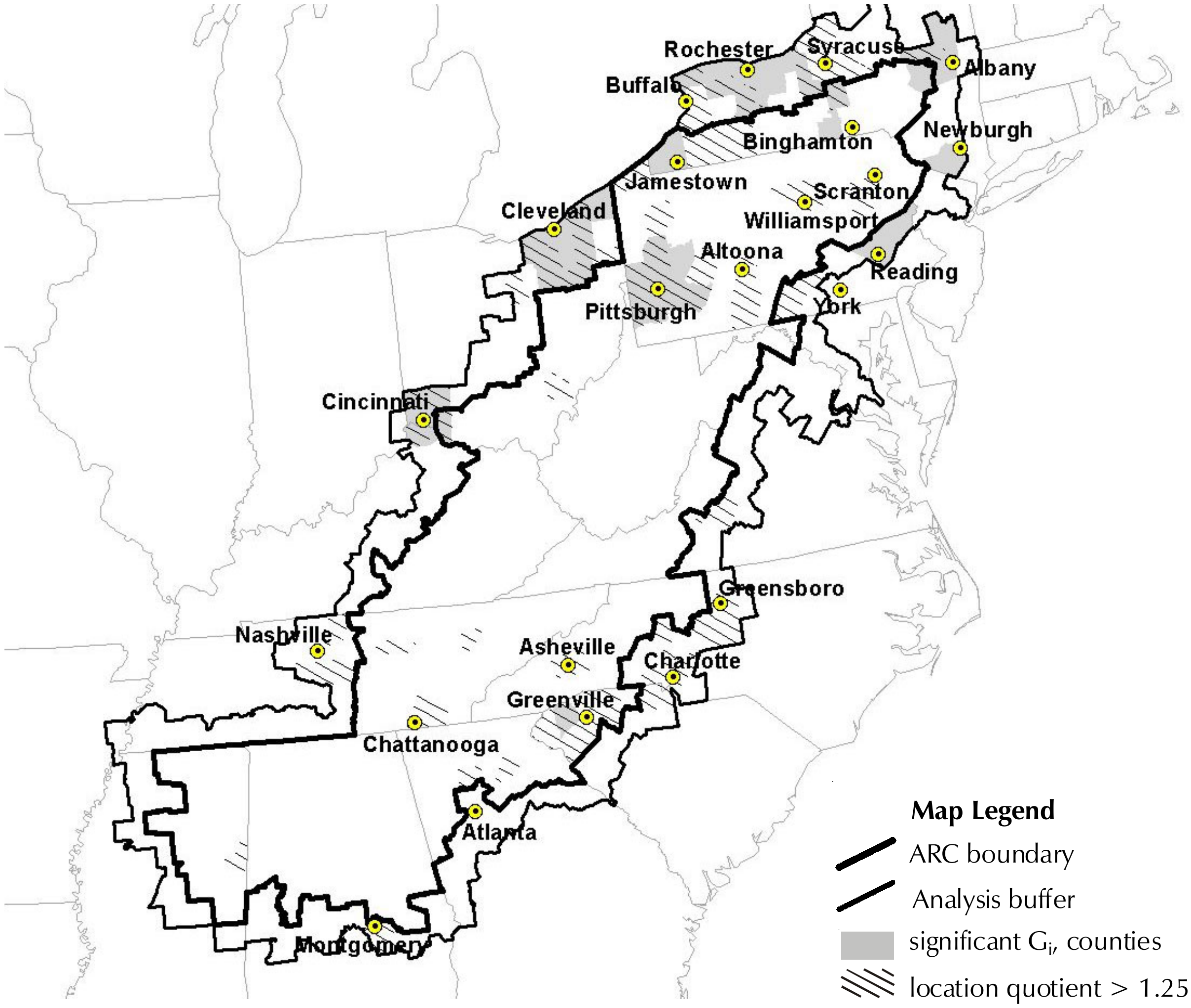


Figure 22

Spatial concentration: Chemicals and plastics patent grants, 1990–1999

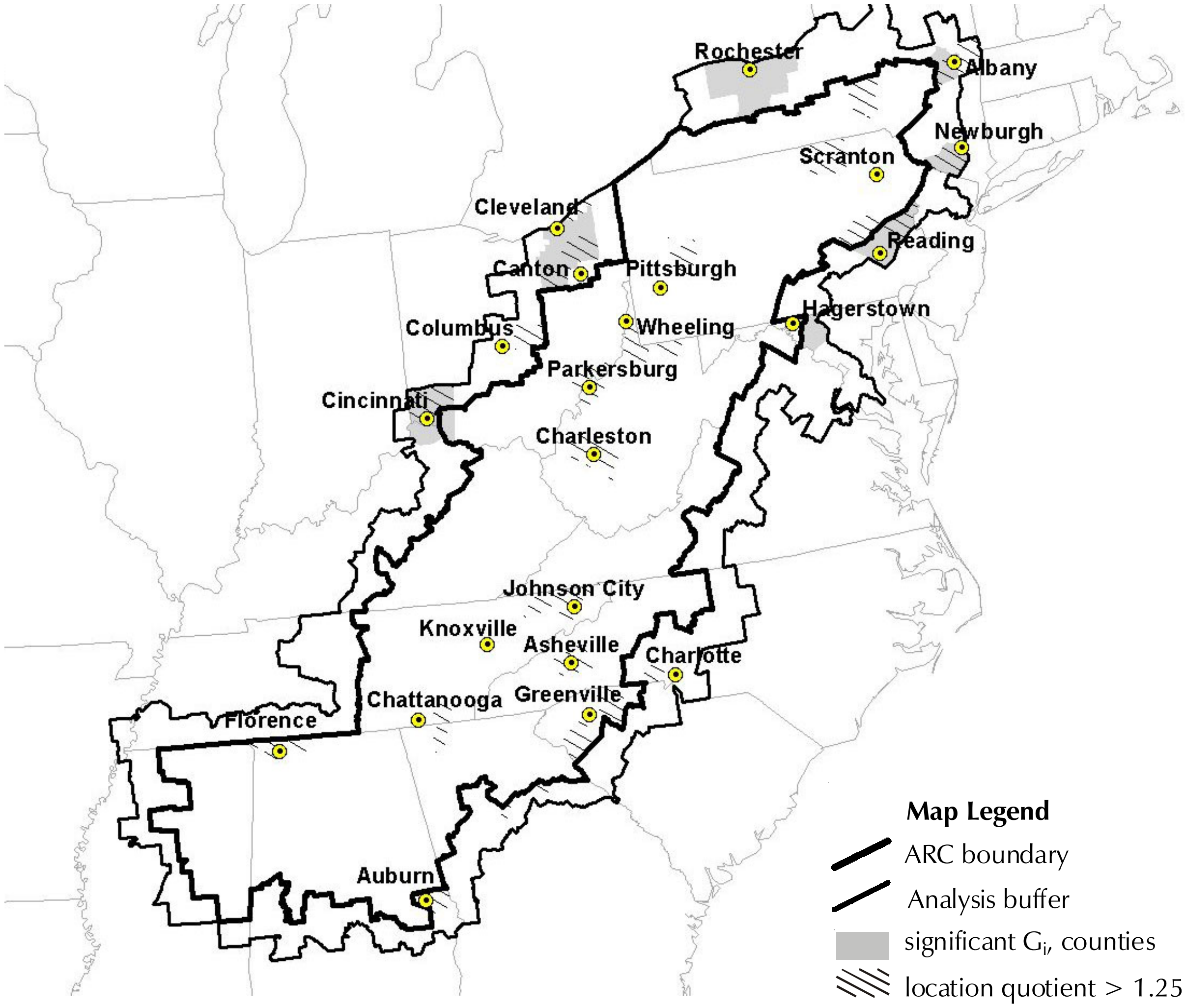
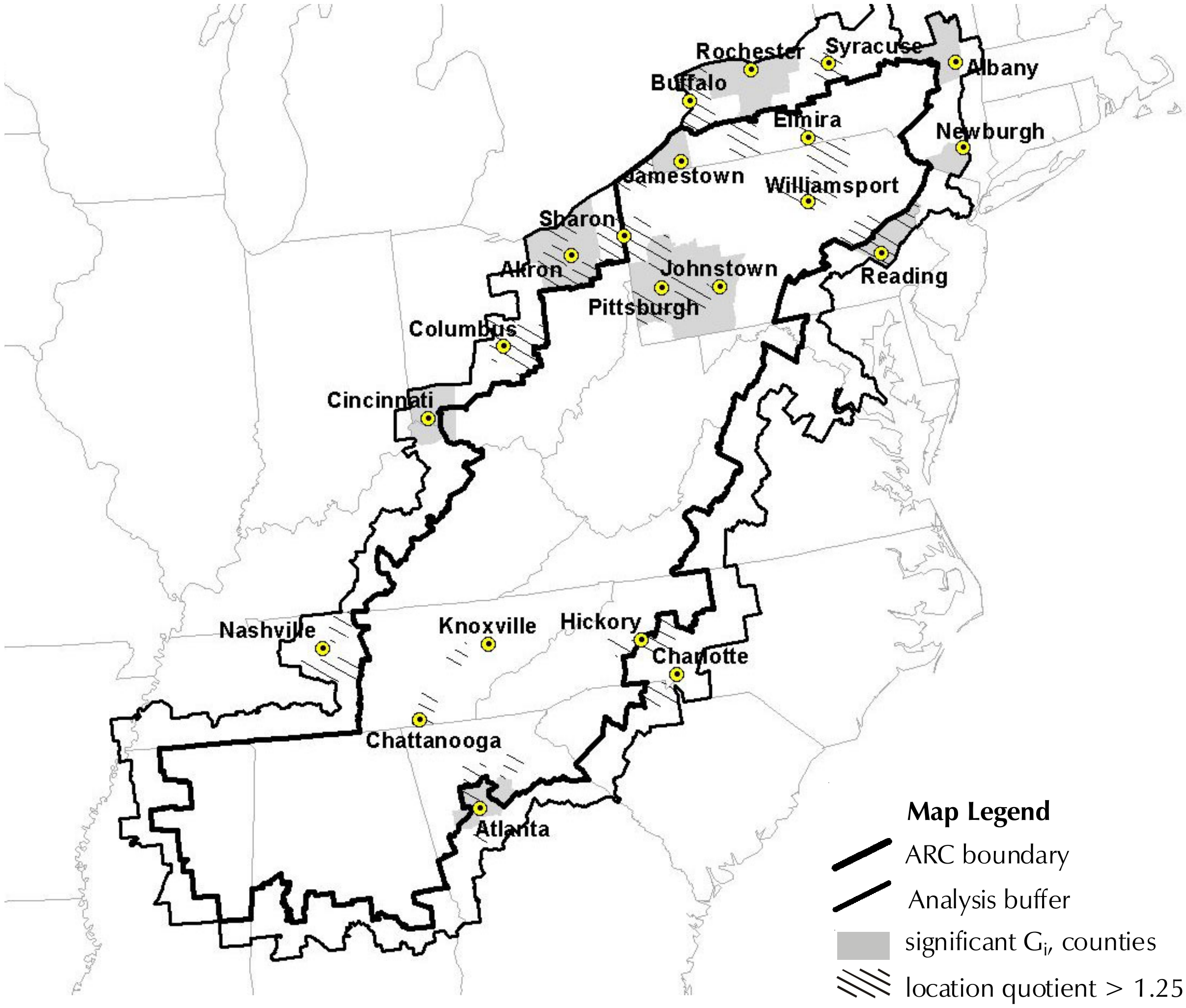


Figure 23

Spatial concentration: Metals and metalworking patent grants, 1990–1999



We found considerably fewer spatial concentrations of patent grants among the remaining technology categories. The most important include:

- In information technology: Binghamton and eastern New York, with high location quotients for Huntsville and the Roanoke area (Figure 24);
- In pharmaceuticals: high location quotients in Birmingham and in Chenango County, New York (home to Proctor & Gamble), with border concentrations near Reading, Washington, Newburgh, and Cincinnati (Figure 25);
- In aerospace: Johnson City and Owego in New York (home to Lockheed Martin facilities), Pittsburgh, Greenville-Spartanburg, and Erie, with key border concentrations in Albany, Rochester, York, Akron, and Middletown, Ohio (Figure 26);
- In scientific instruments: high location quotients in Asheville and Knoxville, with border concentrations in Rochester and Utica, New York (Figure 27);
- In household appliances: greater Atlanta, with border concentrations in New York and Ohio (Figure 28);
- In motor vehicles: high location quotients for the Syracuse area; Scranton, Williamsport, Pittsburgh, and Bedford County in Pennsylvania; Parkersburg in West Virginia; Johnson City and Chattanooga in Tennessee; and border concentrations in the Cincinnati, Akron, Rochester, Albany, Newburgh, and Reading areas (Figure 29).

A significant number of patent grants in the ARC region over the 1990s fell into a variety of miscellaneous categories. Miscellaneous patents accounted for 10 percent of Appalachia's total between 1990 and 1999, compared to 6.5 percent for the U.S. as a whole. Key geographical concentrations are found in Atlanta, Greenville-Spartanburg, and a large region that extends from Rochester south to Elmira and Owego (including a number of non-metro counties). Places such as Pittsburgh, Asheville and Chattanooga also contained counties with high patent location quotients (Figure 30). A summary of the spatial findings by metropolitan area is provided in Appendix Table 10.

Federal Innovation Programs. 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 406-county ARC area. As in the case of patents, each grant was mapped to a set of technology areas that roughly are consistent with the value-chain industry classification utilized in Section 2. We then calculated the total number of SBIR/STTR/ATP grants by location for each technology category.[31]

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31. The seven technology area categories were based on a compromise between the competing objectives of 1) minimizing error in the assignment of grants and organizations to specific areas (given incomplete descriptions) and 2) the eventual need to develop a concordance table between the innovative activity described in this section and the industry activity analyzed in Section 2.

Figure 24

Spatial concentration: Information technology patent grants, 1990–1999

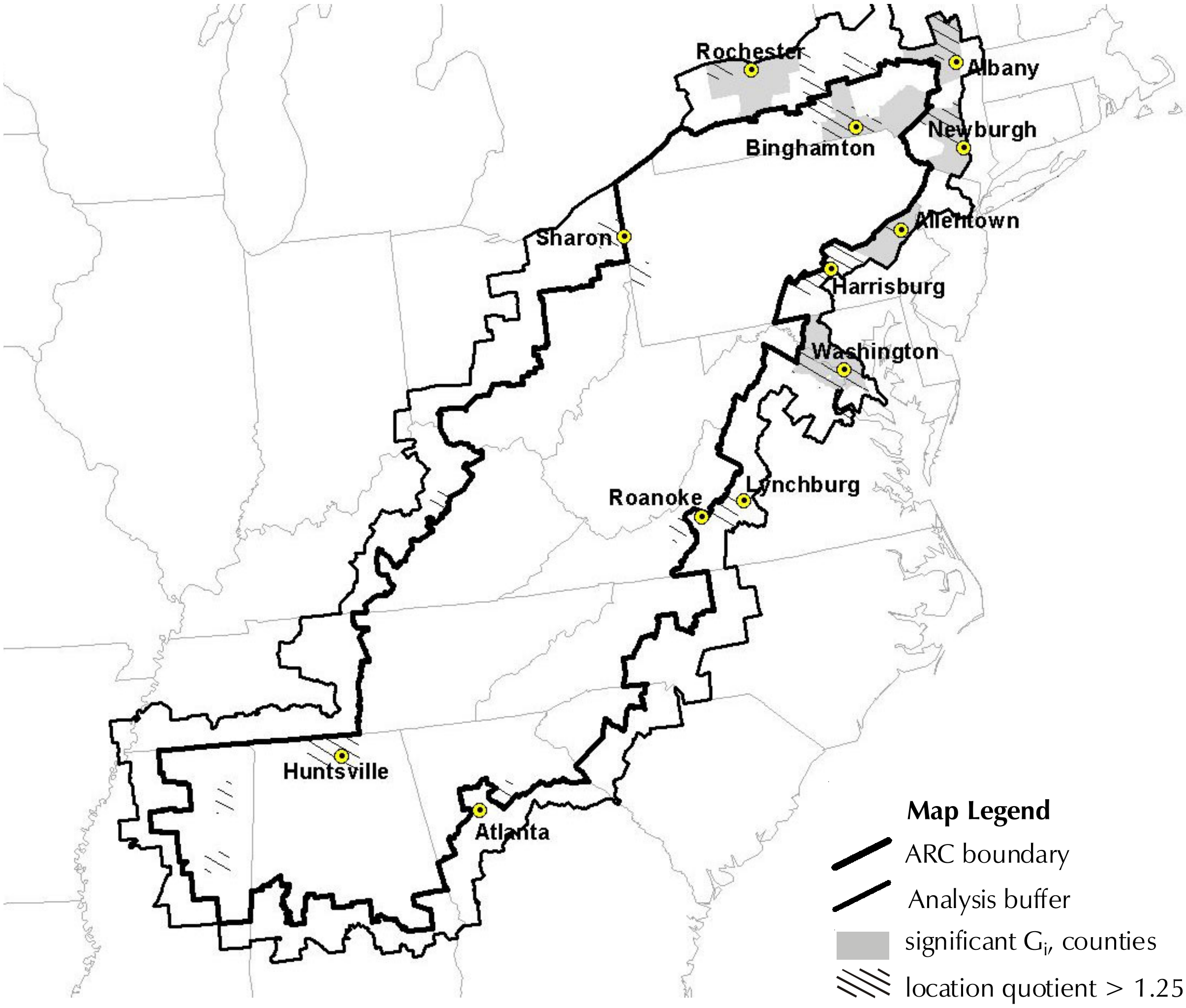


Figure 25

Spatial concentration: Pharmaceuticals patent grants, 1990–1999

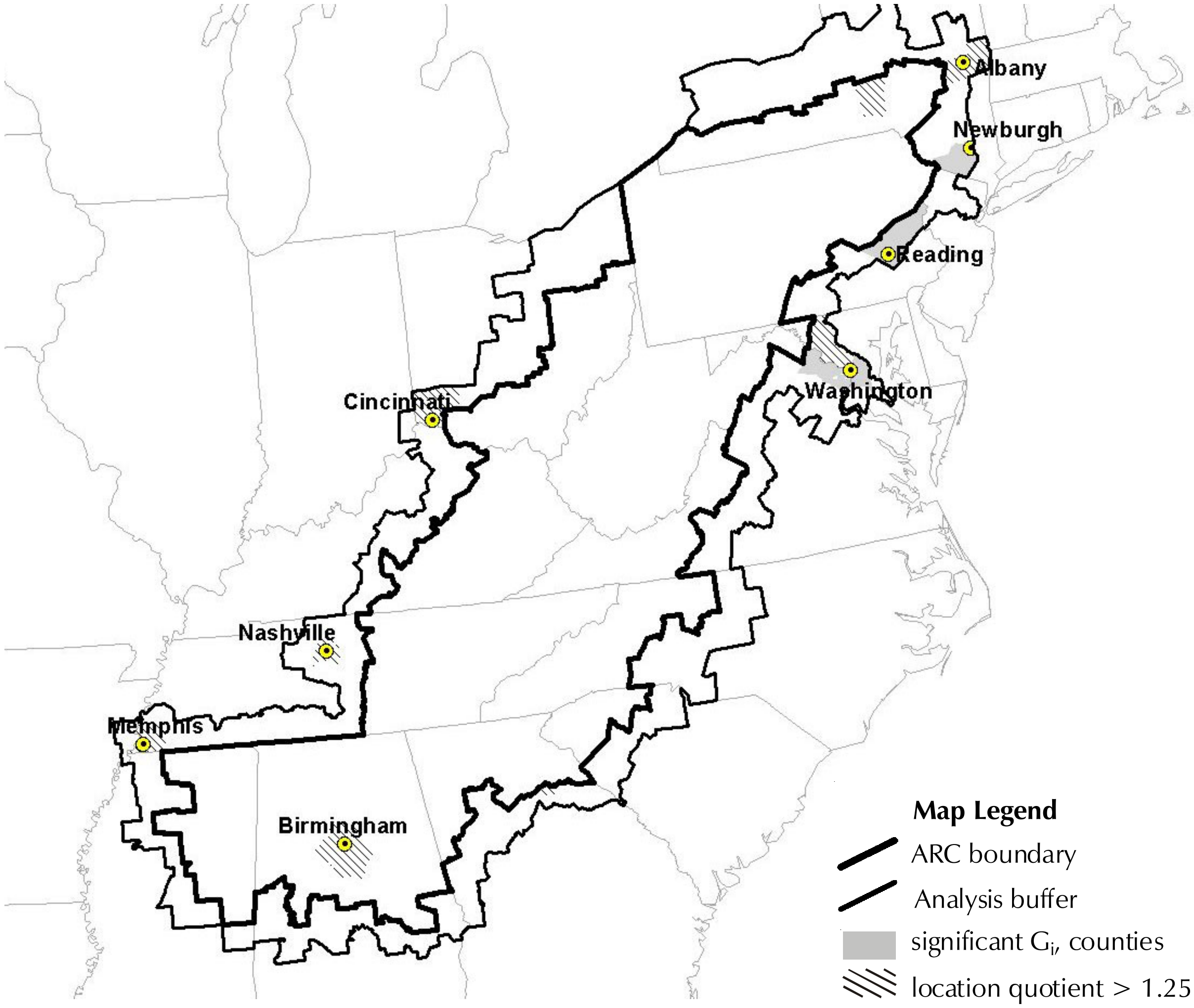


Figure 26

Spatial concentration: Aerospace patent grants, 1990–1999

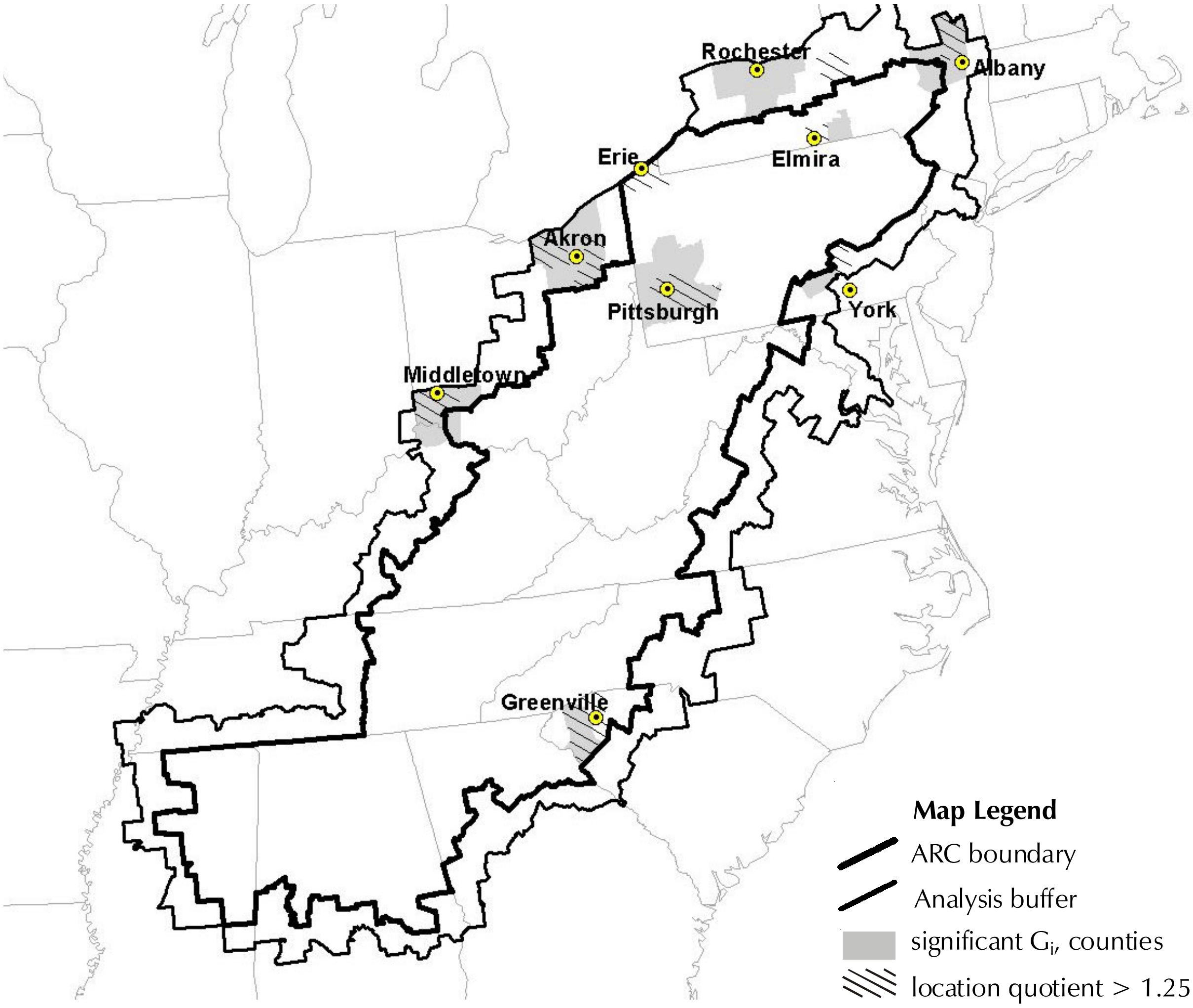


Figure 27
Spatial concentration: Scientific instruments patent grants, 1990–1999

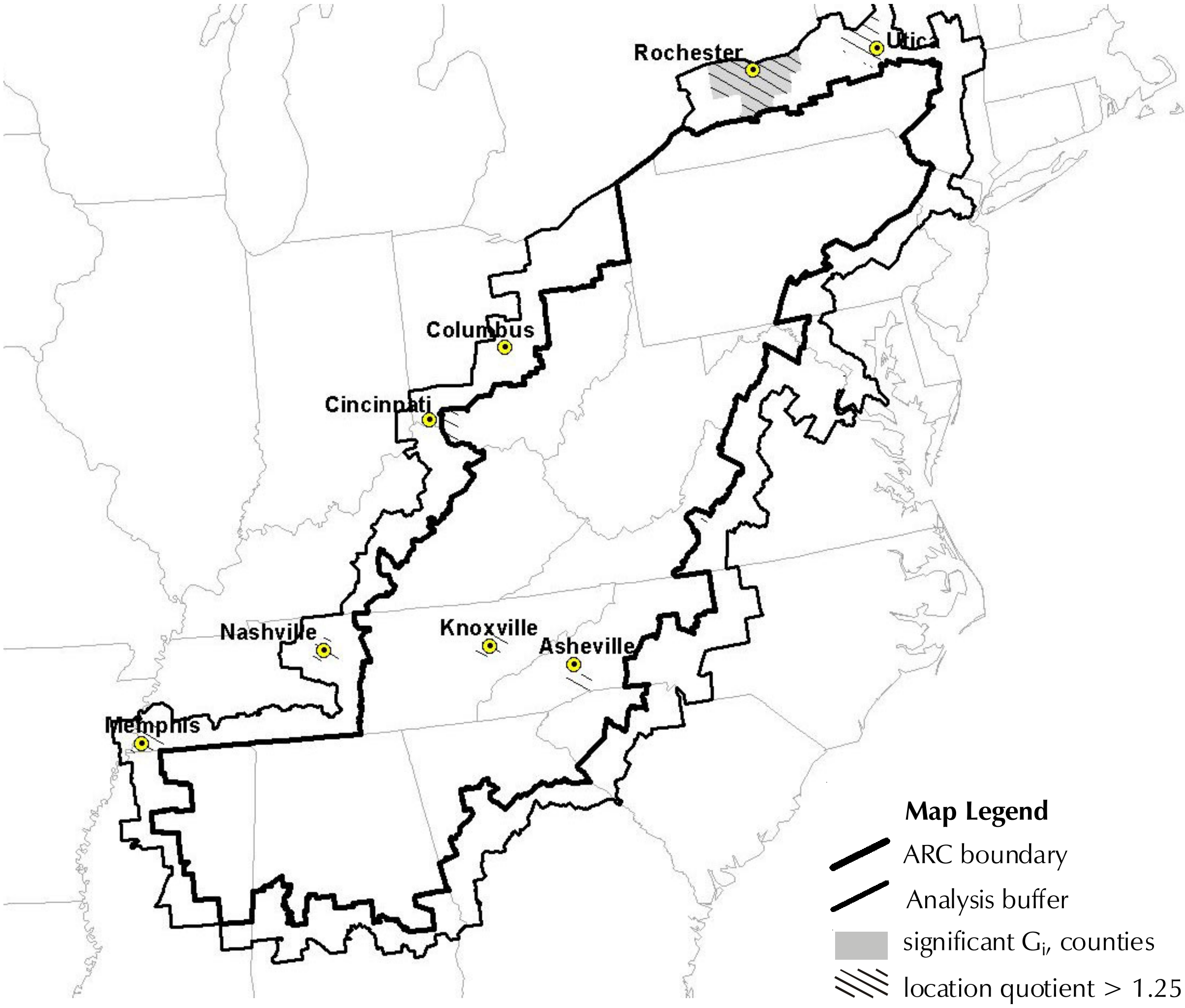


Figure 28

Spatial concentration: Household appliances patent grants, 1990–1999

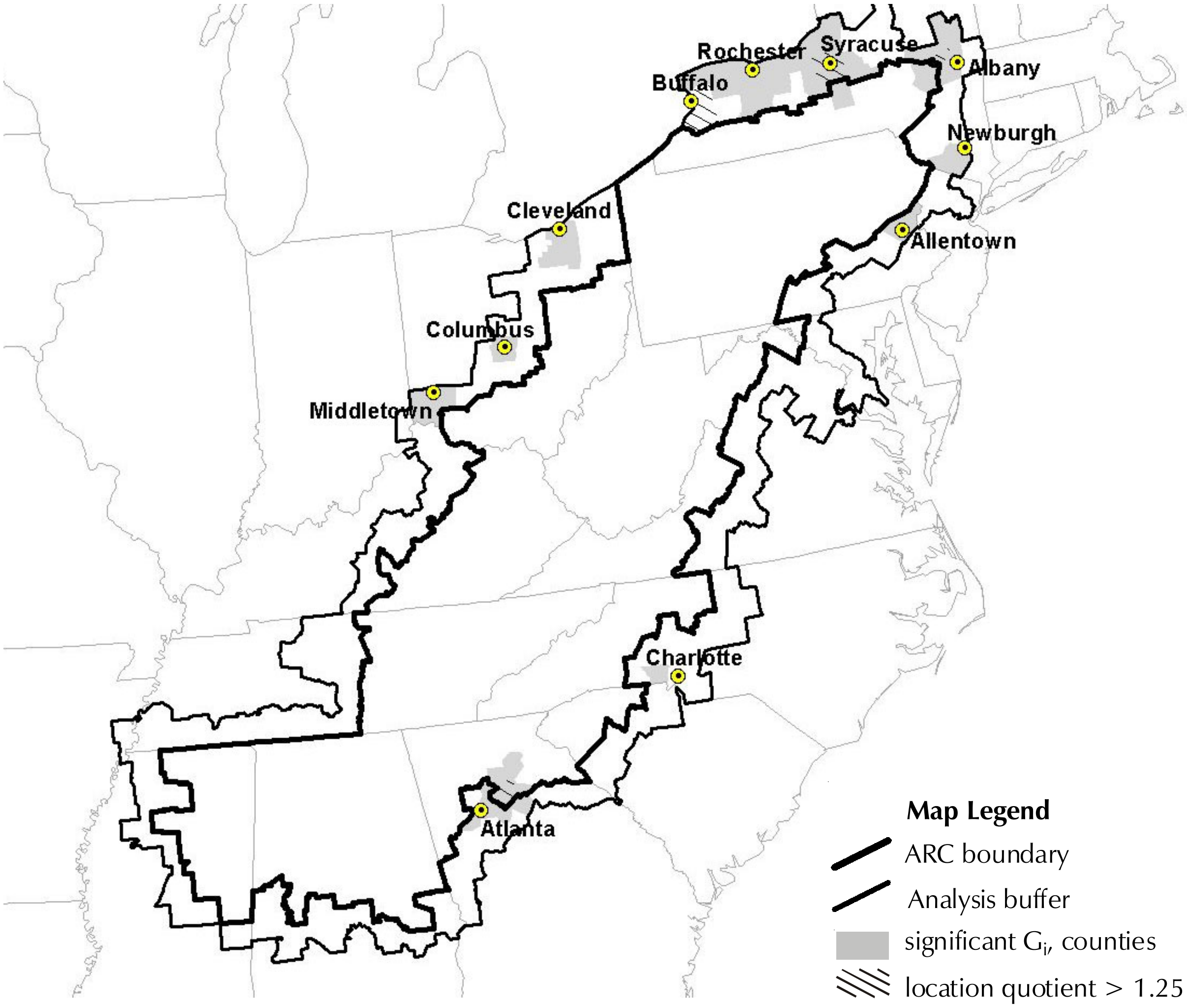


Figure 29

Spatial concentration: Motor vehicles and related products patent grants, 1990–1999

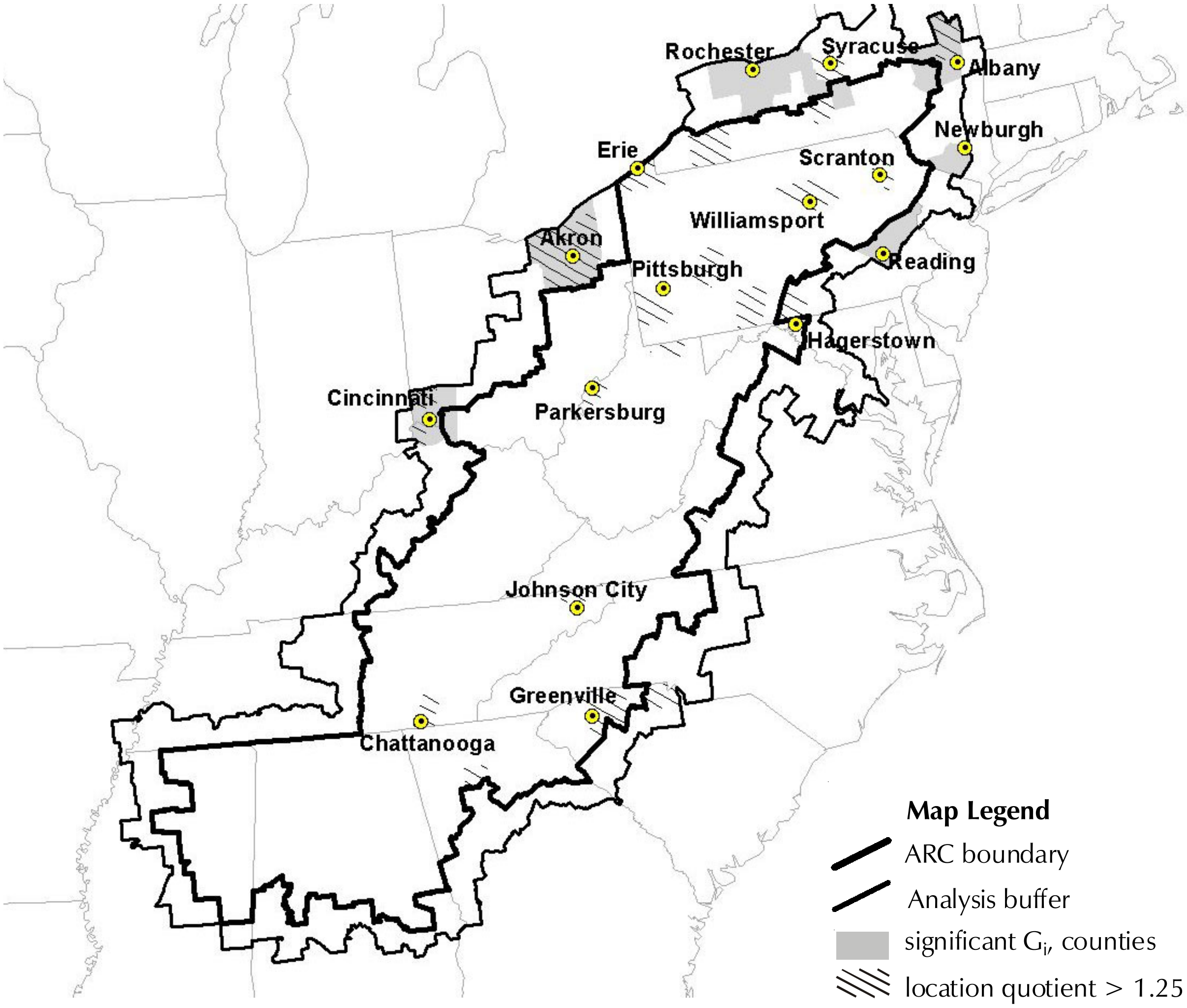
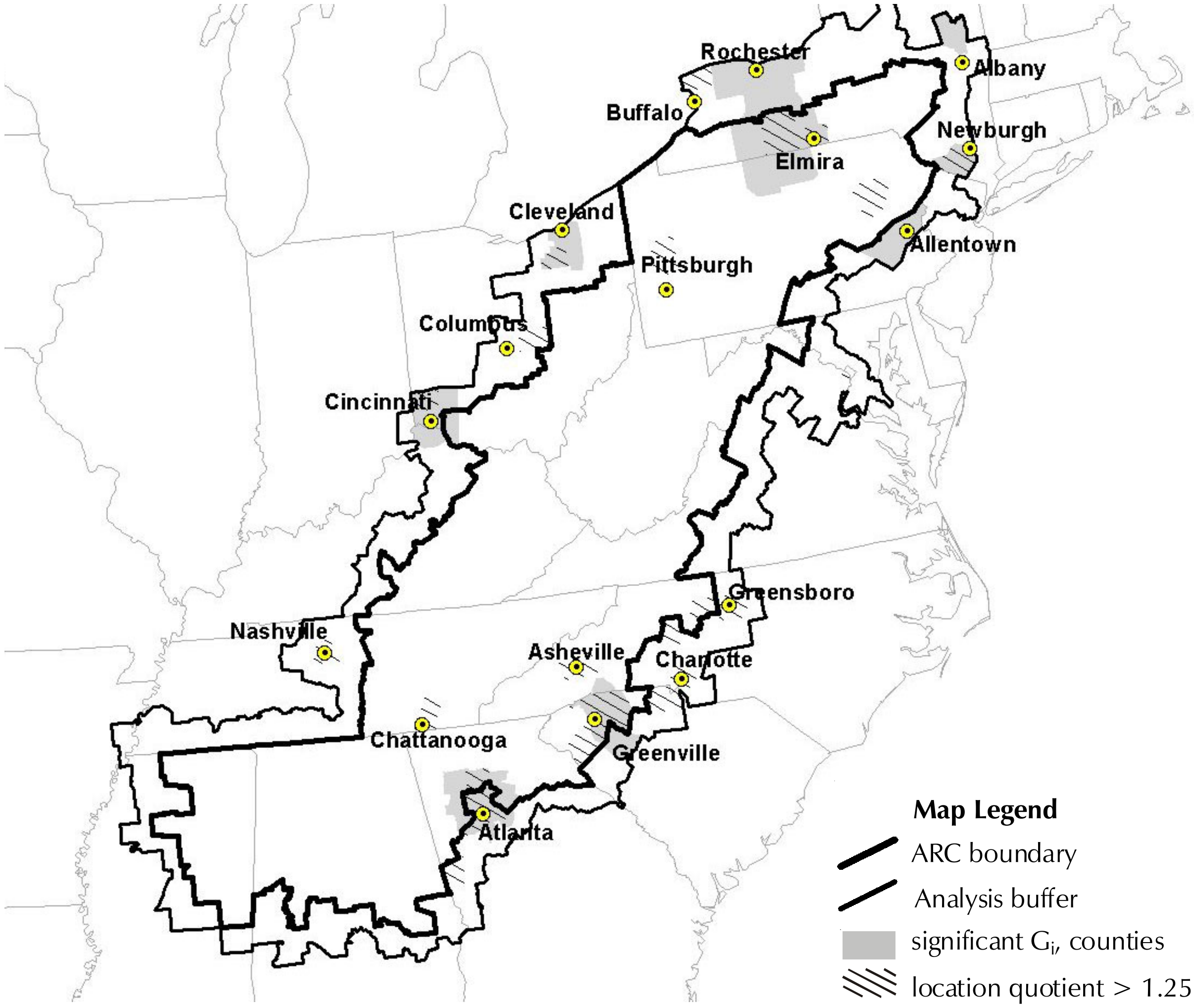


Figure 30

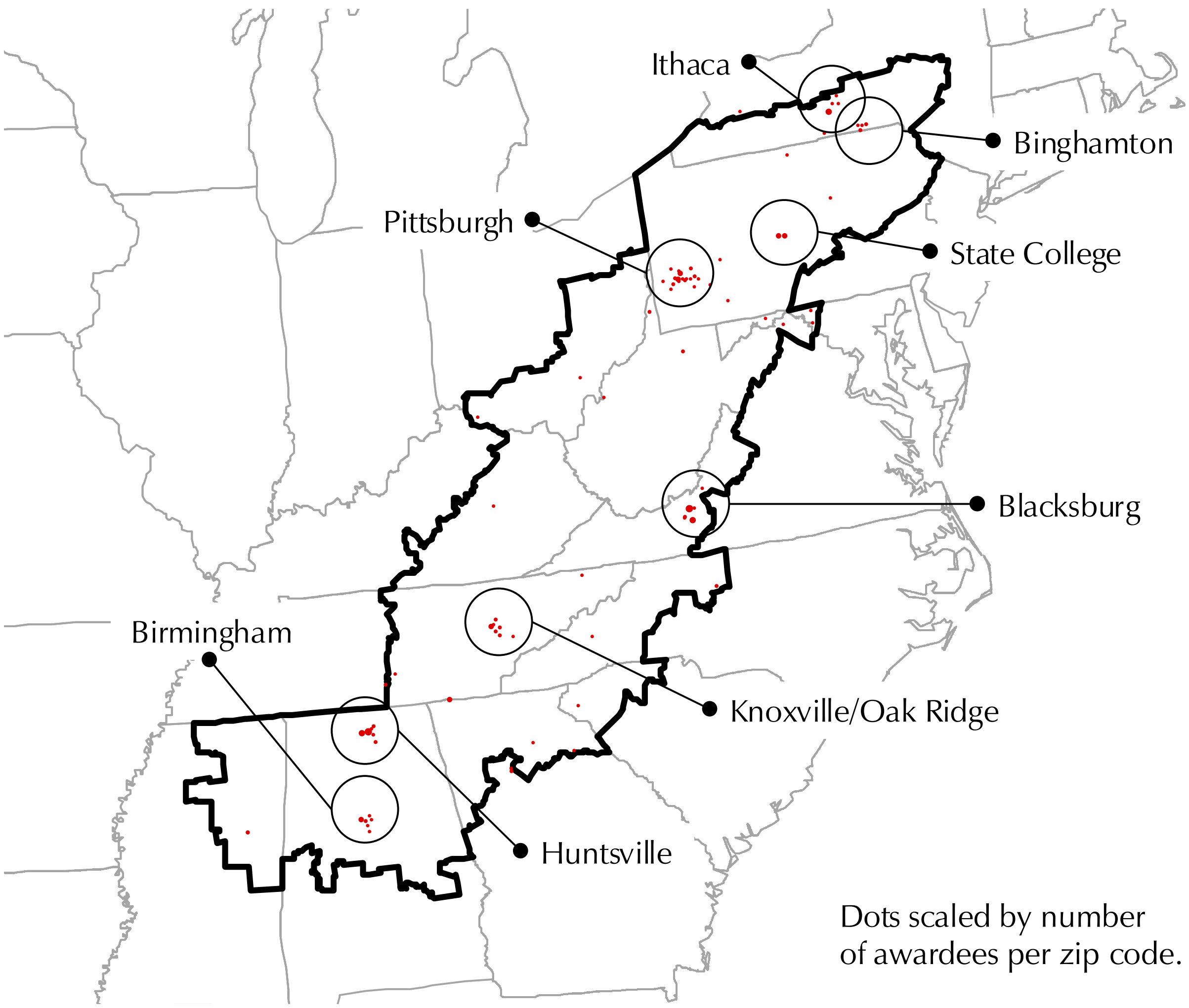
Spatial concentration: Patent grants in all other categories, 1990–1999



There were over 220 SBIR, STTR, or ATP awards given to mostly small, for-profit businesses conducting R&D in the ARC region in FY 2000. The distribution of awards by technology area is as follows: information technology and instruments (52 awards); pharmaceuticals and medical technologies (49 awards); communications services and software (41 awards); aerospace (38 awards); chemicals and plastics (24 awards); industrial machinery (18 awards); and motor vehicles (1 award).[32] Appendix Table 11 is the complete list of SBIR/STTR/ATP award winners for FY 2000.

Figure 31 plots the location of award winners. Awardees were concentrated in a relatively small number of places, especially Huntsville, Blacksburg, Pittsburgh, State College, and Ithaca, New York. Secondary nodes of concentration were Birmingham and Knoxville/Oak Ridge. When disaggregated

Figure 31
SBIR/STTR/ATP award winners in the ARC region, FY 2000
All technology categories



32. Some awards are classified in two categories. Four awards could not be classified. See Appendix Table 11.

by major technology area, a more distinct spatial specialization pattern emerges. The following are the principal nodes of concentration for each major technology area:

- Information technology and instruments: Huntsville, Oak Ridge, Blacksburg, and State College;
- Pharmaceuticals and medical technologies: Birmingham, Pittsburgh, Knoxville/Oak Ridge, and Blacksburg; note that Birmingham and Pittsburgh are the home of universities with prominent medical schools and teaching hospitals;
- Communications services and software: Huntsville, Pittsburgh, Ithaca, and Starkville (the location of Mississippi State University);
- Aerospace: a very large percentage of awardees were located in Huntsville, while there were smaller concentrations of awards in Blacksburg, State College, Chattanooga, and Ithaca;
- Chemicals and plastics: Pittsburgh, Blacksburg, Knoxville/Oak Ridge, and Huntsville.

Industrial machinery is the technology area with the most widely dispersed awardees. While minor nodes are found in Huntsville, Pittsburgh, and Blacksburg, there were one or two awardees in a number of other places. There were no SBIR/STTR/ATP awards in the ARC region in 2000 in the area of household appliances.

3.1.2 State Science and Technology Programs

State government-funded organizations involved in technology-based economic development and technology diffusion are an important element of Appalachia's science and innovation base. While such programs do not generally engage in R&D themselves, they often support science and innovation by diffusing new ideas and technology or providing assistance with technology-related problems facing smaller firms.

In this section, we discuss programs in Appalachia that are centrally focused on technology issues. For example, we include manufacturing modernization programs but not general business incubators. Also, we consider only state-funded programs; local or regional programs are not included unless they utilize state funding.[33] Where possible, we classified the activity of the program or organization by technology area that corresponds, as closely as possible, with the industrial technology categories utilized in Section 2. However, there are a substantial number of organizations that provide

33. We used several sources to generate a draft list technology-based economic development agencies for each state, including Coburn and Berglund (1995); State Science and Technology Institute staff for a list of contacts within the lead science and technology organization within each state; the membership directory of the National Business Incubator Association (http://www.nbia.org); and each state's web site. We then sent the draft list to the key contact person in the state's lead science and technology organization for review and inclusion of any omitted programs or organizations. This process was implemented in December 2000 and January 2001. Note that a number of new programs that had been announced by several states but were not yet in place are not included in our list.

broad technology-related services to businesses that span a wide range of industries. Such organizations could not be classified into any one technology area.

As might be expected, state S&T initiatives are distributed more evenly geographically than are R&D performers. Many state-funded organizations have as a principal mission the provision of services (technical assistance, consulting, education and training) to a broad region, so the actual delivery of services is even more geographically dispersed than would be suggested by the location of the organizations themselves.[34]

A large share of the state-funded S&T assets are based at smaller branches of public universities or community colleges, rather than concentrated at flagship research universities or in larger metropolitan areas. The smaller branch universities are intended to increase the number of state residents with access to higher education. Likewise the placement of technical assistance, support, and training functions at non-research public universities and community colleges is meant to target technology-based small- and medium-sized businesses located in more peripheral areas. Appendix Table 12 reports the full list of state-funded science and technology organizations we were able to identify. Industrial machinery is easily the most common technology focus. Within the ARC region, there are at least thirty different locations of technical assistance services targeted to that general industry, reflecting an emphasis on manufacturing modernization and process innovation in some of the region's traditional industry sectors (textiles, apparel, furniture, and metals).

Two technology areas are particularly important given projections for growth in related industries: information technology and biotechnology. State programs and initiatives targeted at those areas appear to be very few in the ARC region. There are only twelve programs focused primarily on the information technology industry (either instruments or communications services and software): four in West Virginia, two in Virginia, two in Alabama, and one each in Georgia, Ohio, Pennsylvania, and New York. It is notable that we were not able to identify any major IT-related extension or tech transfer programs in the Appalachian regions of Kentucky, Tennessee, North Carolina, South Carolina, and Mississippi. In the case of biotechnology, we identified three programs that receive some state support: the Georgia Biotechnology Center, the Edison Biotechnology Institute in Ohio, and the Cornell Institute for Biotechnology and Life Sciences.

3.2 Appalachia's Higher Education Infrastructure

The higher education and training component of Appalachia's knowledge infrastructure in the sciences and engineering fields is comprised of the over 250 universities, colleges, and institutes that offer degree programs in fifteen technology-related disciplines. The literature on technology-related regional

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34. Unfortunately, we were not able to obtain detailed data on the location of clients or actual service delivery.

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.

This section evaluates the human capital dimension of the Appalachia's colleges and universities using the 1997/98 data on degrees granted by program from the U.S. Department of Education's Integrated Postsecondary Education Data System (IPEDS).[35] 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 trades schools and technical institutes.[36] The IPEDS degree completions data are reported at a very high level of programmatic detail. We aggregated the figures into fifteen disciplinary/program areas that parallel, as much as possible, the National Science Foundation discipline classification.[37] Appendix Tables 13 and 14 detail our classification scheme.

Academic year 1997/98 degree completions at four-year colleges and universities in the 406-county ARC region are reported in Table 15. Consistent with the distribution of degrees nationwide, two fields accounted for just under half of the total 23,635 degrees granted in Appalachia: agricultural sciences/technology and industrial engineering/technology. Indeed, a comparison with the national distribution of degrees by discipline indicates that the overall mix of programs in Appalachian four-year schools parallels the national mix fairly closely. Judging by total degrees completed, Appalachian universities'

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35. 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.

36. 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.

37. 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 13. Appendix Table 14 lists the excluded CIP codes.

Table 15

Estimated degree completions, 1997/98, ARC 4-year colleges and universities

4-year public and private postsecondary educational institutions in 406-county ARC region

Aggregated disciplinary area title	Insti-tutions	Degree completions	Pct share	US pct share*
Aerospace Engineering, Aviation Science, & Astrophysics	137	1,346	5.7	6.1
Agricultural Sciences & Technology	149	5,672	24.0	23.8
Basic Medical Science	131	2,286	9.7	8.2
Biochemistry & Biomedical Engineering	10	345	1.5	0.8
Botany, Biology, Bacteriology, & Biotechnology	9	119	0.5	0.5
Chemical Engineering & Technology	13	216	0.9	0.8
Communications & Computer Sciences & Technologies	15	168	0.7	1.5
Environmental Engineering & Controls	21	1,898	8.0	6.0
Forestry Science & Forestry Technology	55	666	2.8	2.5
Geological & Geophysical Engineering	6	126	0.5	0.3
Industrial Engineering & Technology	137	5,455	23.1	28.6
Materials Engineering & Science	64	2,756	11.7	10.9
Mathematics	32	1,245	5.3	3.6
Mechanical Engineering, Engineering Physics & Science, & Systems Engineering	52	712	3.0	3.4
Physics & Nuclear Engineering	80	625	2.6	2.8
TOTAL		23,635	100.0	100.0

Source: U.S. Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System, *Completions* survey, 1997-1998 and *Consolidated* survey, 1998. *Total US completions in disciplinary area as a share of all US completions for 4-year institutions. Disciplinary areas were defined by the authors as aggregates of related Classification of Instructional Programs (CIP) codes. Completions include any degrees or certification programs offered, whether 4 years or less in duration.

programs in basic medical science, environmental engineering and controls, mathematics, materials engineering and science, and biochemistry and biomedical engineering are slightly larger than the national average while industrial engineering and science is significantly smaller than the national average.

As compared to the national average, proportionately more Appalachian students at two-year colleges earn degrees in agricultural sciences/technology, industrial engineering/technology, and mechanical engineering, physics, and systems engineering, while proportionately fewer earn degrees in the computer and communications sciences (see Table 16). That likely reflects the region's orientation toward agriculture and heavy traditional industry. In general, Appalachia's two-year schools are more heavily specialized in a few disciplinary areas than the national average. Four principal disciplines dominate: communications and computer sciences and technologies (50 percent of degrees granted in 1997/98); mechanical engineering, engineering physics, and systems engineering (28 percent); agricultural sciences and technology (11 percent); and industrial engineering and technology (5 percent). Although communications and computer sciences/technology account for half of all technology-related degrees at two-year schools in the region, the share of students earning such degrees is well below the national average of 61 percent.

Table 16

Estimated degree completions, 1997/98, ARC 2-year colleges and institutes

2-year public and private postsecondary educational institutions in 406-county ARC region

Aggregated disciplinary area title	Institutions	Degree completions	Pct share	US pct share*
Aerospace Engineering, Aviation Science, & Astrophysics	2	61	0.5	0.4
Agricultural Sciences & Technology	3	1,288	10.5	2.0
Basic Medical Science	0	0	0.0	0.0
Biochemistry & Biomedical Engineering	3	10	0.1	5.4
Botany, Biology, Bacteriology, & Biotechnology	6	28	0.2	2.3
Chemical Engineering & Technology	10	201	1.6	0.8
Communications & Computer Sciences & Technologies	139	6,168	50.4	60.8
Environmental Engineering & Controls	19	117	1.0	2.7
Forestry Science & Forestry Technology	8	77	0.6	0.3
Geological & Geophysical Engineering	3	103	0.8	0.8
Industrial Engineering & Technology	29	655	5.4	3.4
Materials Engineering & Science	1	12	0.1	0.0
Mathematics	5	16	0.1	0.8
Mechanical Engineering, Engineering Physics & Science, & Systems Engineering	71	3,480	28.4	18.9
Physics & Nuclear Engineering	4	23	0.2	1.3
TOTAL		12,239	100.0	100.0

Source: U.S. Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System, *Completions* survey, 1997-1998 and *Consolidated* survey, 1998. *Total US completions in disciplinary area as a share of all US completions for 2 year institutions. Disciplinary areas were defined by the authors as aggregates of related Classification of Instructional Programs (CIP) codes. Completions include any degrees or certification programs offered, whether 2-year or less in duration.

Figures 32 and 33 plot the spatial distribution of total 1997/98 degree completions by county. The maps show two things: first, the location of two- and four-year institutions offering degrees in science-related fields (only counties with at least one school are highlighted), and second, the quantity of science and engineering degrees by location. While four-year schools are more evenly distributed throughout the region than two-year schools on the whole, small concentrations of four-year institutions can still be identified (e.g., in Pennsylvania). The dominance of larger institutions such as Penn State in Central Pennsylvania is also evident. Among two-year schools, the extensive programs in North and South Carolina, and to a lesser extent Pennsylvania and Alabama, contrast sharply with the very limited evidence of substantial degree programs in Tennessee, eastern Kentucky, and West Virginia. Indeed, the IPEDS completions data suggest that central Appalachia is relatively poorly served by two- and four-year institutions offering degree programs in technology-related areas.

Many two- and four-year schools in Appalachia are below the national average in terms of "technology intensity," or the ratio of technology-related degree completions to total degree completions. Figures 34 and 35 plot technology intensity in percentage terms by county.[38] Only counties at or above

38. The measure is the ratio of total technology degrees to all degrees in county *i*, expressed as a percent, where degree completions for all schools in the county are summed. Four-year (Figure 34) and two-year (Figure 35) institutions are evaluated separately.

Figure 32

Total degree completions by county, four-year universities and colleges, 1997/98

All technology-related fields

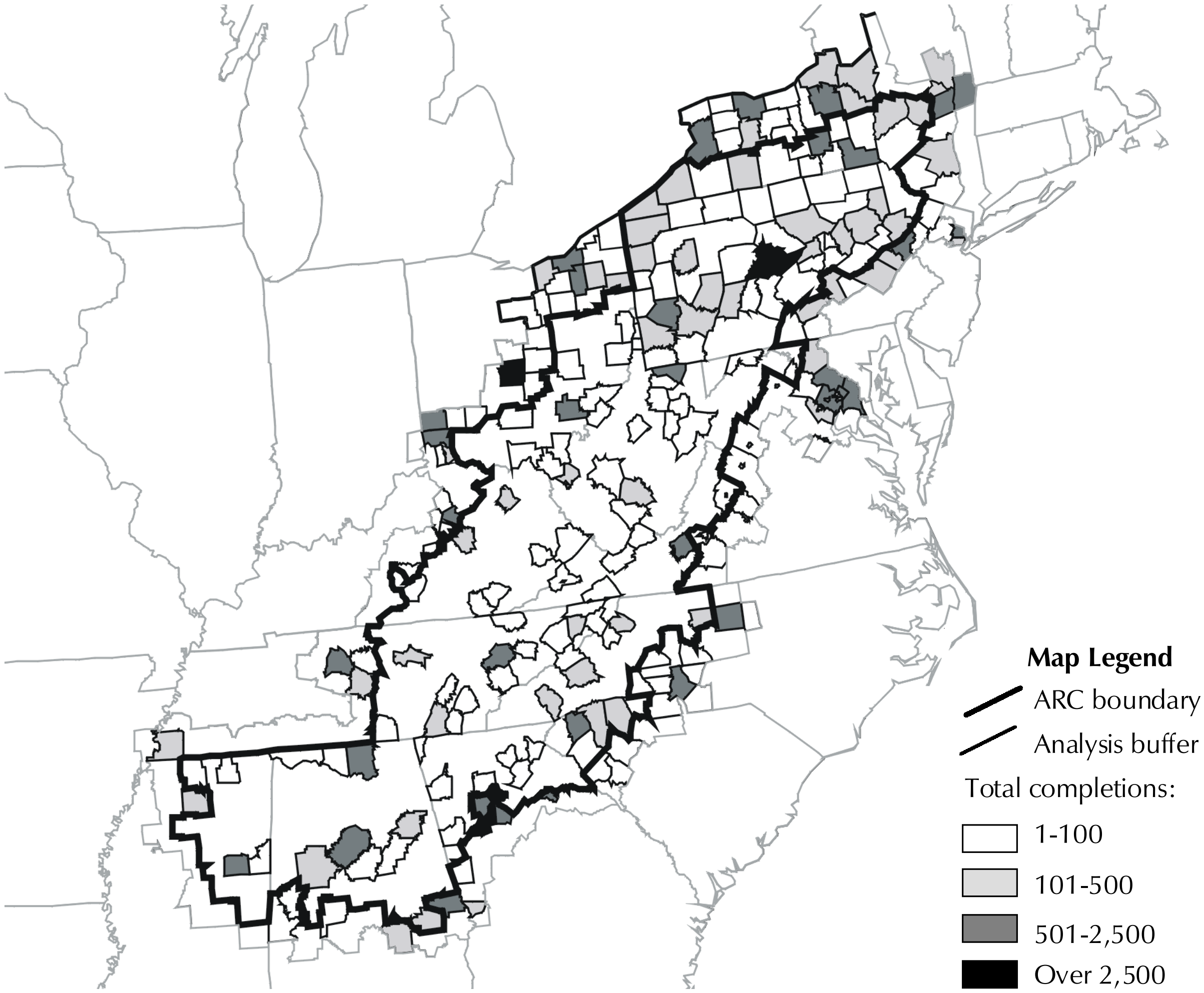


Figure 33
Total degree completions by county, two-year universities and institutes, 1997/98
All technology-related fields

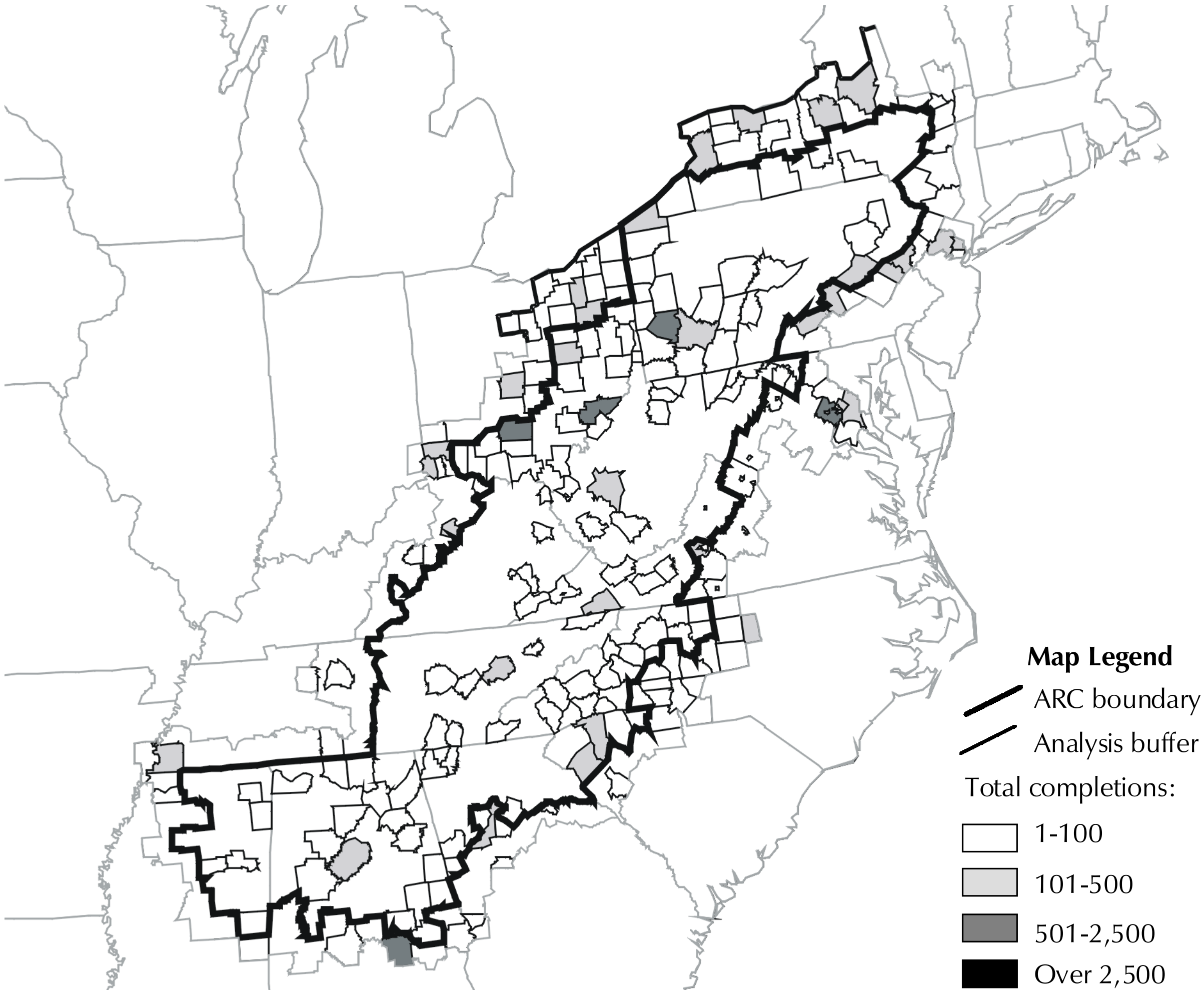


Figure 34
Technology intensity, four-year universities and colleges, 1997/98
Technology degrees as percent share of total degrees

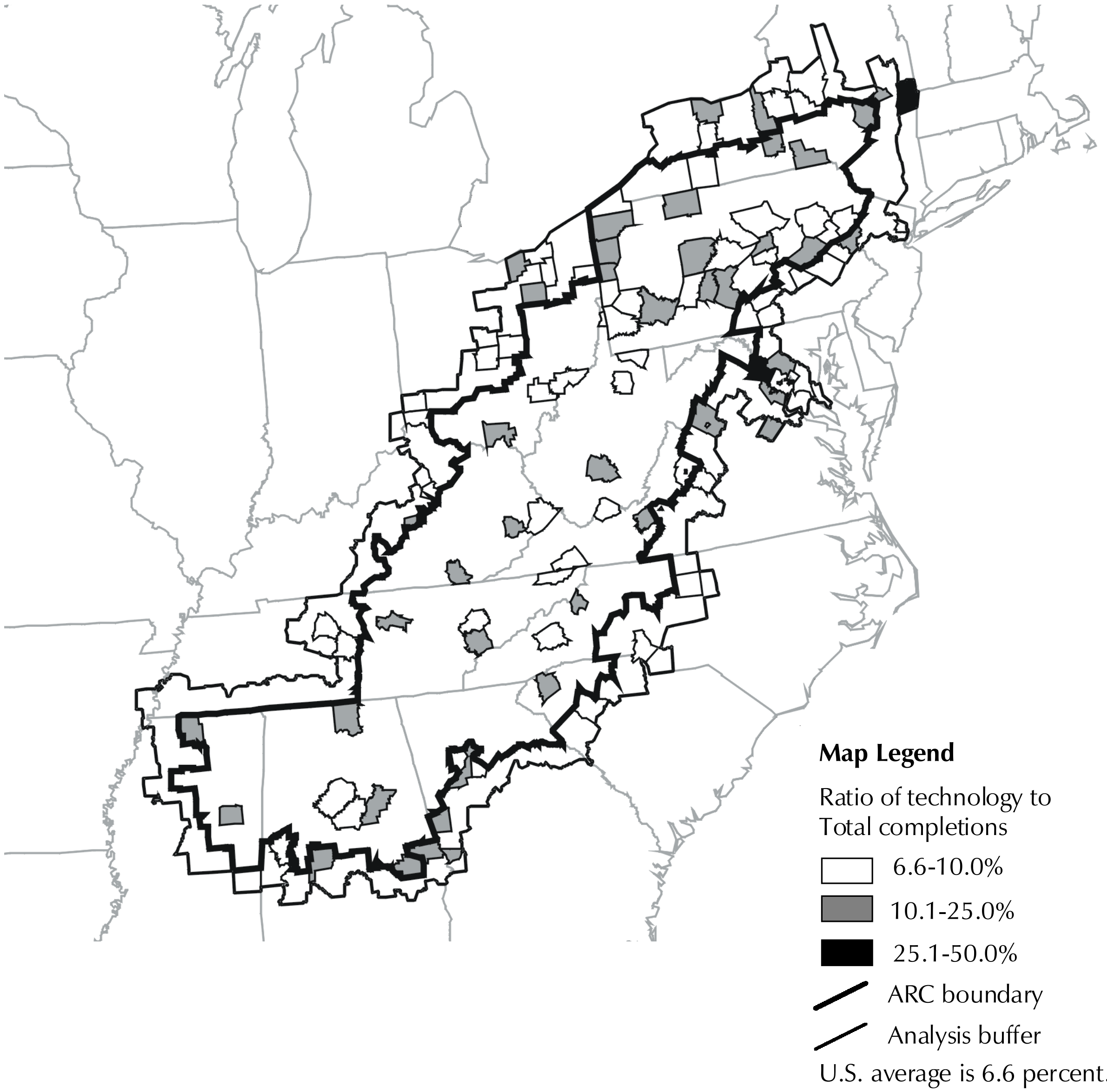
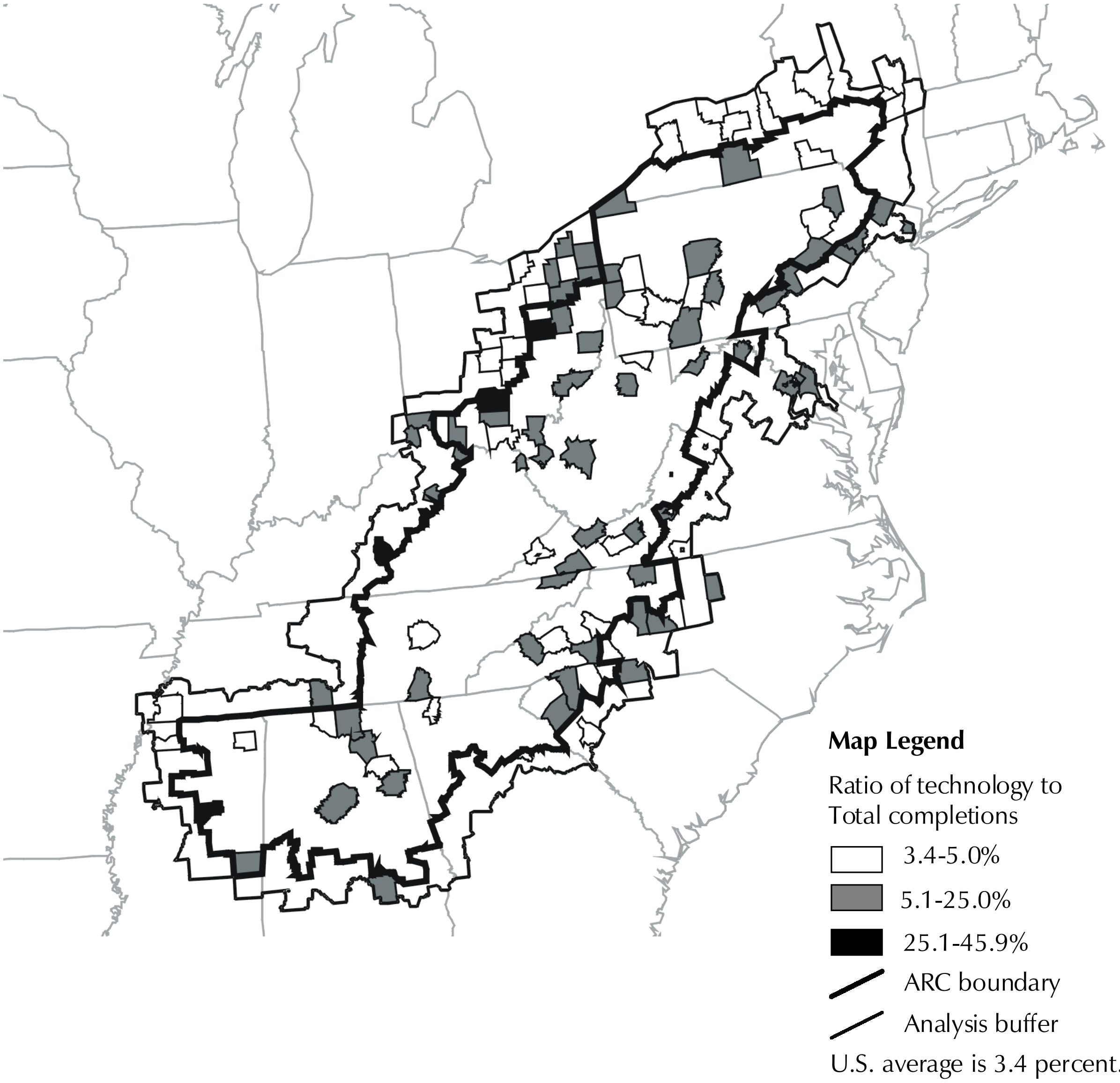


Figure 35

Technology intensity, two-year universities and institutes, 1997/98

Technology degrees as percent share of total degrees



the national average are depicted. Technology-intensive two-year schools are concentrated primarily in Pennsylvania, Virginia, North and South Carolina, West Virginia, and Alabama. Appalachian Tennessee, Kentucky, and northern Georgia have few, if any, technology intensive two-year schools. Again, technology-intensive four-year schools are somewhat more evenly distributed, though such institutions are again concentrated somewhat in Pennsylvania.

3.3 Summary

This section examined the competitive strength and sub-regional geographic distribution of the two major components of Appalachia's knowledge infrastructure: its performers of R&D and its institutions of higher education. The former consist of 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 latter are the over 250 universities, colleges, and community colleges offering degree programs and specialized training in fifteen science and engineering-related fields.

We demonstrate that there are clearly a number of nationally competitive R&D strengths within the ARC region. They span a number of technology areas, including all major disciplines of engineering, computer science, mathematics and statistics, and the agricultural sciences. Geographically, most of the R&D strength is located at around fifteen nodes anchored by major research universities, as well as near large federal government labs in Oak Ridge and Huntsville. Unsurprisingly, the large majority of SBIR/STTR/ATP award winners are located within or close to those same nodes. Only state-funded R&D assets aimed at providing direct services to technology-oriented businesses or to individuals seeking advanced training are broadly distributed in the region. The principal R&D nodes tend to have strengths within a number of technology areas, rather than being highly specialized. Thus, even though Huntsville's principal strength is in aerospace, there are also notable strengths in other disciplines including industrial engineering, chemical engineering, and computer science. The following are specific findings from this section:

- Based on national ratings of faculty quality, there are six major nodes of highest competitive strength in the universities in Appalachia (either within or adjacent to the ARC region): Cornell (Ithaca NY), Carnegie-Mellon (Pittsburgh PA), Georgia Tech (Atlanta GA), Emory University (Decatur, Georgia), Penn State (State College PA), and Virginia Tech (Blacksburg, VA).
- While faculty quality rankings indicate that the greatest competitive strengths among Appalachian research universities as a group are oriented toward the physical sciences and engineering rather than the biological and medical sciences, national R&D funding rankings suggests some Appalachian universities are actually very strong in the life sciences disciplines.

- A number of Appalachian universities boast programs that are rising steadily in the national rankings (based on R&D funding and graduate student enrollments). The majority of such "emergent programs" are at Carnegie-Mellon, Georgia Tech, Ohio, Penn State, University of Kentucky, Virginia Tech, West Virginia University, and Mississippi State.
- SBIR/STTR/ATP award winners tend to be concentrated in a relatively small number of places, namely Huntsville, Blacksburg, Pittsburgh, State College, and Ithaca, with smaller concentrations in Birmingham and Knoxville/Oak Ridge. The nature of those federal programs tends to favor locations nearby universities or labs.
- Industrial machinery is easily the most common technology focus among the some 220 SBIR/STTR/ATP awards in fiscal year 2000. That may simply reflect the dominance of the region's traditional industry sectors (textiles, apparel, furniture, and metals).
- There are a great many state-funded technology assistance, transfer, and modernization programs and agencies in the ARC region. Comparatively few, however, are focused on technology areas that are projected to drive significant growth in the next decade: information technology and biotechnology.
- Somewhat surprisingly, Appalachian four-year universities and colleges grant proportionately fewer degrees in industrial engineering and related sciences than their counterparts elsewhere in the U.S. Indeed, based on degree completions in 1997/98, Appalachian universities and colleges grant proportionately more degrees in basic medical science, environmental engineering and controls, mathematics, materials engineering and science, and biochemistry and biomedical engineering than national averages would predict.
- The share of annual degrees awarded in the computer and communications sciences by two-year colleges and institutes in Appalachia is substantially below the national average. That may reflect the comparatively limited job opportunities in IT-related industries in the region (a problem of labor demand) or an inadequate training network for an emerging industry (a problem of labor supply).
- Two- and four-year higher education institutions with an emphasis in technology-related areas are comparatively few in central Appalachia (namely Tennessee, Kentucky, and much of West Virginia).