AMERICA'S KNOWLEDGE ECONOMY | A STATE BY STATE REVIEW

April 2015

ELSEVIER | THE COUNCIL OF STATE GOVERNMENTS

Title Page

TABLE OF CONTENTS

BACKGROUND

DAVID ADKINS
CSG Executive Director/CEO

BRAD FENWICK
Senior Vice President, Global Strategic Alliances

The Council of State Governments (CSG) and Elsevier are proud to partner on this report to analyze the research strengths of the United States. Using a variety of measures, including Scopus—Elsevier's proprietary abstract and citation database of peer-reviewed research literature—this report assesses where states have a comparative advantage in research and how they can capitalize on those advantages to drive innovation, attract jobs and foster economic growth.

As the only organization that serves all three branches of state government, CSG plays a unique role in informing and bringing together state decision-makers. A key focus of CSG's policy work in 2015 is the "State Pathways to Prosperity" initiative, designed to assist states in growing their economies through workforce and economic development strategies based on nonpartisan, evidence-based research. By providing its members and the broader public with comparative state information—particularly which research fields states specialize in and how researchers collaborate across states lines and internationally—CSG aims to spur and inform discussions about research funding and prioritization and how the policy goals of a state align with the goals and expertise of its research institutions.

With more than a century's experience in providing research information and tools, Elsevier works closely with the global science and health communities. Every day, Elsevier serves more than 30 million scientists, students, and health and information professionals in over 180 countries by delivering journals, books and research databases. Through its unique vantage point on the world of research, Elsevier can help leaders in the world of research shape and implement larger research strategies.

This report combines CSG's strong state and national-level policy expertise with Elsevier's experience in quantitative research performance evaluation to offer state decision-makers a new, data-driven perspective on the strengths of their research institutions and on how researchers in those institutions are collaborating across state lines and internationally.

EXECUTIVE SUMMARY

KEY FINDINGS

NATIONAL
1.7 PUBLICATIONS
PER 1,000 RESIDENTS

NATIONAL
6.5 PUBLICATIONS
Per million $USD R&D Expenditures

TOP STATE
MASSACHUSETTS
7.5 publications produced per 1,000 residents, the highest of any state.

TOP RESEARCH AREA (RELATIVE CITATION IMPACT)
COMPUTER SCIENCES
US research in computer science achieves a field-weighted citation impact of 1.74, or 74% above the world average.

TOP RESEARCH
1. MEDICINE
2. ENGINEERING

COLLABORATION PARTNERS
NEW YORK & MASSACHUSETTS
From 2004–2013, researchers from these states collaborated on 37,972 publications, of which 43% were in medicine.

TOP STATE
MINNESOTA
10.5 publications produced per million $USD of R&D expenditures, the third rate among all states after Massachusetts and Delaware.

TENNESSEE | GROWTH IN RESEARCH IMPACT
The field-weighted citationimpact of Tennessee's research grew from 1.54 in 2004 to 1.76 in 2013, or 1.5% per year over the past decade. This was the top growth rate among states that already achieved am impact above the US average (1.49).

NORTH CAROLINA | RESEARCH STRENGTH IN MEDICINE
ranked in the top five among all states in both the relative volume of its research in medicineand the relative citation impact of its research in medicine.

INTRODUCTION

Research and development (R&D) is a critical contributor to innovation and long-term economic growth, and the United States has a long history of being a global leader.

As the United States' economy gains momentum from the recession recovery, everyone—from legislators and regional planners to corporations and the everyday worker—is focused on answering a few key questions. How can the U.S. sustain that momentum? Where should states and institutions place their bets and invest their resources to create long-term pathways to prosperity?

This report explores the comparative research strength of states, offering state leaders a number of new metrics by which to measure their institutions and better direct investment decisions.

Previous studies have touted both the short-term and long-term benefits of increasing investments in research and development. In an environment in which all stakeholders increasingly demand more accountability for the risks they take, particularly when it comes to public dollars, states and universities do not want to just invest more money. They are adopting strategies to identify which areas to most effectively invest their available resources.

Moreover, while public officials should not be dissuaded from investing in moon shots—areas with long-time horizons for maturity—policymakers need to be sure they are choosing the right moon shots, those that build on a state's existing strengths and critical mass of expertise.

Once states' comparative research advantages have been identified, it is imperative that policymakers and stakeholders around the country receive that information. It is important that local universities, businesses, government agencies, not-for-profit incubators and economic development organizations recognize what they are doing best to collaborate and coordinate on maximizing those advantages. Getting the word out to dynamic companies and talented workers which research areas your state is a national or world leader in helps link the economic development and policy goals of a state to its research institutions. To do this, however, those claims must be backed up with narratives and facts. That is where this report comes in.

This report outlines a process that states can undertake to both identify and showcase their research strengths—those areas in which they have a comparative research advantage—and ties those strengths to economic development outcomes.

CHAPTER ONE

RESEARCH OUTPUT & IMPACT

This chapter provides an introduction to and overview of indicators related to research output and impact. These indicators help individual states benchmark themselves to one another and the entire country.

1.1 MOTIVATION

"In the second half of the twentieth century, a new and quintessentially American type of community emerged in the United States: the city of knowledge. These places were engines of scientific production, filled with high-tech industries, homes for scientific workers and their families, with research universities at their heart. They were the birthplaces of great technological innovations that have transformed the way we work and live, homes for entrepreneurship, and, at times, astounding wealth. Cities of knowledge made the metropolitan areas in which they were located more economically successful during the twentieth century, and they promise to continue to do so in the twenty-first."

» Margaret Pugh O'Mara, "Cities of Knowledge: Cold War Science and the Search for the Next Silicon Valley"

Research plays a key role in defining a region's future economic prosperity. From Silicon Valley to Silicon Alley in New York, the Research Triangle in North Carolina to Kendall Square in Boston/Cambridge, there are countless examples over the past several decades of how research drives innovation, attracts jobs, and fosters economic growth.

Due to the difficulty of gathering comprehensive, long-term data that track the larger economic and societal impacts of research, previous studies typically focus on indicators of short-term economic activity, such as the direct level of research and development (R&D) expenditures, the amount of employment generated by those expenditures, and the indirect multiplier effect such expenditures have on a local economy. Some of the most recent and rigorous analyses of the immediate economic impact of research come from the STAR METRICS and U-METRICS initiative.

Just as important, but more difficult to track, is the long-term impact of research on a region's economic prosperity. Universities attract and train talented students in the latest technologies. As urban studies theorist Richard Florida and others caution, an increasingly mobile creative class makes it more important to attract and retain talented students and future knowledge workers. For example, a recent study of (living) Massachusetts Institute of Technology alumni found that those alumni have started more than 25,800 active companies that "employ 3.3 million people and generate annual world revenues of nearly $2 trillion." Of those 25,800 companies, 6,900 are headquartered in Massachusetts and generate worldwide sales of about $164 million. Likewise, a similar study of Stanford University alumni found that those alumni have created 18,000 firms that are headquartered in California, generating annual worldwide sales of about $1.27 trillion.

More importantly, research conducted in universities and national labs provide the seed corn for future breakthrough innovations. As Mariana Mazzucato describes in her book, "The Entrepreneurial State: Debunking Public vs. Private Sector Myths," many of the key technological breakthroughs that created modern products such as the Internet and mobile telephony.

States with strong research ecosystems are able to attract, grow, and retain large, innovative companies and high-wage jobs. Firms seek to co-locate next to universities and other highly innovative firms within the same or complementary industries to benefit from knowledge spillovers. As economist Enrico Moretti notes from an interview with the CEO of ECOtality, an emerging clean-tech company, it is important for companies "to be close to the action." The action is where the most innovative research is happening.

Given budget constraints, investing more money in research is not necessarily the most practical option for many states. Moreover, as federal funding for research stagnates and calls for greater accountability on research spending increase, it is important for states and universities to do more with less, to collaborate and pool their research resources with others, and to showcase how they are doing so.

Through analyzing trends in a state's research performance, this report outlines a process to help policymakers and research decision-makers identify in what areas and along what dimensions their states have research strengths and where they can improve.

1.2 RESEARCH OUTPUT

This report draws on a number of indicators and data sources related to research output and performance. At its core, all of these indicators are related to the output of peer-reviewed publications.

For academic researchers, peer-reviewed publications are the medium by which they both communicate new ideas and assess each other's contributions. Scholarly peer review is a practice by which a drafted paper or manuscript is scrutinized by other experts in the same field; the draft will be published only if those experts determine that it is suitable for publication.

Research output for a given entity—whether it is an individual university or institution, a state or a country—is defined as the number of publications with at least one author affiliated with the respective entity.

In 2013, the U.S. published more than 536,000 publications. U.S. research output increased at a compound annual growth rate of 2.93 percent per year over the past decade, which was lower than the compound annual growth rate of the entire world at 5.19 percent. That means that the United States' share of all publications worldwide actually decreased. In contrast, countries such as China, India and South Korea have grown their research outputs by 15.6 percent, 13.7 percent and 9.3 percent over the past decade respectively.

Which U.S. states have produced the most research during the past 10 years?

Figure 1.1 shows a heat map of the number of publications for U.S. states from 2004-13, where darker shades indicate a higher level of output. California, New York, Massachusetts, Texas and Pennsylvania produced the largest absolute number of publications. To put this in perspective, the number of publications by California-based researchers in 2013 (almost 92,000) comprised 17.1 percent—more than one-sixth—of the total U.S. publication output and was higher than the entire output of Canada. The combined absolute outputs of the top five states comprised more than 50 percent of the total U.S. output.

Figure 1.1 shows a heat map of the number of publications for U.S. states from 2004–2013, where darker shades indicate a higher level of output. California, New York, Massachusetts, Texas, and Maryland produced the largest absolute number of publications. To put this in perspective, the number of publications by California-based researchers in 2013 (almost 92,000) comprised 17.1 percent (more than one-sixth) of total U.S. publication output and was higher than the entire output of Canada. At the same time, the combined absolute outputs of the top five states comprised more than 50 percent of the total U.S. output.

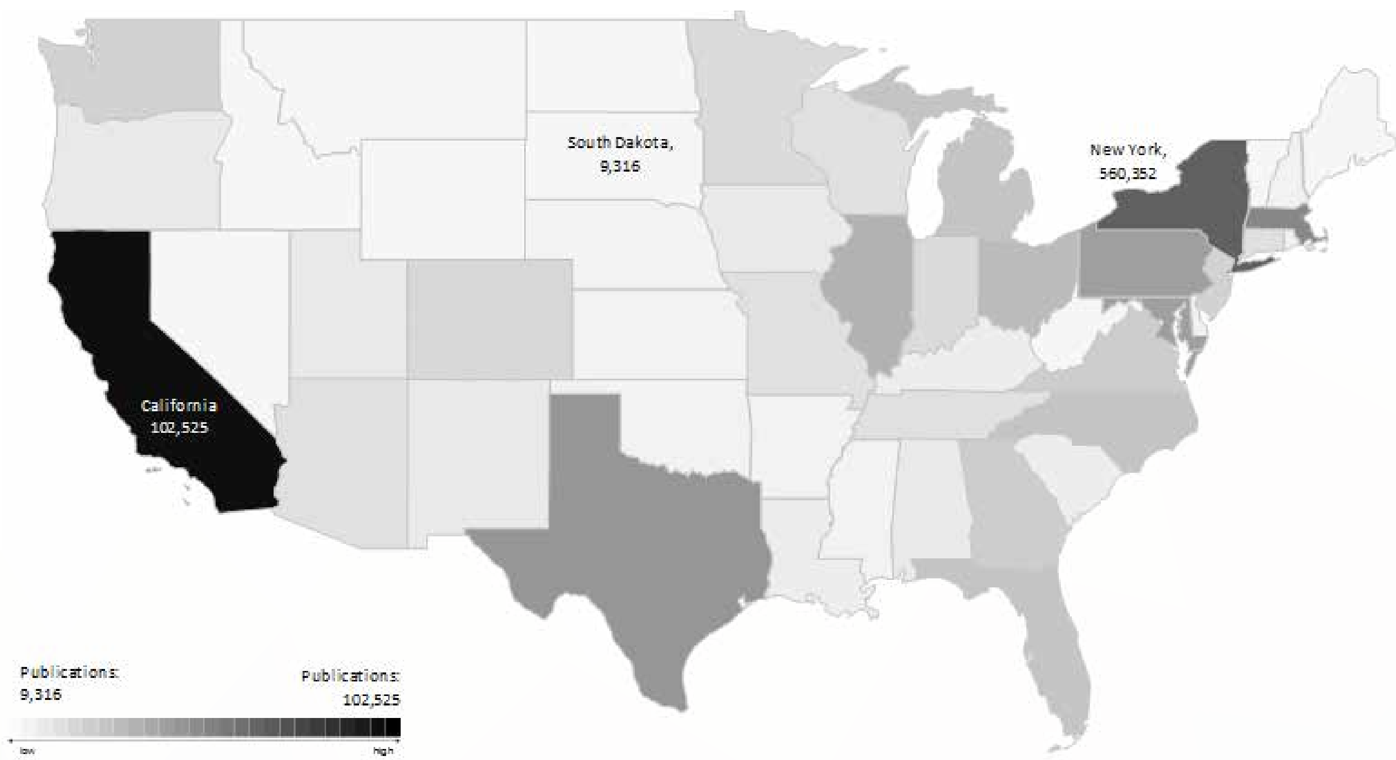


Figure 1.1—*Number of Publications for U.S. States, 2004–2013. Source: Scopus®*

Unsurprisingly, states with larger populations tended to produce more publications. **Figure 1.2** displays a similar heat map for U.S. states' publication output in 2013 per 1,000 residents. The U.S. as a whole produced 1.7 publications per 1,000 residents. While states such as Massachusetts and Maryland produced high levels of research per capita (7.5 and 6.6 publications per 1,000 residents, respectively), states with smaller populations such as Rhode Island (4.2 publications per 1,000 residents), New Mexico (3.8 publications per 1,000 residents) and Connecticut (3.5 publications per 1,000 residents) also performed quite well.

Which states increased their publication output the most? **Figure 1.3** plots publication output (scaled from 0 to 1 by each state's percentile relative to all other states) against growth in publication output volume. States with small outputs overall tended to grow the most – South Dakota, North Dakota, and Wyoming grew their annual research output by 10.8 percent, 6.1 percent and 5.4 percent per year respectively. Florida stood out as a state that achieved both a high level of publication output (210,016 publications, 9th overall and in the top quintile of all states) and a high compound annual growth rate over the past decade (5.1 percent per year, 7th among all states).

Which sectors contributed the most to Florida's growth?

Growth in Florida's research output can primarily be traced to its academic sector. As **Figure 1.4** demonstrates, research output from Florida universities and research institutions grew from 13,465 publications in 2004 to 20,888 publications in 2013 (an increase of 7,838 publications, 5.0 percent compound annual growth rate).

However, research output from the medical sector (hospitals not otherwise affiliated with universities), such as the Mayo Clinic hospital in Jacksonville and the Cleveland Clinic Florida in Weston, comprised a small but important percentage of the state's total (5.41 percent). In absolute numbers, the size of Florida's medical sector's research output is 8th among all states, as shown in **Figure 1.5**. More importantly, Florida's medical sector's output grew 5.5 percent per year, a rate faster than all other sectors for the state and faster than the U.S. medical sector as a whole (4.0 percent).

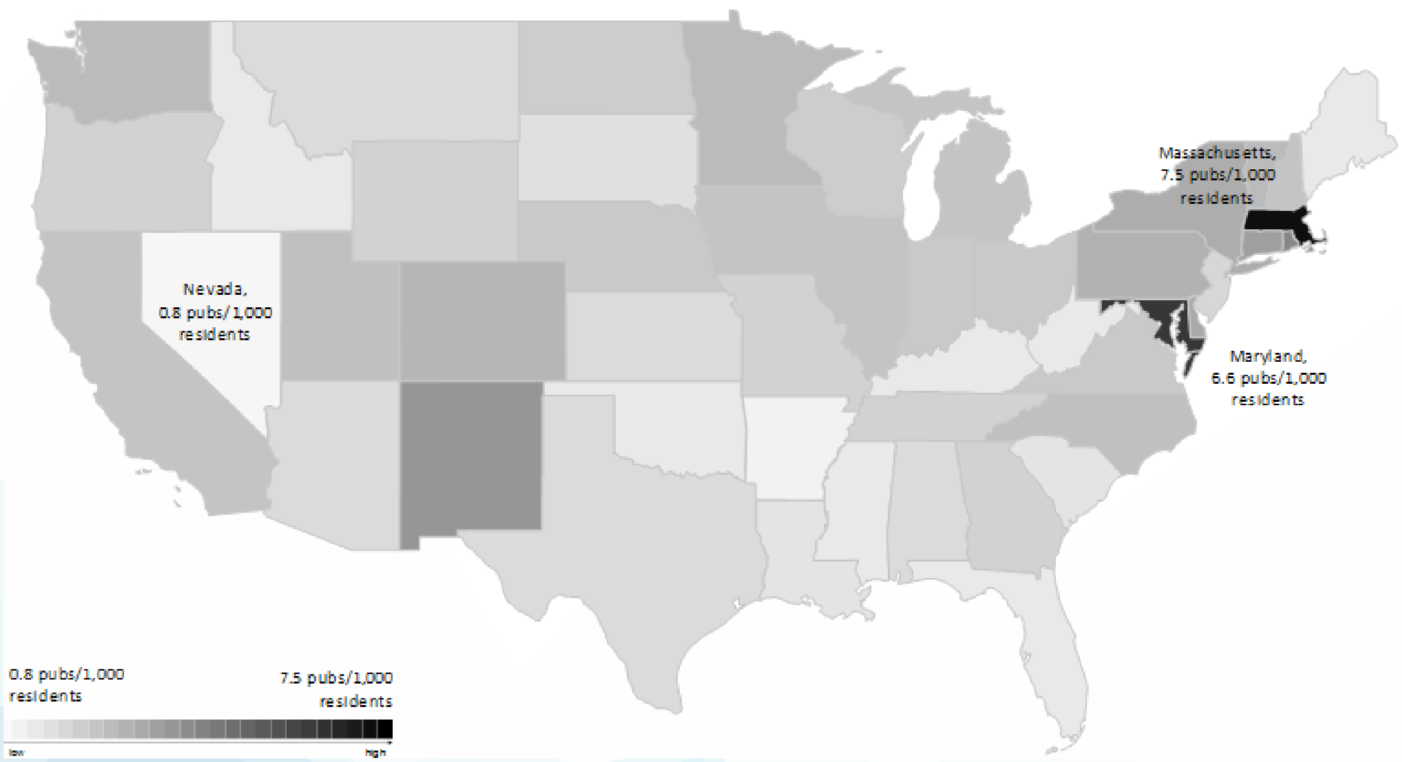


Figure 1.2—*Number of Publications Per 1,000 Residents for U.S. States, 2013. Source: Scopus® and the U.S. Census Bureau*

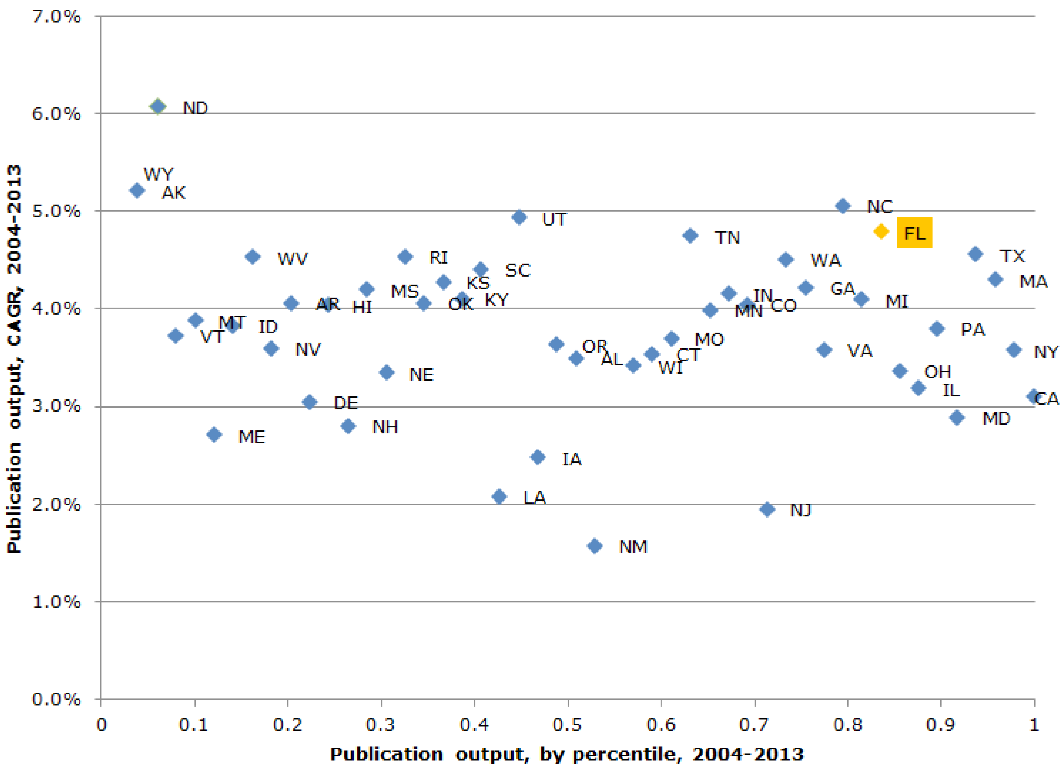


Figure 1.3—*Scatterplot of Publication Output Versus Compound Annual Growth Rate in Publication Output for U.S. States, 2004–2013. Scaled from 0 to 1 by percentile .*
Note: South Dakota is excluded from figure because the state's compound annual growth rate was an extreme outlier. Source: Scopus®

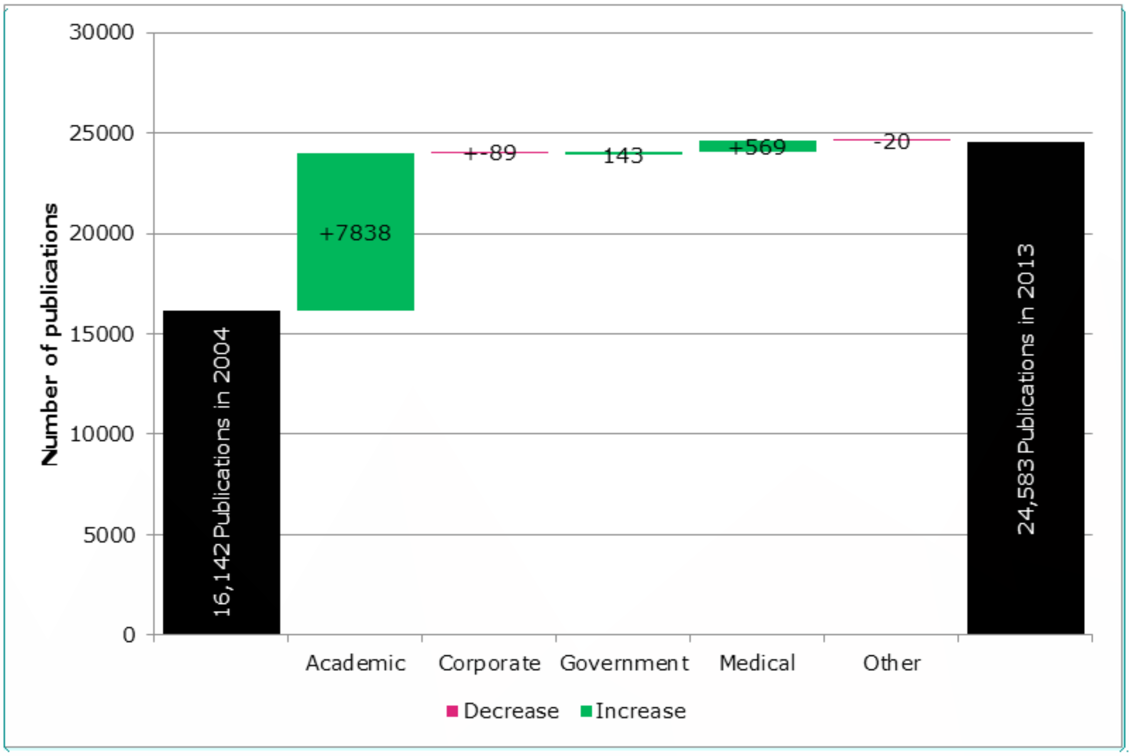


Figure 1.4—*Distribution of Growth in Research Output for Florida Across Sectors, 2004-2013. Source: Scopus®*

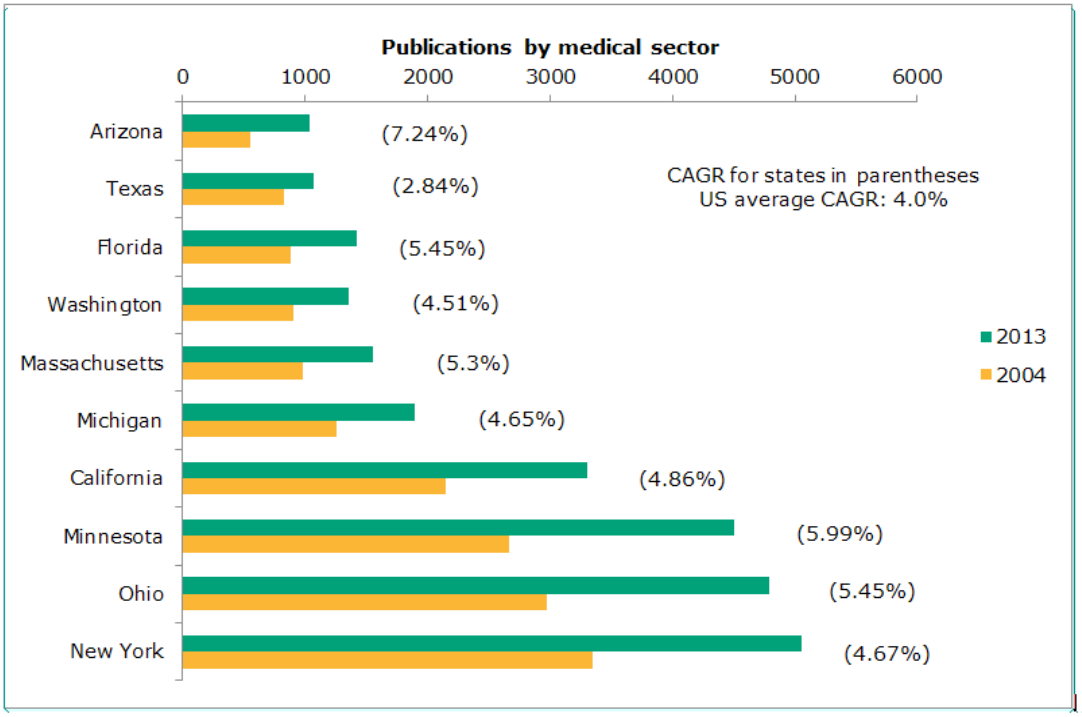


Figure 1.5—*Top Ten States, Publication Output by Medical Sector, 2004 versus 2013. Source: Scopus®*

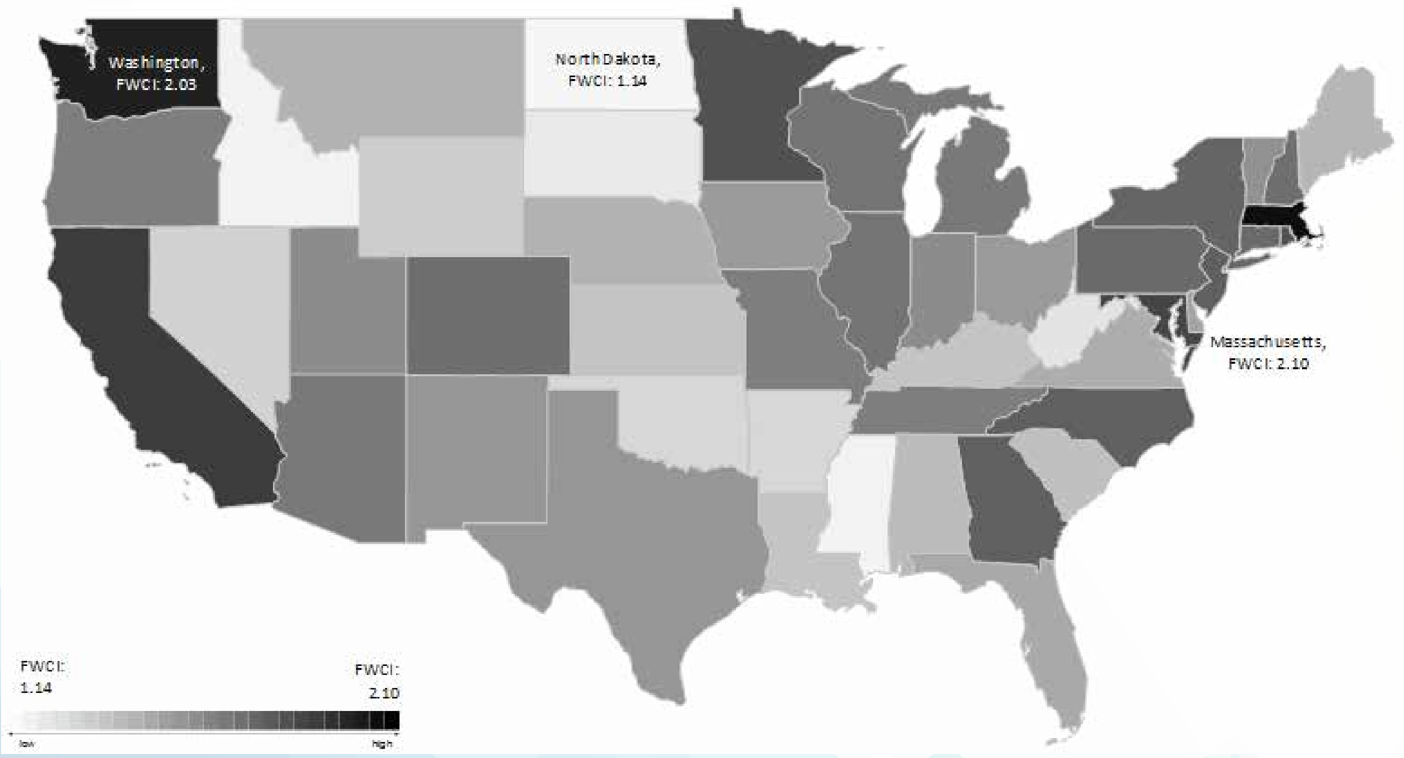


Figure 1.6—*Field-Weighted Citation Impact for U.S. States, 2004-2013. Source: Scopus®*

1.3 CITATION IMPACT

In assessing a state's research performance, it is important to take into account both the volume and the quality of research output. Citations are widely recognized as a possible proxy for quality.

A publication usually cites or makes formal references to previous works upon whose findings or ideas the research builds. The number of citations a publication receives from subsequently published articles is often interpreted as a proxy of the quality or importance of that publication.

Since it takes time for publications to accumulate citations, it is normal that the total number of citations for a state's cumulative publications is lower for the most recent years. Moreover, different states have different research strengths, and citations in research from one field may accumulate faster than others because that field simply produces more publications. Therefore, instead of comparing absolute counts of citations across years and states, we recommended using a citation measure called field-weighted citation impact (also known as FWCI) that adjusts for these differences.

A field-weighted citation impact divides the number of citations received by a publication by the average number of citations received by publications in the same field, of the same type, and published in the same year. The world average is indexed to a value of 1.00. Values above 1.00 indicate above-average citation impact, and values below 1.00 likewise indicate below-average citation impact. For example, a state with a field-weighted citation impact of 1.16 indicates that the average paper from that state was cited 16 percent above the world average whereas a state with a field-weighted citation impact of 0.91 indicates that the average paper from that state was cited 9 percent below the world average.

The overall field-weighted citation impact of all U.S. research output from 2004 to 2013 was 1.49. **Figure 1.6** shows a heat map of all of the states and their respective field-weighted citation impacts. Massachusetts and California achieved the highest field-weighted citation impacts among all states at 1.97 and 1.93, respectively. Other states with high field-weighted citation impacts for their respective region include Washington (1.56, second among all states in the West), Minnesota (1.66, first among all states in the Midwest), North Carolina (1.80, first among all states in the South), and Maryland (1.82, second among all states in the East and third among all states overall). In contrast to **Figure 1.1**, there is a much more even distribution of highly impactful research throughout the country.

While the relative positions of states on this measure are mostly stable over time, some states significantly improved the citation impact of their research over the past ten years. For example, the field-weighted citation impact of Colorado's research output grew 1.52 percent per year from 1.59 in 2004 (17th among all states) to 1.83 in 2013 (sixth among all states). This was the highest growth rate in field-weighted citation impact among all states that had a field-weighted citation impact above the U.S. average.

More importantly, as the next section illustrates, different states—and not necessarily those with the highest research expenditures or outputs—have comparative advantages in different fields.

Although there is a positive correlation between a state's research output and its field-weighted citation impact (see **Figure 1.7**), many states have field-weighted citation impacts that are higher than one would otherwise predict from a linear regression. This includes both those with smaller absolute levels of output such as Rhode Island, New Hampshire and Vermont and those with larger absolute levels such as Minnesota and Washington.

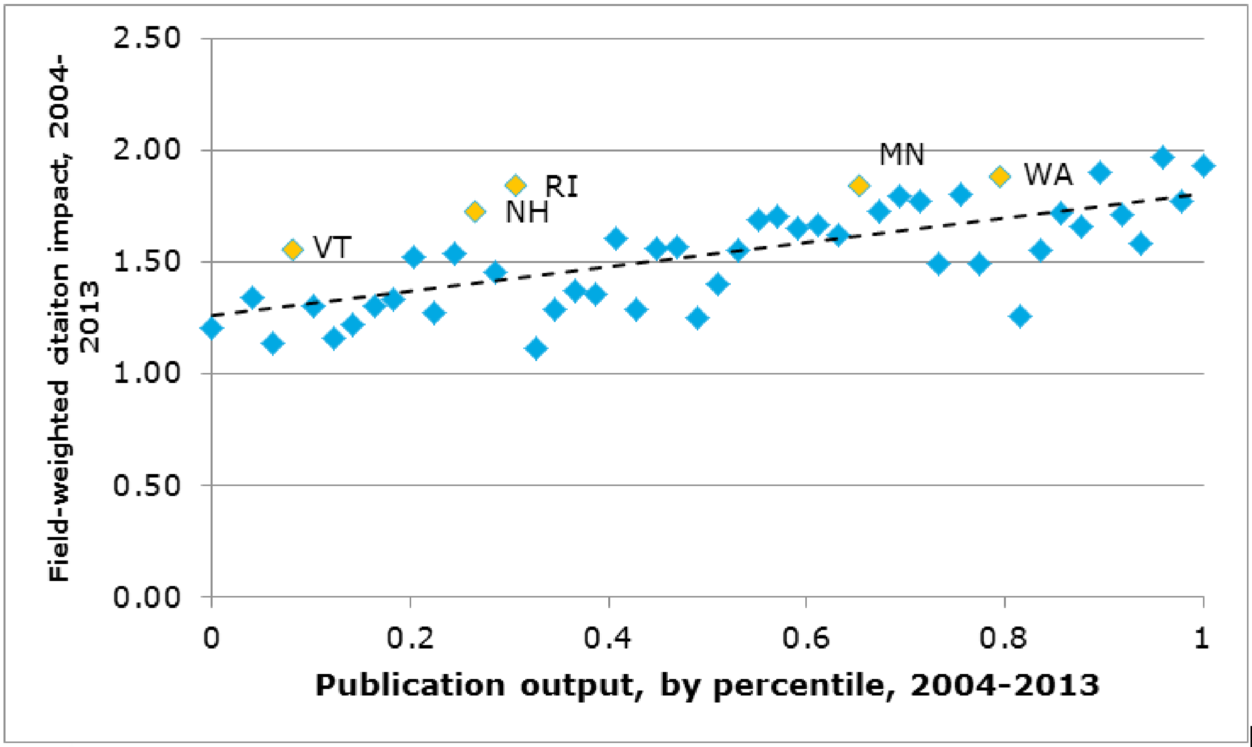


Figure 1.6—*Publication Output Versus Field-Weighted Citation Impact for U.S. States, 2004-2013. Source: Scopus® Normalized from 0 to 1 by percentile. Best-fit straight line added.*

CHAPTER TWO

RESEARCH FOCUS

The chapter analyzes the distribution of outputs by field, identifying states' comparative research strengths.

2.1 RESEARCH FOCUS

In order to identify the fields in which a state has a comparative advantage in research, this report looks at two indicators – relative volume and relative impact – along two dimensions. First, a state's performance in a given research field was compared to its own performance in other research fields. For example, how does Colorado's research in environmental science compare to its research in medicine? Second, a state's performance in a given research field was compared to other states' performances in the same research field. For instance, how is Colorado's research in environmental science relative to Maryland's research in environmental science?

Analogous to the location quotient for an industry, the relative volume of a state's research output in a field takes into account the total amount of research that a state produces. A value above 1.00 indicates that the state produces a higher proportion of its research output in that field than the national average and vice versa. For example, even though research in agricultural and biological sciences comprise only 8.4 percent of Alabama's total research output from 2004 to 2013, the state's relative volume in this field of 1.18 indicates that its output is 18 percent higher than the national average.

As mentioned in the previous section, the field-weighted citation impact provides a normalized measure of citation counts. Both the relative volume and the field-weighted citation impact of research output enable comparisons across different research fields.

For consistency, in all subsequent figures that use indicators across fields, those fields are arranged in a way such that those closely related to each other are placed next to each other on the axis or along the edge of the chart. Fields with an asterisk (*) or caret (^) indicate that the total output of the entity in that field was less 100 publications in 2004 or 2013, respectively. Due to the low number of publications in these fields, calculated measures are noisier, and we caution against making strong inferences about trends.

This section provides in-depth case studies of several states that have distinct comparative advantages in various research fields. It is not meant to be a comprehensive report of every state's research strengths, but rather an outline of the process by which one can use different indicators to identify and showcase such strengths.

National Measures

To understand and better appreciate in which fields certain states have a comparative advantage over others, it is important to have a sense of in which the fields in which the U.S. excels as a whole. As **Figure 2.1** shows, from 2004 to 2013, 28.7 percent of the country's total research output—or about 1.4 million publications—was in medicine. Engineering and biochemistry, genetics and molecular biology were the two fields with the next highest levels of research output at 17.4 percent and 15.4 percent respectively. Within medicine, the top 3 states in terms of relative volume were: Minnesota, Rhode Island and North Caroline. Within engineering, the top 3 states in terms of relative volume were: New Mexico, Idaho and Virginia. Within biochemistry, genetics and molecular biology, the top 3 states in terms of relative volume were: Maryland, North Carolina and Nebraska.

Relative to the total world output, the U.S. produced a particularly high relative volume of research in psychology (3.6 percent of total U.S. research output compared 2.2 percent of total world output) and neuroscience (3.8 percent of total US research output compared to 2.5 percent of total world output).

As **Figure 2.2** shows, the relative citation impact of the total U.S. research output tended to be well above the world average across all fields. The fields in which the U.S. achieved the highest field-weighted citation impacts are: computer science (1.74); materials science (1.62); economics, econometrics and finance (1.62); arts and humanities (1.61); and chemistry (1.61). For all of these areas, Massachusetts was among the top four states in terms of field-weighted citation impact.

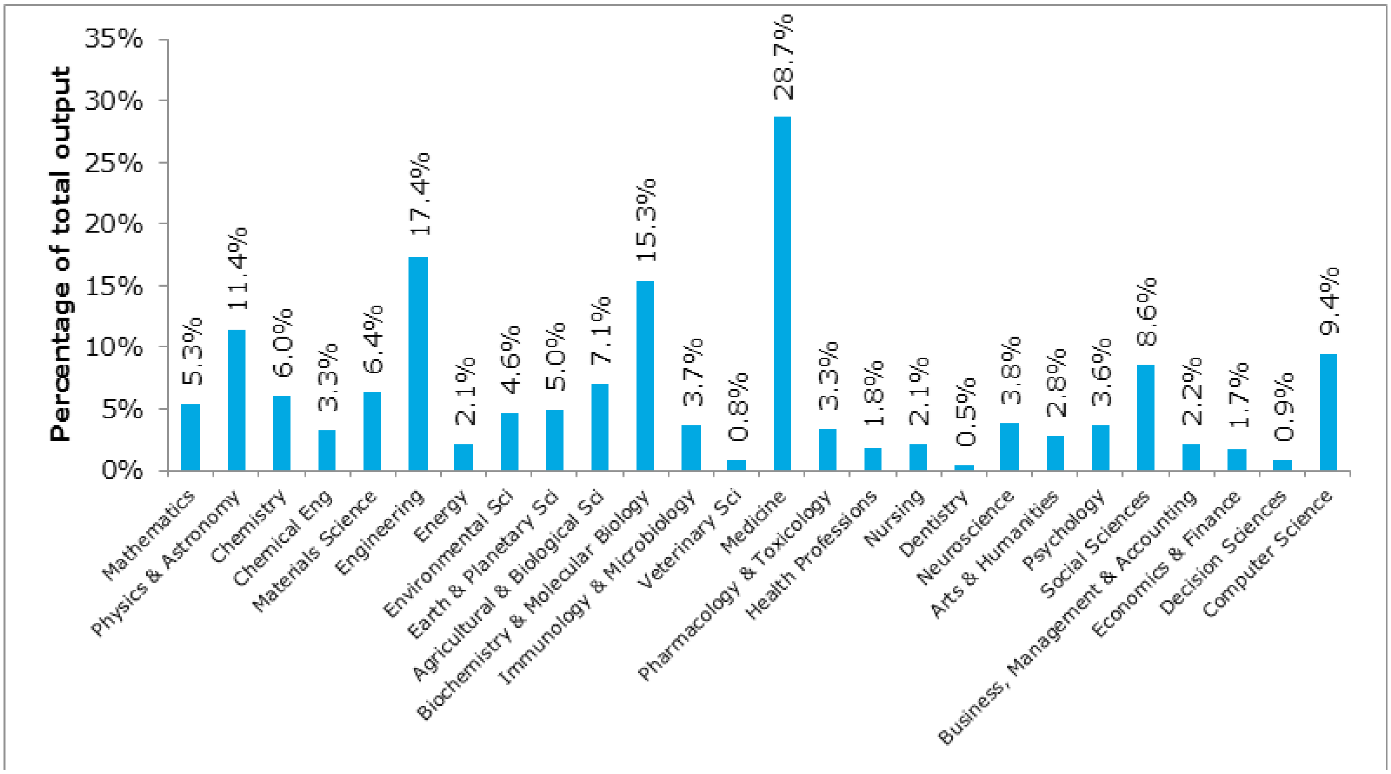


Figure 2.1—*U.S. Research Output by Fields as Percentage of Total U.S. Output, 2004-2013. Source: Scopus®*

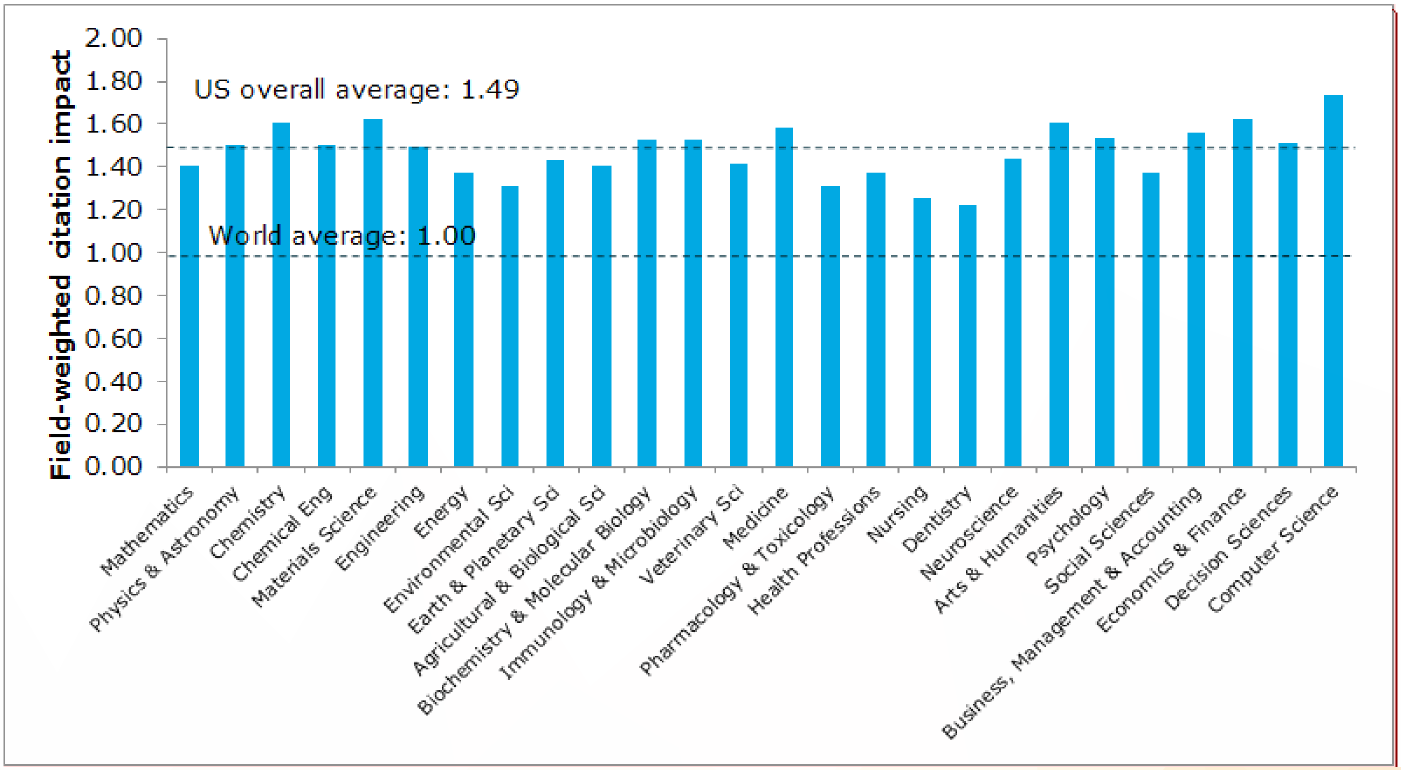


Figure 2.2—*Field-Weighted Citation Impact of U.S. Research Output, by Field, 2004-2013. Source: Scopus®*

2.2 CASE STUDIES

Case Study: North Carolina

When one talks about ground-breaking research in medicine, Maryland, Massachusetts, and Minnesota first come to mind due to their strong medical schools and hospital systems, including Johns Hopkins University and the National Institutes of Health, Harvard Medical School and its affiliated teaching hospitals and the Mayo Clinic. Based on its performance along multiple research metrics, North Carolina should also be included in that conversation.

North Carolina ranked third among all states (and first in the south) in terms of the relative volume of research in medicine, producing 35 percent more than the U.S. average. As **Figure 2.3** shows below, relative to the U.S. average, the distribution of North Carolina's research skews strongly toward the health sciences.

From 2004 to 2013, North Carolina's field-weighted citation impact in medicine was 2.15, fourth among all states and trailing only Maryland, Massachusetts and Georgia. As **Figure 2.4** shows, North Carolina's field-weighted citation impact in medicine was the highest across all other fields for the state, outpacing the field-weighted citation impact in fields that more closely align with major companies in North Carolina's Research Triangle region for economics and finance (1.95), biochemistry, genetics and molecular biology (1.76) and computer science (1.75).

In addition to marketing itself as a hub for finance, life sciences and technology, these indicators suggest that the state can also showcase its strengths in medicine.

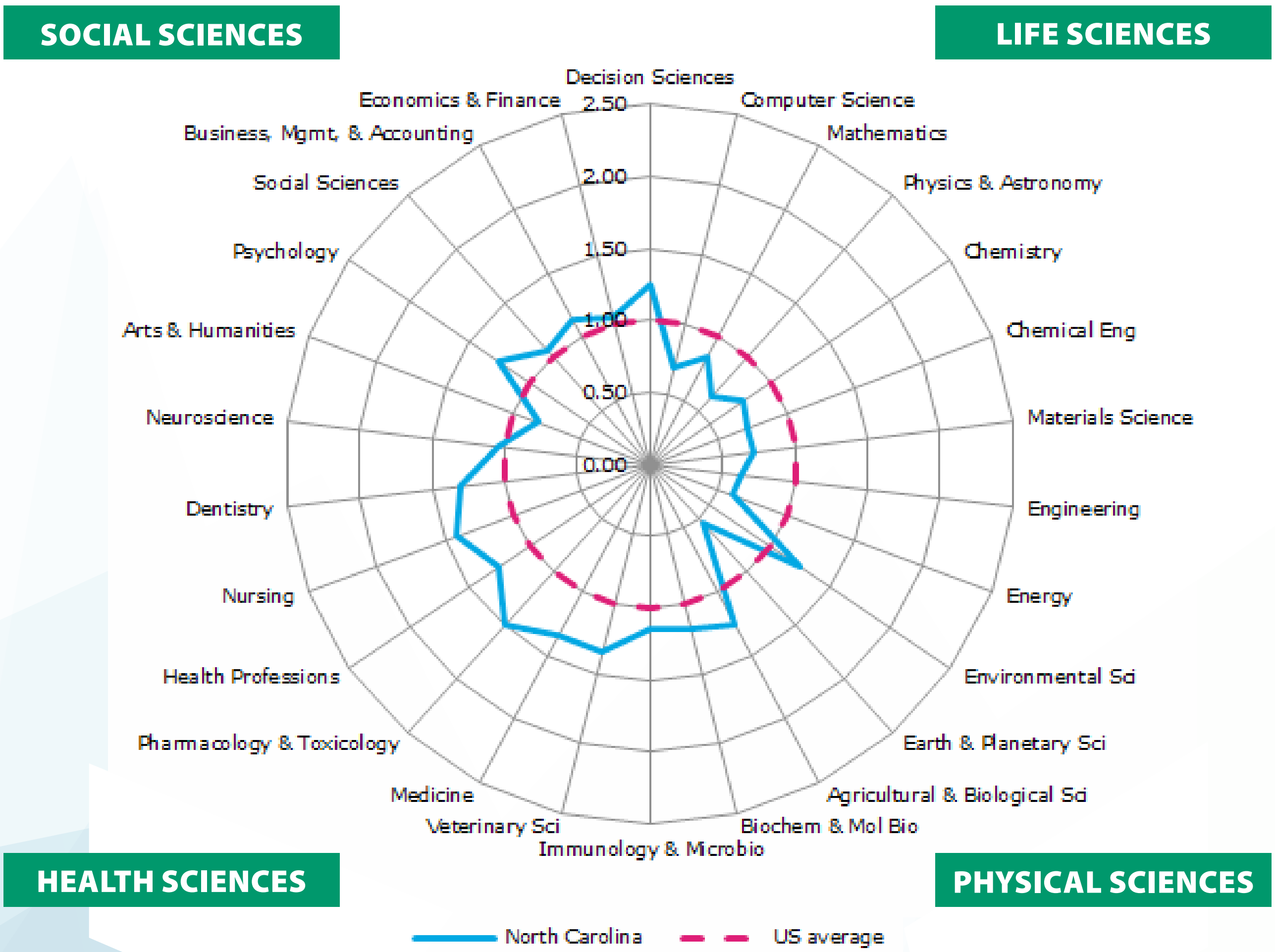


Figure 2.3— *Relative Volume of North Carolina's Research Output Across Fields, 2004-2013. Source: Scopus®*

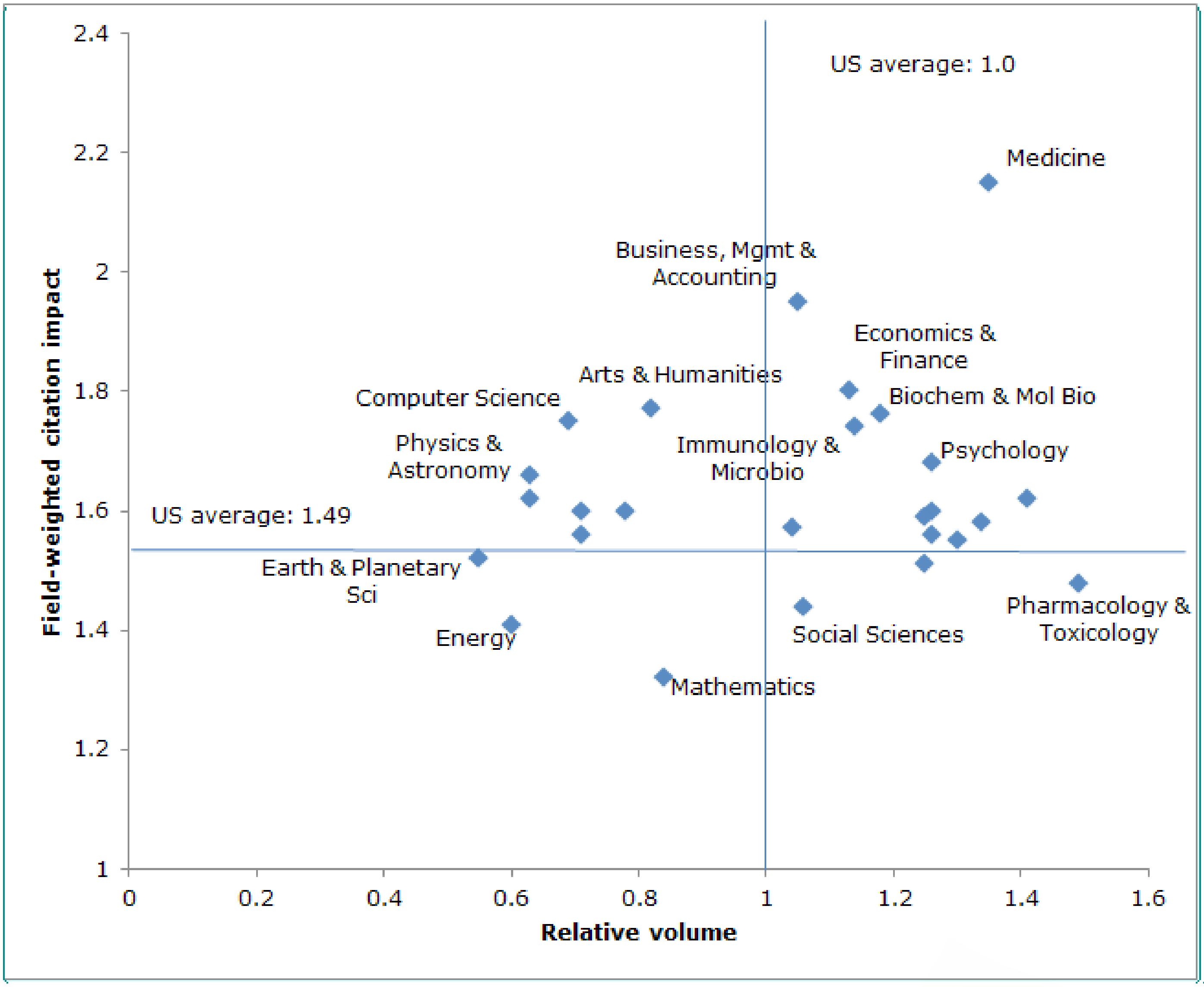


Figure 2.4—*Field-Weighted Citation Impact Versus Relative Volume of North Carolina's Research Output Across Fields, 2004-2013. Source: Scopus®*

Case Study: New York

When people think of tech meccas, they usually think of California and Silicon Valley, the greater Seattle area and Microsoft or Boston/Cambridge and Route 128. New York's "Silicon Alley" should increasingly be added to that conversation.

From 2004 to 2013, New York achieved a relative volume of 1.18 in computer science, fourth among all states. Compared to New York's research in other fields, its relative volume in computer science ranked second after only neuroscience (1.23). New York's 62,200 publications comprised 13.6 percent of all U.S. publications in computer science, second only to California, which had 96,996 publications and 21.2 percent of the U.S. publication share. Those 62,200 publications comprised 11.1 percent of all research output by New York.

At 1.89, the field-weighted citation impact of New York's research in computer science ranked 10th among all states and 4th among all research fields for New York.

All of these indicators suggest that New York has a distinct research advantage in computer science. As Bruce Katz and Jennifer Bradley detail in their book, "The Metropolitan Revolution," New York City has already identified computer science and related areas as a distinct strength to further build on. New York City's Applied Science Initiative is a good example of how city leaders identified research areas in which the city had a growing strength and then made additional investments in those areas.

Katz and Bradley note, "For its part, New York City already had a few tech clusters – some quite established, others just emerging. There was what one report called 'a better than average foundation of [information technology] and biotech companies that could easily be built upon' as well as a large and growing digital media sector. Since these and many of the city's other clusters, such as fashion, media, and health care, needed engineering and technical talent, the NYEDC [New York City Economic Development Corporation] concluded that the game changer they were looking for would be a new science and engineering graduate campus."

After a year-long competition in which universities around the world were invited to submit proposals to build campuses, the city actually moved forward with three ideas —a joint Cornell and Technion-Israel Institute of Technology graduate school on Roosevelt Island, a New York University campus called the Center for Urban Science and Progress, and Columbia University's new Institute of Data Sciences and Engineering.

Similar to **Figure 2.4**, **Figure 2.5** plots the relative volume versus the field-weighted citation impact of New York's research outputs across different fields. While New York achieves a field-weighted citation impact well above the world and U.S. national average in most research fields, those in the upper right quadrant of the graph—medicine; computer science; economics, econometrics and finance; and neuroscience —are fields in which the state has a critical mass of highly impactful research. They are the most promising areas for the state to further invest in and showcase its research strengths.

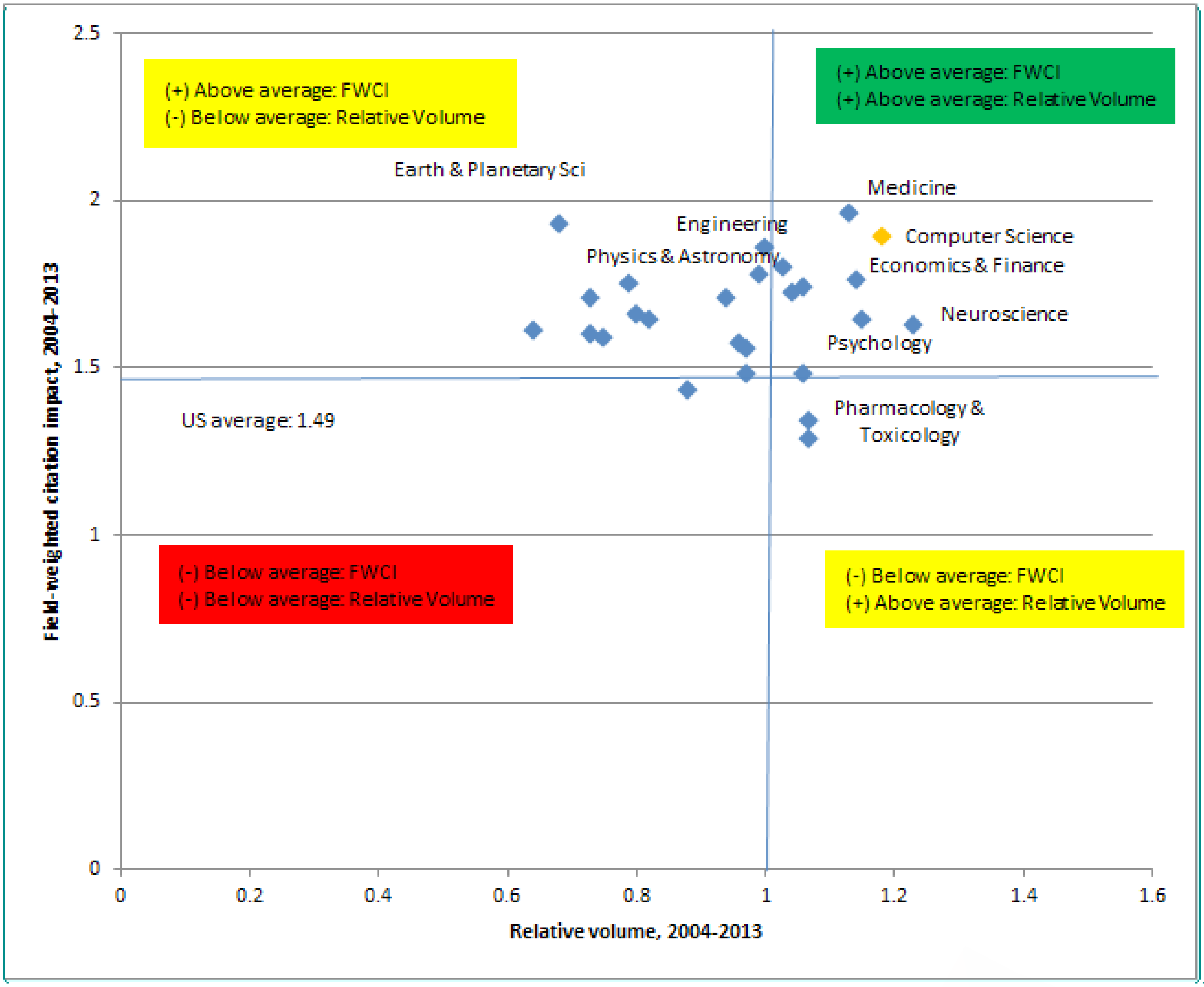


Figure 2.5— *Field-Weighted Citation Impact Versus Relative Volume of New York's Research Output Across Subject Areas, 2004-2013. Source: Scopus®*

Case Study: Arkansas

Research in business, management and accounting comprised 3.3 percent of all research output from Arkansas, but the state has a distinct comparative advantage in this field.

Buoyed by the Sam Walton College of Business at the University of Arkansas, the relative volume of Arkansas's research from 2004-2013 in this field was 1.50, the fourth highest among all fields for Arkansas. Only research in agricultural & biological sciences; veterinary sciences; and pharmacology, toxicology and pharmaceutics had a higher relative volume in Arkansas.

The state's relative volume in business, management and accounting ranked second among all states in the U.S.; only Oklahoma had a higher level at 1.65. In addition, Arkansas' annual research output in this area grew by 10.42 percent per year, from 50 publications in 2004 to 122 in 2013.

Arkansas' research in business, management and accounting was quite impactful, achieving a field-weighted citation impact of 2.04, the fourth highest level among all states in this field. Only Arizona (2.33), New Hampshire (2.29), and Massachusetts (2.17) achieved higher levels. Likewise, as Figure 2.6 shows, across other fields for Arkansas, only the state's research output in decision sciences (a closely-related field) attained a higher field-weighted citation impact.

Given the high location-relative concentration of farming, fishing and and forestry occupations in Arkansas, it is not surprising that research in agricultural and biological sciences comprised 17.2 percent of the state's total research output (and a relative volume of 2.42) or that research in veterinary sciences had a relative volume of 2.41, the highest across all fields for Arkansas. However, as **Figure 2.6** demonstrates, the field-weighted citation impact of Arkansas' research in agricultural and biological sciences was 1.08, slightly above the world average of 1.00 and below the national average of 1.41. Likewise, the field-weighted citation impact of the state's research in veterinary sciences is 0.83, below the world average.

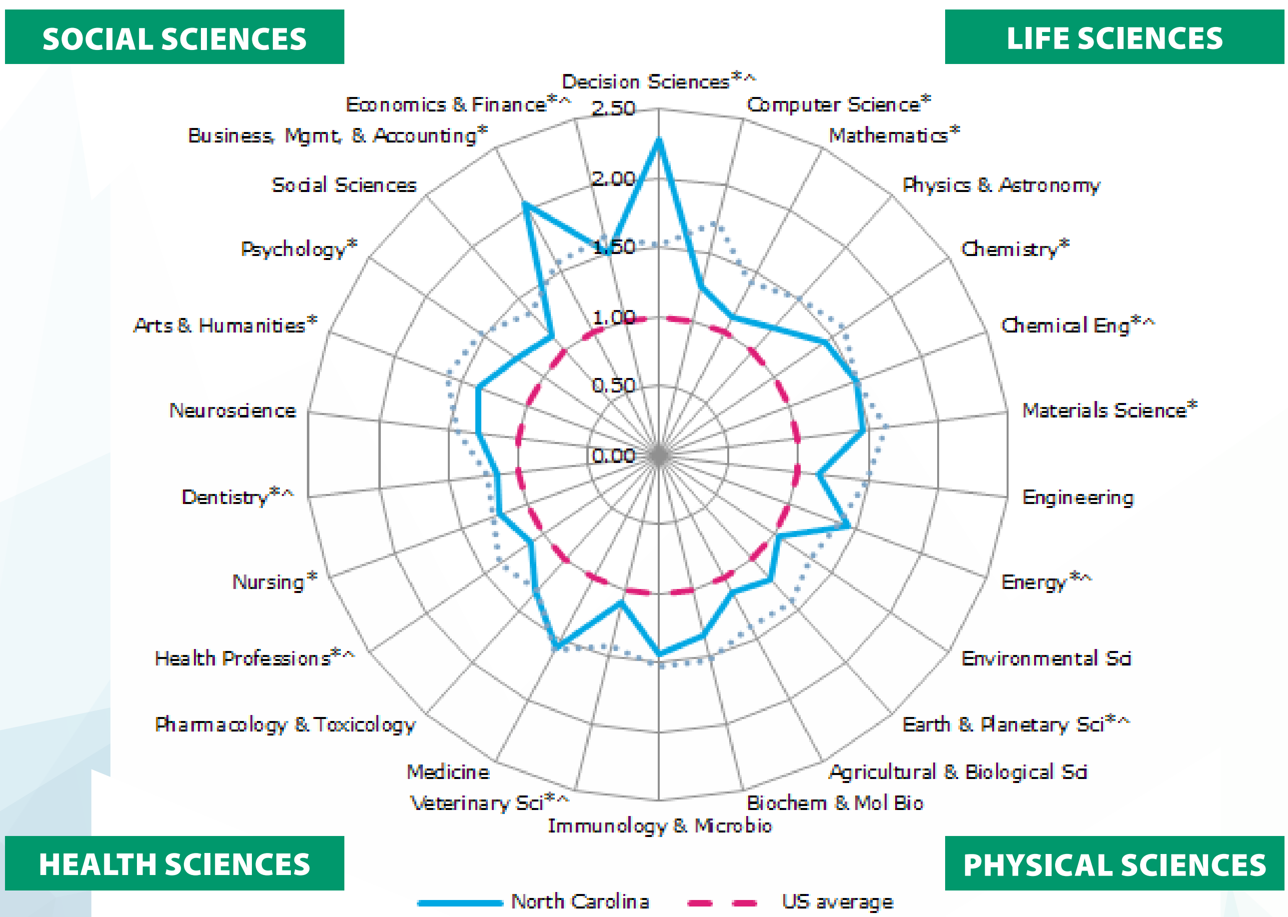


Figure 2.3— *Field-Weighted Citation Impact of Arkansas' Research Output Across Fields, 2004-2013. Source: Scopus®*

CHAPTER THREE

RESEARCH & DEVELOPMENT INPUTS

This chapter looks at three indicators on the inputs to the larger research and development process: expenditures, research space and number of faculty. By normalizing our previous measures on research output by these input indicators, this chapter assess how effectively different states make use of the resources they have available.

3.1 RESEARCH AND DEVELOPMENT EXPENDITURES

Research and development expenditures play important roles in the larger context of states' research ecosystems.

According to the National Science Foundation's Higher Education Research and Development Survey, in 2013 U.S. higher education institutions spent $67 billion on research and development. When adjusted for inflation and accounting for the American Recovery and Reinvestment Act of 2009, increases in total research and development expenditures have slowed in the most recent years, and the percentage of expenditures from federal funding agencies has actually declined.

Moreover, as the National Institutes of Health's Data Book details, the average success rate for National Institutes of Health grants continues to fall. The combination of these pressures – less overall research and development money to distribute and more intense competition for that money – has forced universities and states to a) be more strategic about which research areas they invest in, b) collaborate and pool together funds to enable larger projects, and c) showcase their research strengths to improve their applications and chances of winning those grants.

In the face of these pressures, some states have been more successful than others when maintaining and even growing their total research and development expenditures.

From 2004-2013, the top states in terms of total research and development expenditures were: California ($87.6 billion), New York ($52.5 billion), Texas ($46.6 billion), Maryland ($34.2 billion), Pennsylvania ($33.3 billion) and Massachusetts ($40.0 billion). These six states accounted for 42.8 percent of all U.S. higher education research and development expenditures over this period.

The top five states in terms of growth in research and development expenditures were: Rhode Island (6.90 percent), South Dakota (5.42 percent), North Carolina (4.53 percent), Washington (3.71 percent) and Delaware (3.61 percent)

As Figure 3.1 shows, North Carolina and Massachusetts both secured high levels of total research and development expenditures and also grew those levels significantly.

Given these differences in total research expenditures, which states tend to produce the highest number of publications relative to their level of Research and development funding? As a benchmark, U.S. universities as a whole produced 6.5 publications per million $USD of research and development (in 2013 dollars) from 2004-2013. Massachusetts universities produced 12.7 publications per million $USD of research and development funding. The rest of the top five states were: Delaware (11.4 publications), Michigan (10.5 publications), Wyoming (10.3 publications) and Connecticut (10.3 publications).

What is most surprising about this list is how different these states are in terms of their absolute research and development expenditures and research output levels, suggesting that there are multiple paths to maximizing research efficiency.

For example, Massachusetts and Michigan were among the top 10 states in terms of total research and development expenditures and total output. They exemplify a model in which states both attract a high level of research and development and produce a high quantity of research.

The distribution of the sources of a state's research and development funding is another important consideration, affecting how exposed or insulated that state's research ecosystem is to federal or state funding pressures.

- For the U.S. in 2013, about 58.9 percent of total research and development expenditures came from federal funding agencies.
- The top five states in terms of federal funding as a percentage of their total research and development expenditures were: Wyoming (82.4 percent), Maryland (79.0 percent), Colorado (74.5 percent), New Hampshire (73.8 percent) and Vermont (73.6 percent).
- Arkansas (39.1 percent) and North Dakota (38.8 percent) had the lowest relative levels of federal funding. On the other hand, Arkansas and North Dakota ranked second and first respectively in terms of the relative levels of state/local funding as a percentage of their total research and development expenditures (21.3 percent and 25.4 percent).
- The states with the highest percentages of their total research and development originating from neither federal nor state/local funding sources were Rhode Island (53.2 percent) and Nebraska (52.8 percent). These states led all others in terms of relative institutional contributions to research and development funding (44.7 percent and 42.1 percent, respectively).

Although funding from business and industry comprises only 5.2 percent of total research and development expenditures at U.S. universities, they play an increasingly important role, especially as funding from federal and state/local sources become more competitive. As Figure 3.2 shows, across all states, North Carolina attained the highest relative level of research and development funding from business at 9.8 percent.

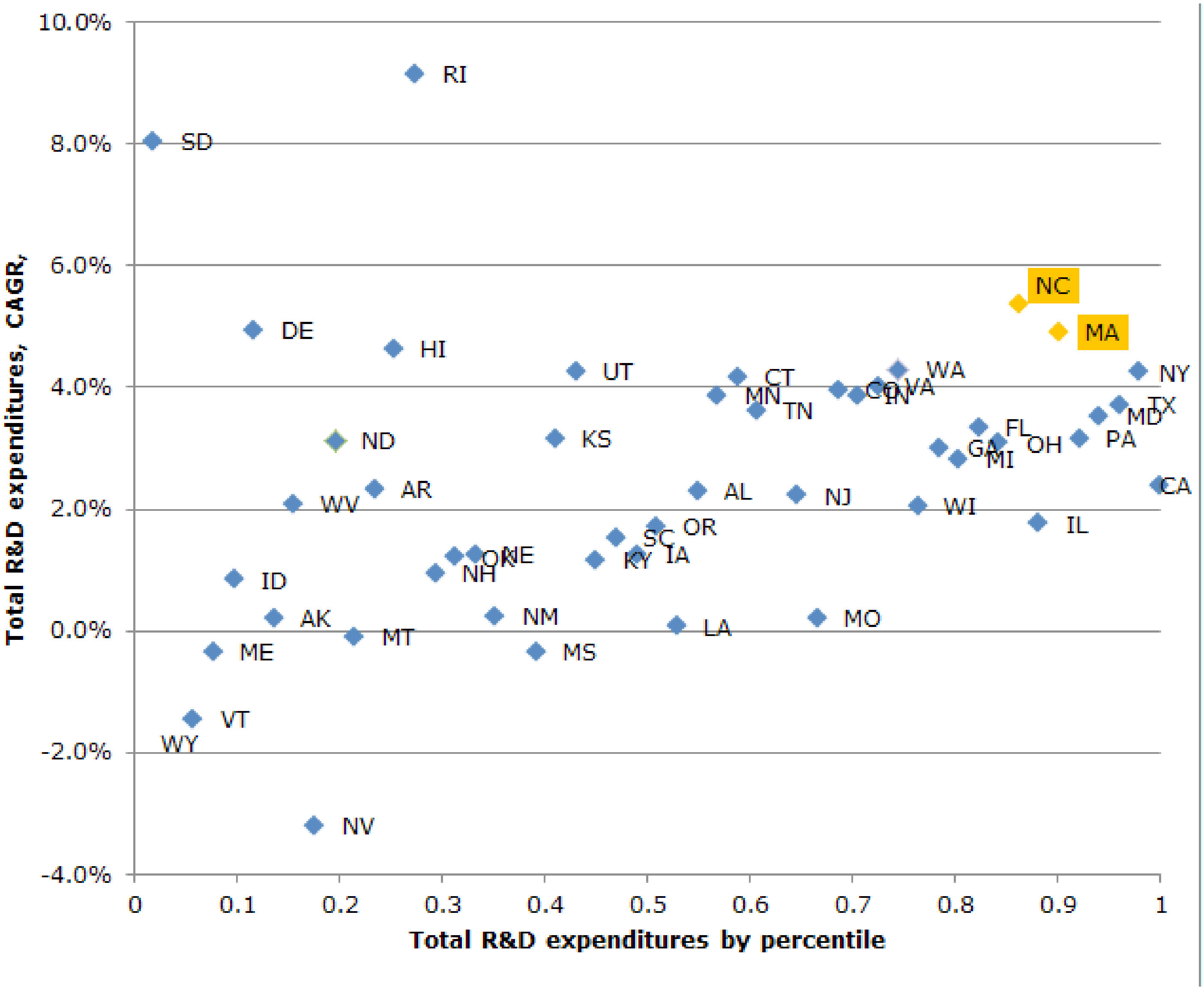


Figure 3.1—*Compound Annual Growth Rate, Total Research and Development Expenditures Versus Total Research and Development Expenditures by Percentile for U.S. States, 2004-2013.*
Note: Research and development expenditures calculated and normalized to 2013 dollars. Source: National Science Foundation, Higher Education Research and Development Survey

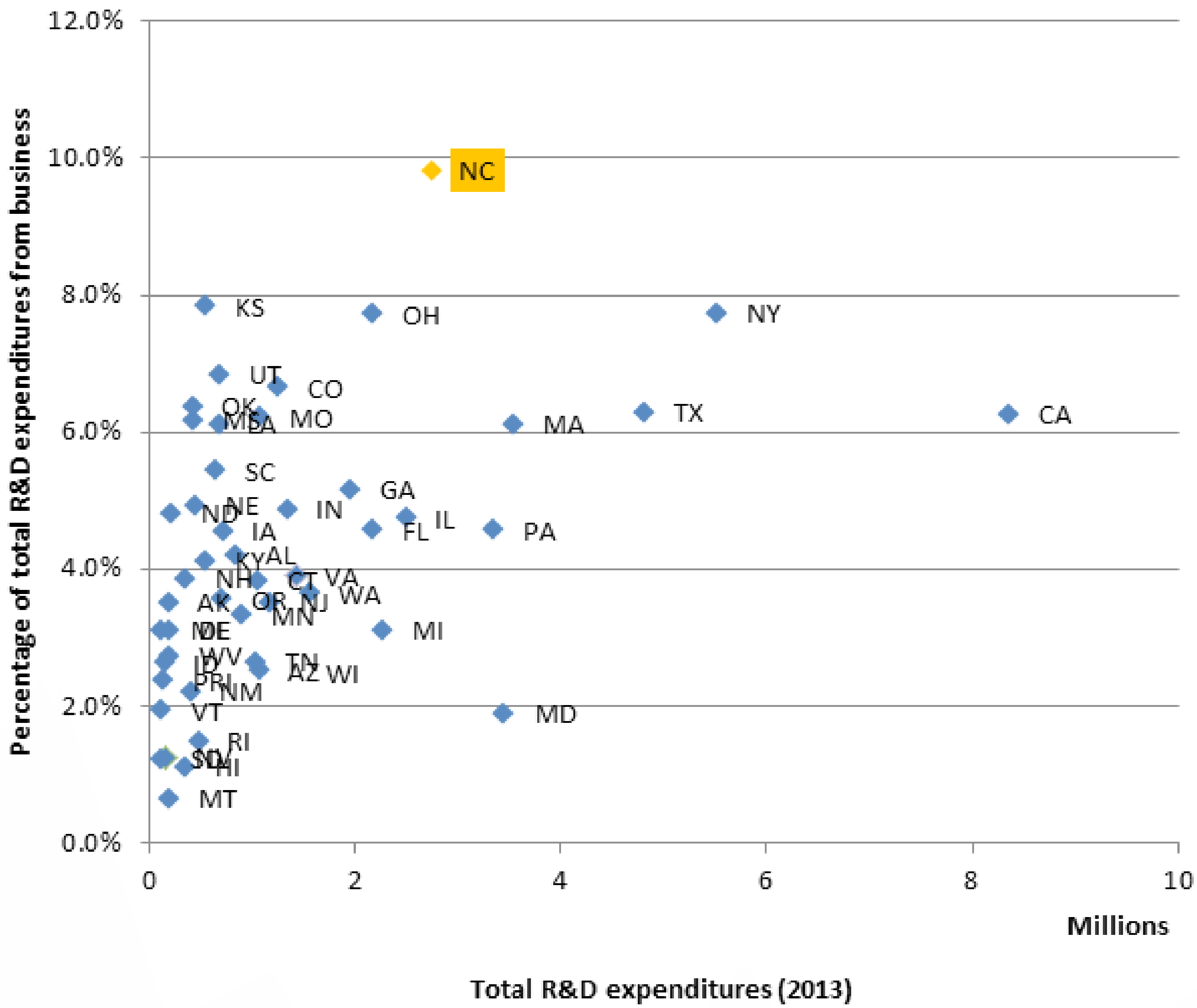


Figure 3.2— *Percentage of Total Research and Development Expenditures from Business Versus Total Research and Development Expenditures Across All States, 2013. Source: NSF Higher Education Research and Development Survey*

3.2 RESEARCH SPACE AND EFFICIENCY

Another important input for research is space. We use data from the National Science Foundation's 2011 Survey of Science and Engineering Research Facilities to calculate how many net assignable square feet of research space is available across different states. By dividing a state's research output by its net assignable square feet, we derive another measure of how efficient that state is in terms of producing research.

Across the U.S., academic institutions produced on average 0.8 publications per 1,000 net assignable square feet.

Rhode Island was the top-ranked state; in 2011, its academic institutions produced 4.7 publications per 1,000 net assignable square feet.

Massachusetts and Vermont were second and third, with 4.6 and 4.0 publications, respectively. When this analysis is restricted to just medical publications from academic institutions per 1,000 net assignable square feet of medical school research space, Massachusetts and Rhode Island led all states with 9.9 and 7.4 publications, respectively.

Figure 3.3 plots publications from academic institutions versus net assignable square feet; states with high levels of publications per 1,000 net assignable square feet are highlighted.

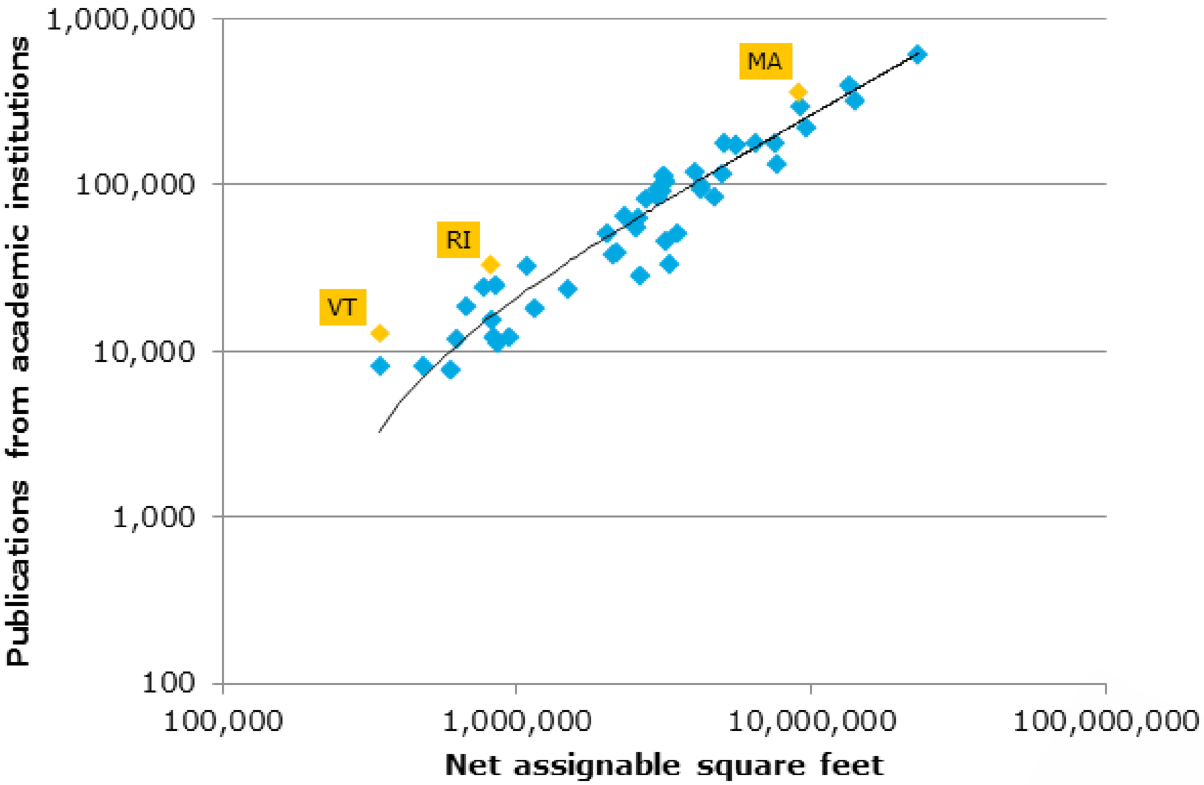


Figure 3.3— *Publications from Academic Institutions versus Net Assignable Square Feet for Research across all States, 2011. Source: Scopus® and NSF Survey of Science and Engineering Research Facilities*
Note: for ease of viewing, the x- and y-axes are expressed in logarithmic instead of linear terms.

3.3 HUMAN CAPITAL: FACULTY

The total number of faculty at states' universities is another important aspect of a state's research inputs. This section draws on data from the Integrated Postsecondary Education Data System Human Resources Survey.

In terms of academic faculty per 1,000 residents, the top five states in 2013 were: Rhode Island (3.40), Vermont (3.11), Massachusetts (3.09), North Dakota (2.98), and Iowa (2.61).

In 2013, across the entire U.S., academic faculty produced 0.77 publications on average.

In terms of publications from academic institutions per academic faculty per year, the top five states in 2013 were: Massachusetts (2.12 publications per faculty), Maryland (1.97), Connecticut (1.49), Washington (1.39), and California (1.32).

West Virginia stood out for having both a high level of publications per faculty and a strong growth rate in the number of publications per faculty over the past ten years. In 2004, its faculty produced 0.93 publications on average, while in 2013, its faculty produced 1.30 publications on average.

CHAPTER FOUR

KNOWLEDGE TRANSFER

This chapter looks at several measures of knowledge transfer between academia and other sectors. Such indicators can provide greater insights into the extent to which a state's research contributes to innovation. This chapter also looks at the research collaboration networks among states, highlighting which states collaborate the most and in what areas.

4.1 RESEARCH BY SECTOR

Although universities produce the majority of research output, the larger research ecosystem spans government labs, corporations, hospitals, not-for-profit think-tanks, and other institutions. It is important to understand the distribution of a state's research output across different sectors. When researchers and knowledge workers can easily collaborate with and move across different sectors, all stakeholders benefit from the exchange of ideas and talent. In order for states to maximally benefit, there needs to be a critical mass of research occurring across academia, government, and business and a robust triple-helix ecosystem spanning those sectors that enables such cross-fertilization.

Research suggests that proximity plays a key role in fostering university-industry collaboration and exchange. States with low levels of research outside the academic sector—particularly the corporate sector —have to work harder to develop academic-corporate collaborations and other connections that facilitate knowledge transfer. States with high levels of research output outside the academic sector have a head-start, but they still need to make sure the different sectors are connected to one another.

About 8.5 percent of all published U.S. research is conducted by corporate institutions. **Figure 4.1** shows a heat map of the relative percentage of each state's total output from the corporate sector.

From 2004 to 2013, 20.8 percent of New Jersey's total output (33,504 publications) was from corporate researchers, the highest among all states in the country and more than twice the rate of the entire country. The states with the next highest relative levels of corporate output were: Delaware (13.9 percent), California (13.2 percent) and New York (10.9 percent).

Figure 4.2 presents the fields in which New Jersey corporations produced the highest number of publications. The orange or top bar denotes the relative percentage of New Jersey's corporate publications in that field. The olive or middle bar denotes the relative percentage of all New Jersey publications, regardless of sector, in that field. The blue or bottom bar denotes the relative percentage of all U.S. corporate publications, not just those from corporations based in New Jersey, in that field. When the orange or top bar is longer than the olive or middle bar it means that New Jersey's corporate sector produced a higher relative volume in that field compared to the other sectors (academic, government, other). Likewise, when the orange or top bar is longer than the blue or bottom bar, that means New Jersey's corporate sector produced a higher relative volume in that field compared to all other corporations in the U.S. The fields in which New Jersey corporations have a strong comparative research advantage are those in which the orange or top bar is much longer than the other two bars.

Figure 4.1 — *Percentage of Total State Output from Corporate Institutions, 2004-13. Source: Scopus®*

In addition, 8,830 or 26.4 percent of New Jersey's corporate publications were in the field of medicine, the highest among all fields. More significantly, as Figure 4.2 shows, research in pharmacology, toxicology and pharmaceutics comprised 15.2 percent of New Jersey corporate publications, twice the rate of the state's total research output (6.0 percent) and that of the U.S. total corporate research output (7.4 percent). While it is generally known that there is a high concentration of pharmaceutical companies—and particularly their research and development operations—in New Jersey, these measures suggest that they play an outsized role in driving New Jersey's larger research ecosystem, both vis-à-vis its universities and its research corporations in other industries.

For some other states, government labs and agencies constitute a large proportion their total research output and 11.4 percent of all U.S. research output.

As **Figure 4.3** shows, more than 50 percent of New Mexico's total research output originated at government labs – in this case, Los Alamos and Sandia National Laboratories. Likewise, 45.7 percent of Maryland's total research output, which itself comprises 28.4 percent of all government research output in the U.S., comes from government institutions such as the National Institutes of Health. No other state comes close in terms of the relative skew of research output by the government sector, though Idaho (25.1 percent), West Virginia (17.5 percent) and Virginia (16.7 percent) are also home to government labs with large relative research outputs.

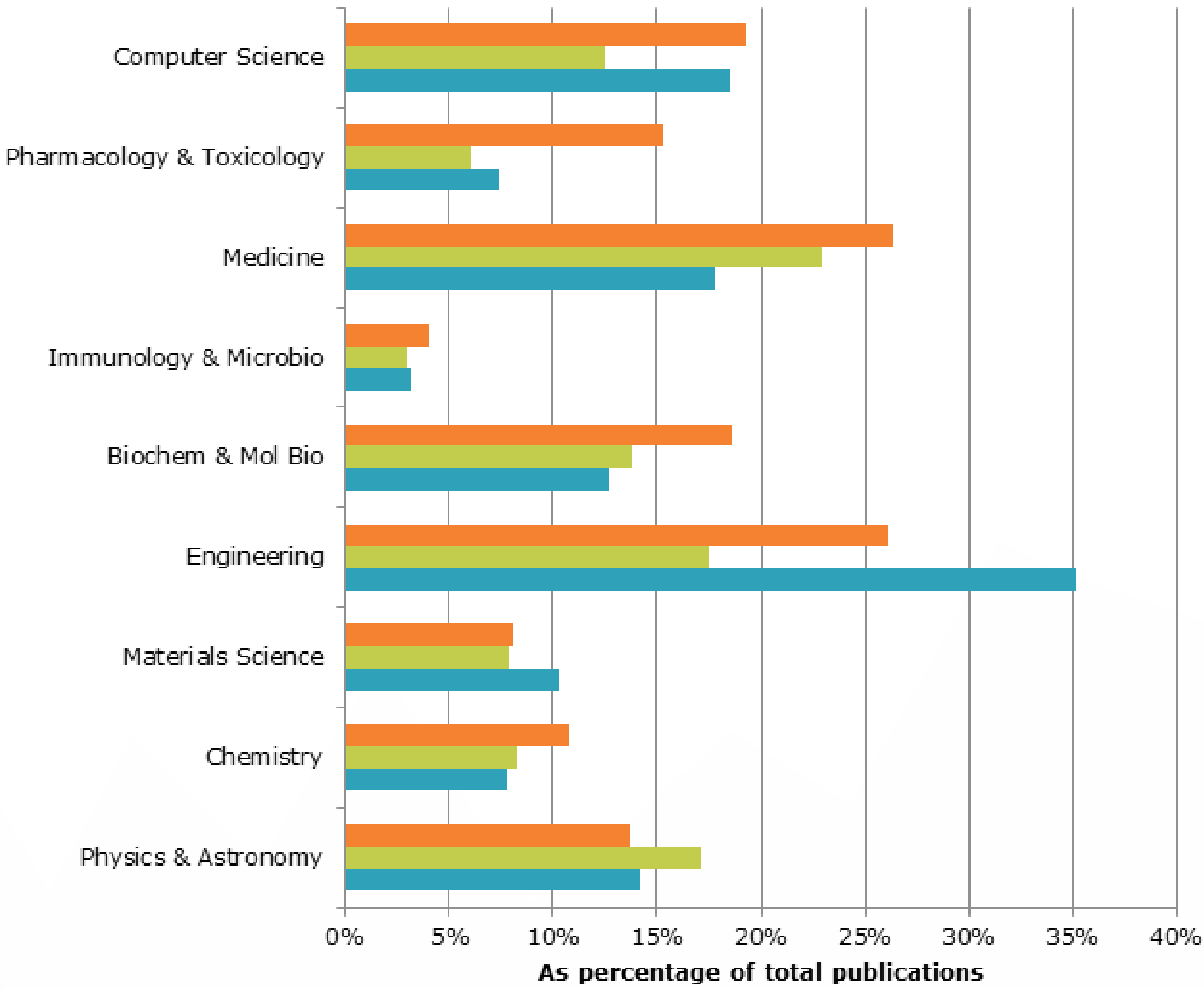


Figure 4.2— *Distribution of New Jersey's Corporate Sector Output by Field, 2004-13. Source: Scopus®*

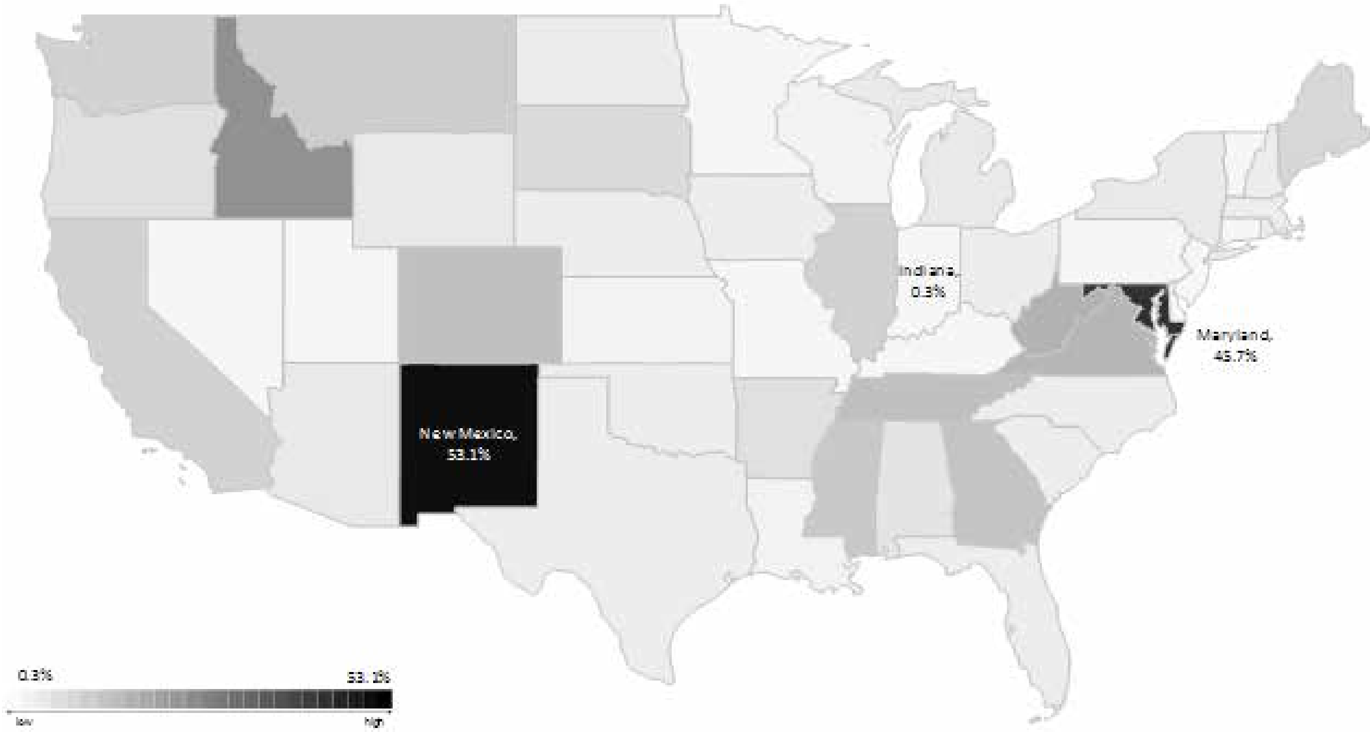


Figure 4.3— *Percentage of Total State Output from Government Institutions, 2004-13. Source: Scopus®*

4.2 RESEARCH USAGE

Research on publication downloads and other usage metrics is an emerging topic within the bibliometric community, and it is increasingly proposed as a proxy for research awareness. Whereas citation measures take time to accrue, usage metrics have the potential to provide immediate insights into developing research areas and trends. The number of publication downloads from a particular field, institution or country may be interpreted as representing the interest in and use of research.

This report uses full text article download data from Elsevier's ScienceDirect database, which provides approximately 20 percent of the world's published journal articles, to offer another perspective on how an institution's research is being used around the world. The number of publication downloads from a particular field, institution or country may be interpreted as representing the interest in and use of research.

Similar to citations, downloads tend to go down in more recent years because recent publications have not had time to accumulate enough downloads. So, we first normalize the number of downloads an entity receives to its publications by the total number of downloads of all U.S. publications in a given year – this is called an entity's national download share. Then, since entities that produce more research output in general will have higher counts of downloads of that output, we compare the entity's national download share to its corresponding national publication share (the number of publications an entity produces divided by the number of all U.S. publications in a given year).

As **Figure 4.4** shows, for most states, there is a strong correlation between their national download share and their national publication share, indicating that their share of all downloads globally is similar to their share of all publications globally. What about those that deviate from the trend?

Tennessee and Michigan are below the trend line. This suggests that usage of those states' research outputs was below what would otherwise be expected given the size of those states' outputs.

Across all of Michigan's research outputs, the national download to publication share ratio was highest for the social sciences (1.04) and physics and astronomy (1.03). On the other hand, Michigan's research in earth and planetary sciences had one of the lowest ratios (0.64). Yet, the field-weighted citation index of Michigan's research in earth and planetary sciences over the same period was 1.66, 16 percent above the U.S. average. This suggests that the state's research in this field is not getting as much attention as it deserves.

On the other hand, Maryland and Massachusetts are above the trend line (the ratios of their national download share to publication share were 1.21 and 1.15, respectively). This means that their publications were downloaded more often than could be expected based on the volume of publications.

Across all of Maryland's research outputs, the national download to publication share ratio was highest for veterinary sciences (1.81). Downloads of research in veterinary sciences comprised 13.4 percent of all downloads of Maryland's research. Indicators of citation impact also reflected the strength of Maryland's research in veterinary sciences; it achieved a field-weighted citation index of 1.93 from 2004-2013, ranked fourth among all states.

One potential measure of the larger impact of research is how widely that research is read. For example:

- A total of 68.4 percent of U.S. research published in 2004–2013 was downloaded by readers from outside the U.S.
- Research from Mississippi and Nevada had the highest rates of international readership. 73.5 percent and 73.3 percent of downloads of those states' research output were by readers from outside the U.S.
- In particular, Mississippi and Nevada's research in biochemistry, genetics and molecular biology had higher rates of international readership (74.2 percent and 70.3 percent) than the U.S. average for that field (64.1 percent).

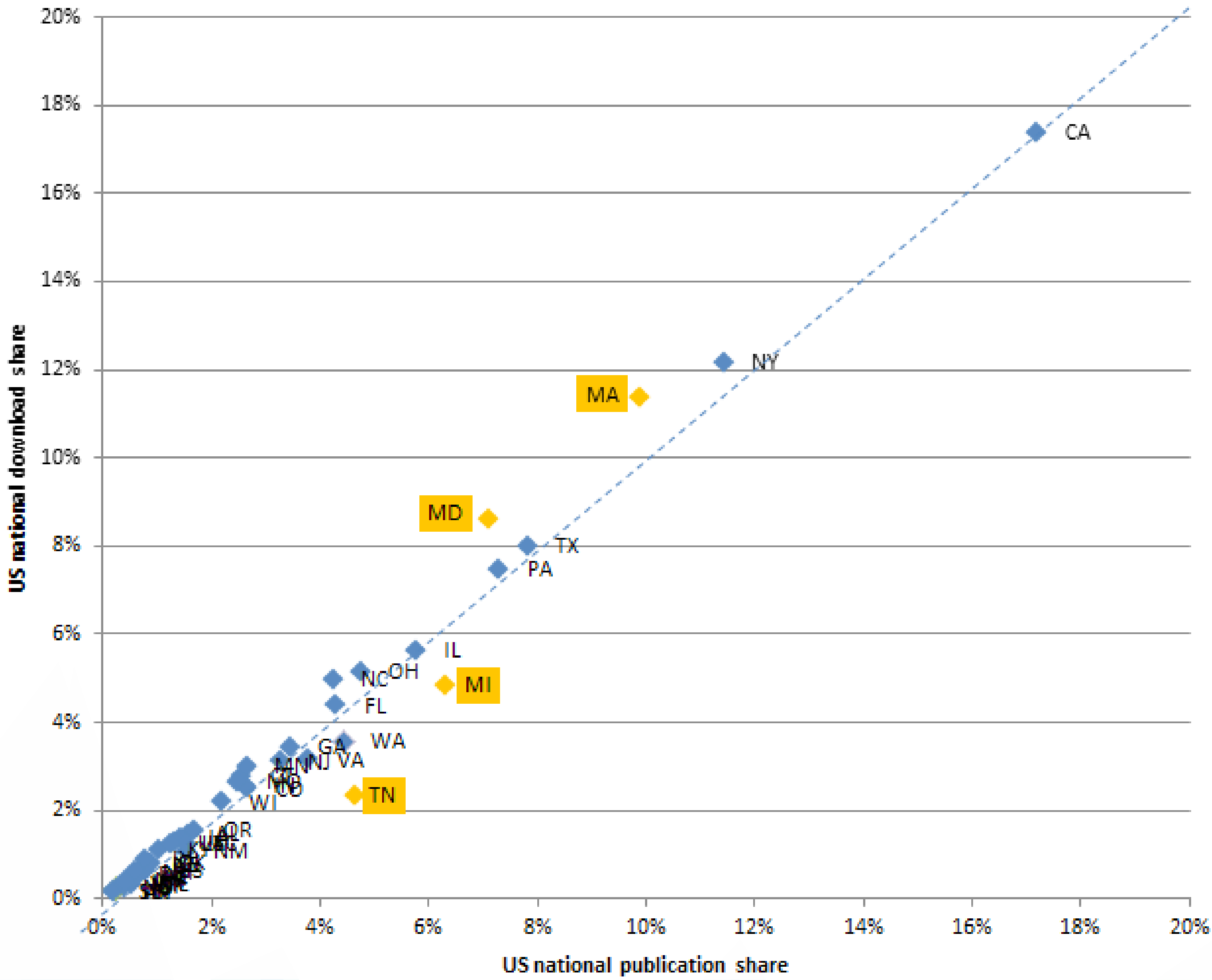


Figure 4.4— *U.S. National Publication Share versus U.S. National Download Share across all States, 2004-13. Source: ScienceDirect® usage metrics and Scopus®*
Note: Trend line indicates publication-to-download share ratio of 1.0.

4.3 PATENTS AND PATENT CITATIONS

There is increasing interest in creating more and better indicators of the commercialization of research to assess how results of research are transferred from the academic sector to the corporate or government sectors. Academic patent citations provide one way of understanding corporate usage of academic research, and they can be used as a proxy for measuring how much academic research contributes to innovation. These are defined as formal citations of academic publications in industry patents.

Past studies suggest that academic researchers and industry interact in a multitude of channels beyond academic co-authorship, and counting patent citations is one of several lenses for understanding the linkage between academic research and intellectual property.

From 2004-to 2013, 959,172 patents were granted to U.S. inventors. California, with 25.1 percent of all patents granted to U.S. inventors, had a national patent share more than three times the level of the next closest state, Texas (7.1 percent). The rest of the top five states in terms of patents granted were: New York (6.4 percent), Massachusetts (4.5 percent), and Washington (4.2 percent).

While California and especially Silicon Valley generates a high level of innovation, these statistics otherwise obscure how much the research produced by other states contributes to patents.

In terms of patent citation share relative to U.S. publication share, as **Figure 4.5** shows, research from across the country —particularly in the Northeast—are cited in patents at rates higher than their underlying publication shares. The top states in terms of this normalized patent citation indicator were: Massachusetts (1.69), Maryland (1.54), Maine (1.45), Michigan (1.40) and Washington (1.38). This means that these states' research outputs had a much greater impact on innovation than their research volume would otherwise suggest.

New York's research in computer science from 2004-2012 was cited in 1,026 patents, comprising 23.5 percent of all patent citations in that field. It had a patent citation share to national publication share ratio of 1.73, the highest among all states. This suggests that the state's research in computer science has a much greater impact on innovation than its national publication volume would suggest.

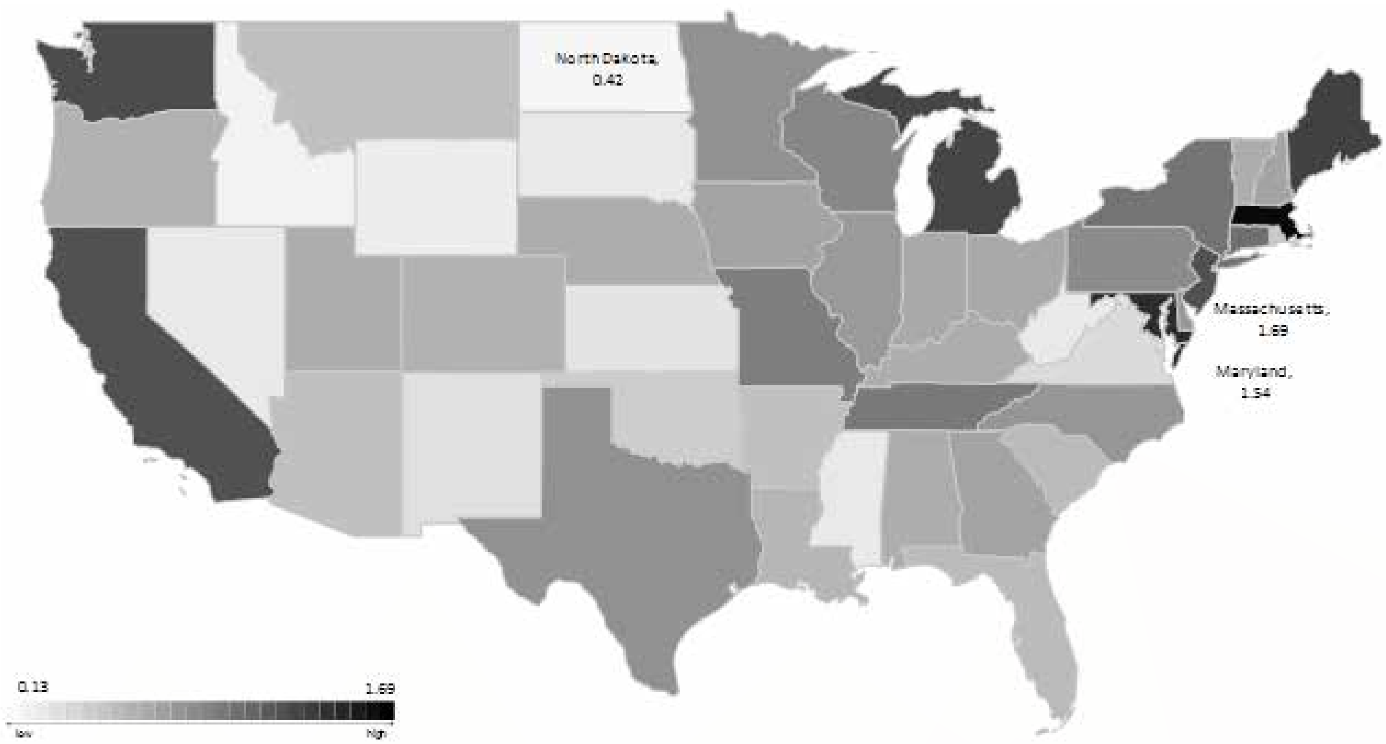


Figure 4.5—*Ratio of National Patent Citation Share to National Publication Share across all States, 2004-2012.*
Source: LexisNexis® patent database and Scopus®

4.4 INTERSTATE COLLABORATIONS

Studies have shown that teams produce more creative and impactful research than single authors do. From 2004-2013, single-authored publications in the U.S. achieved a field-weighted citation impact of 0.80, below the world average field-weighted citation impact of 1.00 and well below the U.S. overall average of 1.49. The percentage of the United States' total research publications that were single-authored declined from 17.5 percent in 2004 to 12.4 percent in 2013, which is consistent with the global trend.

This section focuses on a particular type of team collaborations—those that span multiple U.S. states—which measures interstate research collaborations through co-authorship. For example, when a publication has one author from the University of Kentucky and another author from the University of Kansas, it is consider to be a collaboration between Kentucky and Kansas.

States with large research outputs tend to have more collaborations than other states, which is addressed using a normalized measure of collaboration—called Salton's measure of collaboration strength— that takes into account the size of each state's total research output. The values of Salton's measure can vary between 0 (where there are no co-authored publication between a given pair of states) and 1 (in which every publication of each state was a collaboration with the other state). In practice, the range typically seen at state level is between 0.000 and 0.080 for most pairings of significant size).

Even when the size of states' research outputs is taken into account, the most prolific pairs of states tended to be those with the highest research outputs overall. For example:

- California and Massachusetts show strong ties. There were 53,148 co-authored publications between researchers from California and Massachusetts, with the highest Salton's measure of 0.0833 among all pairs of U.S. states. More than 1 in 10 publications by Massachusetts' researchers were co-authored with researchers from California.
- A total of 35.2 percent of the collaborations between California and Massachusetts were in medicine. This is higher than the overall percentage of California's research output in medicine (25.7 percent) but close to the overall percentage of Massachusetts' research in medicine (34.1 percent).
- New York has strong research connections with all of its neighbors. State to state research collaboration partnerships between New York and one of its neighbors account for three of the top 10 such partnerships in the U.S.
- From 2004-2013, researchers from Massachusetts and New York collaborated on 37,972 publications, of which 43 percent were in medicine.
- After medicine, New York and New Jersey collaborated the most in physics and astronomy. Collaborations in that field comprised 19.4 percent of all New York to New Jersey co-authored papers, even though only 11.3 percent of New York's total research output was in physics and astronomy.

Rank	State 1	State 2	Number of co-authored publications	Co-authored publications as % of state 1's total output	Co-authored publications as % of state 2's total output	Salton's Measure
1	CA	MA	53,148	6.3%	11.0%	0.0833
2	CA	NY	56,736	6.7%	10.1%	0.0826
3	CA	MD	42,985	5.1%	12.4%	0.0795
4	MA	NY	37,972	7.8%	6.8%	0.0729
5	MA	MD	29,123	6.0%	8.4%	0.0710
6	NJ	NY	20,683	12.9%	3.7%	0.0689
7	MD	NY	30,410	8.7%	5.4%	0.0689
8	MD	PA	23,005	6.6%	6.5%	0.0654
9	CA	TX	36,577	4.3%	9.5%	0.0644
10	NY	PA	28,270	5.0%	7.9%	0.0633

Table 4.1—*Research Collaboration Partnerships between U.S. States, 2004-2013. Pairings are sorted by Salton's measure of collaboration strength. Source: Scopus®*

Case Study: Nevada's Interstate Research Collaborations

» Between 2004 and 2013, Nevada researchers collaborated the most with researchers from California in both an absolute and relative sense.

» The highest proportions of those Nevada-California collaborations were in medicine (23.1 percent) and physics and astronomy (19.0 percent). These rates were much higher than Nevada's baseline level of research in these areas, 18.1 percent and 12.7 percent, respectively).

» After California, the state which Nevada researchers collaborated with the most was Arizona.

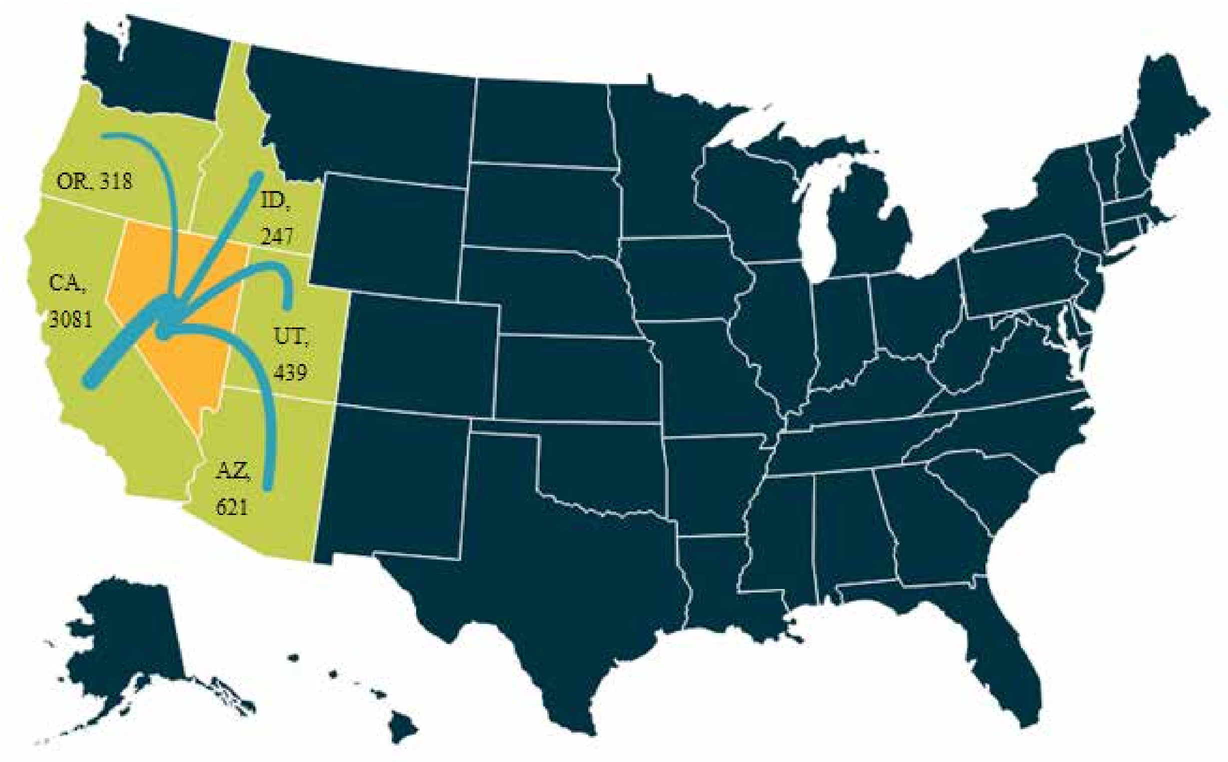


Figure 4.6—*Research Collaboration Partnership between Nevada and Immediate State Neighbors. Source: Scopus®*
Note: Thickness of arcs corresponds to Salton's measure of collaboration strength. Labels correspond to number of collaborations between Nevada and that state between 2004–2013.

CONCLUSIONS

Main Takeaways

Through analyzing four different perspectives – research output and impact, research focus, research inputs, and knowledge transfer and collaboration, this report outlines a process that states can undertake to identify and showcase their research strengths – those areas in which they have a comparative research advantage.

Research Output and Impact

- The combined absolute number of research publications of the top five states (California, New York, Massachusetts, Texas, and Maryland) comprised more than 50 percent of the total U.S. output.
- Over the past decade, Florida achieved both a high level of publication output (210,016 publications, ninth overall and in the top quintile of all states) and a high compound annual growth rate (5.1 percent per year, seventh among all states).
- The overall field-weighted citation impact of all U.S. research output from 2004 to 2013 was 1.49.

Research Focus

- 28.7 percent and 17.4 percent of the total U.S. research output was in medicine and engineering, respectively.
- North Carolina ranked in the top five among all states in both the relative volume and the relative citation impact of its research in medicine.

Research Inputs and Efficiency

- The top six states in terms of research and development expenditures (California, New York, Texas, Maryland, Pennsylvania and Massachusetts) accounted for 42.8 percent of all U.S. higher education research and development expenditures from 2004–2013.
- Massachusetts' universities produced 12.7 publications per million $USD of research and development funding.
- Across the U.S., academic institutions produced on average 0.8 publications per 1,000 net assignable square feet. Rhode Island was the top-ranked state— in 2011, its academic institutions produced 4.7 publications per 1,000 net assignable square feet.

Knowledge Transfer and Collaboration

- About 8.5 percent of all published U.S. research was conducted by corporate institutions. 20.8 percent of New Jersey's total output (33,504 publications) was from corporate researchers, the highest among all states in the country and more than twice the rate of the entire country.
- 68.4 percent of all U.S. research published in 2004-2013 was downloaded by readers from outside the U.S.
- Research from Mississippi and Nevada had the highest rates of international readership. 73.5 percent and 73.3 percent of downloads of those states' research output were by readers from outside the U.S.
- The top states in terms of patent citation share relative to U.S. publication share were: Massachusetts (1.69), Maryland (1.54), Maine (1.45), Michigan (1.40) and Washington (1.38). This suggests that those states' research outputs had a much greater impact on innovation than their national publication volume would otherwise suggest.

APPENDIX A

State Abbreviations and Region Mappings

Region	State	Abbreviation	FIPS Code
South	Alabama	AL	1
West	Alaska	AK	2
West	Arizona	AZ	4
South	Arkansas	AR	5
West	California	CA	6
West	Colorado	CO	8
East	Connecticut	CT	9
East	Delaware	DE	10
South	Florida	FL	12
South	Georgia	GA	13
West	Hawaii	HI	15
West	Idaho	ID	16
Midwest	Illinois	IL	17
Midwest	Indiana	IN	18
Midwest	Iowa	IA	19
Midwest	Kansas	KS	20
South	Kentucky	KY	21
South	Louisiana	LA	22
East	Maine	ME	23
East	Maryland	MD	24
East	Massachusetts	MA	25
Midwest	Michigan	MI	26
Midwest	Minnesota	MN	27
South	Mississippi	MS	28
South	Missouri	MO	29
West	Montana	MT	30

Region	State	Abbreviation	FIPS Code
Midwest	Nebraska	NE	31
West	Nevada	NV	32
East	New Hampshire	NH	33
East	New Jersey	NJ	34
West	New Mexico	NM	35
East	New York	NY	36
South	North Carolina	NC	37
Midwest	North Dakota	ND	38
Midwest	Ohio	OH	39
South	Oklahoma	OK	40
West	Oregon	OR	41
East	Pennsylvania	PA	42
East	Puerto Rico	PR	72
East	Rhode Island	RI	44
South	South Carolina	SC	45
Midwest	South Dakota	SD	46
South	Tennessee	TN	47
South	Texas	TX	48
West	Utah	UT	49
East	Vermont	VT	50
South	Virginia	VA	51
West	Washington	WA	53
East	Washington, D.C.	DC	11
South	West Virginia	WV	54
Midwest	Wisconsin	WI	55
West	Wyoming	WY	56

APPENDIX B

Additional Notes about Methodology

Methodology

Our methodology is based on the theoretical principles and best practices developed in the field of quantitative science and technology studies, particularly in science and technology indicators research. The Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of SandT Systems (Moed, Glänzel and Schmoch, 2004) offers a good overview of this field. It is based on the pioneering work of Derek de Solla Price (1978), Eugene Garfield (1979) and Francis Narin (1976) in the USA, and Christopher Freeman, Ben Martin and John Irvine in the UK (1981, 1987) , and several European institutions including the Centre for Science and Technology Studies at Leiden University, the Netherlands, and the Library of the Academy of Sciences in Budapest, Hungary.

The analyses of bibliometric data in this report are based upon recognized advanced indicators. Our base assumption is that such indicators are useful and valid, though imperfect and partial, measures of research performance. Their numerical values are determined by not only research performance and related concepts, but also by other, influencing factors that may cause systematic biases. They provide unique perspectives on a state's research performance, such as:

» How much research is being produced relative to other comparators?

» What types of organizations (beyond universities) are producing this research?

» In what research fields (e.g., chemistry or psychology) is that research concentrated?

» How impactful or influential is this research on other research, and how much is it being used by non-academic audiences?

» How connected is the state's research enterprise to other states and the rest of the world?

In the past decade, the field of indicators research has developed best practices which state how indicator results should be interpreted and which influencing factors should be taken into account. Our methodology builds on these best practices.

Figure 5.1—*Geographic Distribution of Scopus Source Titles*

Data Sources

The primary data source for this study is the Scopus® abstract and citation database of peer-reviewed research literature, which was developed by and is owned by Elsevier. It is the largest abstract and citation database of peer-reviewed research literature in the world, with 56 million documents published in over 22,000 journals, book series and conference proceedings by some 5,000 publishers. Reference lists are captured for 34+ million records published from 1996 onwards, and the additional 21.3 million pre-1996 records reach as far back as the publication year 1823.

Scopus coverage is multi-lingual and global: approximately 16 percent of titles in Scopus are published in languages other than English (or published in both English and another language). In addition, more than half of Scopus content originates from outside North America, representing many countries in Europe, Latin America, Africa and the Asia Pacific region.

The database contains titles from 105 different countries and 40 "local languages" in all geographic regions.

Scopus coverage is also inclusive across all major research fields, with 11,500 titles in the physical sciences, 12,700 in the health sciences, 6,200 in the life sciences, and 9,400 in the social sciences (the latter including some 3,100 arts and humanities related titles). Titles which are covered are predominantly serial publications (journals, trade journals, book series and conference material), but considerable numbers of conference papers are also covered from stand-alone proceedings volumes (a major dissemination mechanism, particularly in the computer sciences). Acknowledging that a great deal of important literature in all fields (but especially in the social sciences and arts and humanities) is published in books, Scopus now (as of 2015) covers over 75,000 books. See www.elsevier.com/online-tools/scopus for more information.

This report also draws on data from ScienceDirect® (publication usage metrics) and LexisNexis® (patent citations) that is linked to Scopus. ScienceDirect® is Elsevier's full-text journal articles platform. With an invaluable and incomparable customer base, the usage metrics of scientific research on ScienceDirect.com provide a different look at performance measurement. ScienceDirect.com is used by more than 16,500 institutions worldwide, with more than 15 million active users and over 800 million full-text article downloads per year. The average click through to full-text per month is over 65 million. See http://www.elsevier.com/online-tools/sciencedirect for more information.

LexisNexis is a leader in comprehensive and authoritative legal, news and business information and tailored applications. Patent data are obtained via a partnership with LexisNexis and include over 96 million records from over 100 patent authorities, including the United States Patent and Trademark Office (USPTO), the European Patent Office (EPO), the Japanese Patent Office (JPO), the Patent Cooperation Treaty (PCT) of the World Intellectual Property Organization (WIPO) and the UK Intellectual Property Office (UKIPO). Patent data are grouped by families, which refer to the same invention applied for in different authorities. This reports' analyses are limited to only records from the USPTO. Citations in patents to academic publications are linked between the LexisNexis Patent Database and Scopus using a unique record identifier. See http://www.lexisnexis.com/en-U.S./products/total-patent.page for more information.

This report also draws on data from the National Science Foundation's Higher Education Research and Development Survey, (HERD), Survey of Science and Engineering Research Facilities, and the Integrated Postsecondary Education Data System (IPEDS) Human Resources Survey.

The Higher Education Research and Development Survey collects information on Research and development expenditures by NSF's field of research and source of funds (federal, state/local, business, nonprofit, institutional, and other). The survey is an annual census of institutions that expended at least $150,000 in separately budgeted Research and development in the fiscal year (891 such institutions met this threshold in 2013). For statistics that aggregate Research and development expenditures across multiple years (e.g., publications per million $ Research and development expenditures from 2004-2013), all base values were converted to 2013 dollars using the U.S. Department of Labor's Bureau of Labor Statistics' Consumer Price Index (http://www.bls.gov/cpi/data.htm). For more information, please see http://www.nsf.gov/statistics/srvyherd/.

The Survey of Science and Engineering Research Facilities is a congressionally mandated, biennial survey that collects data on the amount, construction, repair, renovation, and funding of research facilities, as well as the computing and networking capacities at U.S. colleges and universities. The survey is an establishment-based survey completed by institutional coordinators at academic institutions and is a census of all research-performing colleges and universities in the U.S. that expended at least $1 million in research and development funds in the prior fiscal year. For more information, please see http://www.nsf.gov/statistics/srvyfacilities/.

The Integrated Postsecondary Education Data System (IPEDS) is a system of interrelated surveys conducted annually by the U.S. Department of Education's National Center for Education Statistics (NCES). This report particularly draws on data from the Human Resources survey, which outlines the number of employees at universities by primary occupational activity, and faculty status/academic rank. For more information, please see http://nces.ed.gov/ipeds/resource/survey_components.asp.

Document types

For all bibliometric analysis, only the following document types are considered:

- Article (ar)
- Review (re)
- Conference Proceeding (cp)

Counting

Counting Publications | To measure trends in publication output over time, it is customary to group publications (and other indicators derived based on publication outputs, such as citations or co-authorships) based on the calendar year in which they were published.
All analyses make use of whole counting rather than fractional counting. A publication may be counted as a publication of multiple entities if it is a joint work of authors from multiple entities. For

example, take the publication entitled "Fischer-Tropsch synthesis: A review of water effects on the performances of unsupported and supported Co catalysts" by Ajay Kumar Dalai and Burtron Davis. It was published in September 2008 in the journal, Applied Catalysis A: General. At the time, Ajar Kumar Dalai was affiliated with the University of Saskatchewan, and Burtron Davis was affiliated with the University of Kentucky. This publication would count toward the output totals in 2008 of the University of Saskatchewan, the University of Kentucky, the state of Kentucky, Canada and the United States. Total counts for each state are the unique counts of publications.

We acknowledge that "there is no fair method to determine how much money, effort, equipment and expertise each researcher, institute or country contributes to a paper and the underlying research effort. Dividing up a paper between the participating units is therefore to some extent arbitrary. Our basic assumption is that each author, main institution and country listed in the affiliated addresses made a non-negligible contribution. Each paper is therefore assigned in the full to all unique authors, institutions and countries listed in the address heading." Extended technical annex to chapter 5 of the 'Third European Report on SandT Indicators '; "Bibliometric Analyses of World Science" by Robert Tijssen and Thed van Leeuwen, CWTS, Leiden University.

The same publication may be part of multiple smaller component entities, such as the calculation of counts of publications in multiple fields. However, this report deduplicates all counts within an aggregate entity, so that a publication is counted only once even if it is included by several component entities. For example, a Kentucky publication on the impact of increased corn production on pricing may be counted once toward the totals of Kentucky's output in agricultural and biological sciences and once toward Kentucky's output in economics, econometrics, and finance. However, this publication counts only once toward the aggregate entity of all Kentucky publications.

Counting Citations | Self-citations are those by which an entity refers to its previous work in new publications. Self-citing is normal and expected academic behavior, and it is an author's responsibility to make sure their readers are aware of related, relevant work. For this report, self-citations are included in citation counts and the calculation of FWCI.
Older publications tend to have more citations than newer publications, simply because they have had longer to receive them from subsequent work. This means that for metrics like Citation Count, where this time factor is not accounted for, there is a "dip" in the timeline in recent years. Comparisons between similar entities will still be useful and valid despite this dip, since the time factor will affect all similar entities equally, but if the user prefers to avoid this display they can select a metric like Field-Weighted Citation Impact which inherently accounts for this.

Measuring Research Efficiency and Productivity

This report provides several indicators that proxy for a state's research efficiency and productivity. It is important to note that all of these indicators are high-level approximations of a deeply complex process. No single indicator or their combination fully captures all the dimensions by which states convert Research and development funding into research outputs. This section outlines some of the key limitations to help readers better understand what can and cannot be inferred from the indicators.

» Research output per million $ research and development provides a high-level indicator of the ability of a state's academic researchers to convert Research and development expenditures into publications. To ensure an apples-to-apples comparison, this indicator and other analogous indicators use data on only higher education Research and development and output from the academic sector. It is important to note that the results of research enabled by Research and development expenditures may not be published in peer-reviewed publications for several years, or sometimes not at all. These time lags and leaky pipelines in publishing research results vary by field and state and may even shift in magnitude over time.

» Research output per 1,000 net assignable square feet (and research output in medicine per 1,000 NASF of medical school research space) provides a high-level indicator of the ability of a state's academic researchers to utilize academic research space efficiently.

Different states specialize in different research fields, and the costs of conducting research vary greatly across fields. More nuanced analyses can take into account how much Research and development states have spent in particular fields (such as medicine versus engineering).

Research Usage Metrics

Advantages and disadvantages of using citations as a proxy for research impact | Downloads and citations, as potential indicators of research awareness and impact, have their own advantages and disadvantages. While it is clear that when a citation occurs, an article has been read and used, it should not be assumed that all downloaded articles are read or used. However, measuring impact through citations is particularly difficult for recently published articles. Citation impact is by definition a lagging indicator. The accumulation of citations takes time.

After publication, articles need to first be discovered and read by the relevant researchers; then, those articles might influence the next wave of studies conducted and procedures implemented. For a subset of those studies, the results are written up, peer-reviewed, and published. Only then can a citation be counted toward that initial article. Moreover, citations do not necessarily capture the full extent to which an article is being used (by either the academic or corporate sectors) and may systematically understate the impact of certain types of research (clinical versus basic).

Limitations to collecting and making inferences about usage metrics | Since full-text journal articles reside on a variety of publisher and aggregator websites, there is no central database of download statistics available for comparative analysis. Despite this, downloads are nonetheless a useful indicator of early interest in, or the emerging importance of, research.

APPENDIX C

Glossary of Terms

CAGR (Compound Annual Growth Rate) is defined as the year-over-year constant growth rate over a specified period of time. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series.

$$\mathrm{CAGR}(t_0, t_n) = \left(V(t_n)/V(t_0)\right)^{\frac{1}{t_n - t_0}} - 1$$

$V(t_0)$: start value

$V(t_n)$: finish value

$t_n - t_0$: number of years.

Citation is a formal reference to earlier work made in an article or patent, frequently to other journal articles. A citation is used to credit the originator of an idea or finding and is usually used to indicate that the earlier work supports the claims of the work citing it. The number of citations received by an article from subsequently-published articles is a proxy of the quality or importance of the reported research.

Downloads are defined as either downloading a PDF of an article on ScienceDirect, Elsevier's full-text platform, or looking at the full-text online on ScienceDirect without downloading the actual PDF. Views of abstracts are not included in the definition. Multiple views or downloads of the same article in the same format during a user session will be filtered out, in accordance with the COUNTER Code of Practice 4.

FWCI (Field-Weighted Citation Impact) is an indicator of mean citation impact, and compares the actual number of citations received by an article with the expected number of citations for articles of the same document type (article, review or conference proceeding paper), publication year and field. Where the article is classified in two or more fields, the harmonic mean of the actual and expected citation rates is used. The indicator is therefore always defined with reference to a global baseline of 1.0 and intrinsically accounts for differences in citation accrual over time, differences in citation rates for different document types (reviews typically attract more citations than research articles, for example) as well as field-specific differences in citation frequencies overall and over time and document types. It is one of the most sophisticated indicators in the modern bibliometric toolkit.

Highly cited articles (unless otherwise indicated) are those in the top-cited X percent of all articles published and cited in a given period. In this report, we specifically report on highly cited articles in the top 10 percent.

Peer-reviewed publications are the medium by which researchers both communicate new ideas and assess each other's contributions. Scholarly peer- review is a practice by which publication drafts or manuscripts are scrutinized by other experts in the same field; the draft will be published only if those experts determine that it is suitable for publication. For this report, peer-reviewed publications refer to research of the following document types: journal articles, review papers, and conference proceedings. Academic journals also publish other records and document types such as editorials, short notes, correspondences, book reviews, letters, and so forth that are not peer-reviewed. For consistency and commensurability in assessing research output and performance, we do not count such records toward research output totals.

National publication share (and other analogous measures of _______ share) is defined for a state as that state's publication output divided by the total publication output of the United States. For example, to calculate the national publication share of New York in Engineering from 2004-2013, one divides New York's total publications in Engineering over that time period (97,041) by the U.S. as a whole (80,774) to get 11.4 percent.

Relative (research) volume of an entity's output in a field is a measure that takes into account the total amount of research that that entity produces. To calculate the relative volume of a state's output in a particular field, we divide the relative proportion of a state's research publications in a given field by the relative proportion of all U.S. publications in that field . For example, from 2004-2013, Indiana produced 13,632 publications in computer science and 128,816 publications across all research fields. Over the same period, the U.S. as a whole produced 458,430 publications in computer science and 4,893,248 publications across all research areas. So, Indiana's relative volume of computer science research is (13,632/128,816) / (458,430/4,893,248) = 1.13.

This means that, normalized for Indiana's total research output level, the state produced 13 percent more research in computer science than the U.S. average.

» An analogous measure is the relative (download) volume of an entity's output. For example, Arkansas's 2013 publications in pharmacology, toxicology, and pharmaceutics have been downloaded 32,575 times so far, which comprise 12.0 percent of all downloads of Arkansas's 2013 publications (271, 593). Downloads of all U.S. 2013 research in medicine comprised only 6.0 percent of all downloads of the U.S.'s 2013 research output. Thus, the relative download volume of Arkansas' 2013 research in medicine was 2.0, or twice the U.S. average.

Salton's measure (also known as Salton's cosine or Salton's index) for the level of collaboration between two partners is calculated by dividing the number of co-authored articles by the geometric mean (square root of the product) of the total article outputs of the two partners. By taking into account the absolute publication output of each constituent partner, the index is a size-independent indicator of collaboration strength. As a cosine measure, the values of Salton's Index vary between 0 (where there are no co-authored articles between a given entity pairing) and 1 (in which all articles from both partners represent co-authorship between them). In practice, the range typically seen at state level is in the range 0.000 to 0.100 for most pairings of significant size). For example,

Sectors in this report are used to delimit the parts of the national research base. The main sectors are Academic, Corporate, Government, Medical, and Other.

Academic

- Univ (university): universities and other institutes that grant undergraduate, graduate, and/or Ph.D. degrees as well as engage in research. Examples: Cornell University, Harvard University.

- Coll (college): two or four year degree granting institutions that also engage in research to some degree. Examples of two year colleges: Trinity Valley Community College (http://www.tvcc.edu/), Mira Costa College (http://www.miracosta.cc.ca.U.S./)

- Meds (medical schools): organizations that offer medical degrees as well as engage in research. Examples: Harvard Medical School; Brown Medical School. We do not designate dental schools and other health related degrees as "meds".

- Resi (research institutes): organizations whose primary function is to conduct research and may include some educational activities but are not universities. Example: Salk Institute for Biological Studies, Whitehead Institute for Biomedical Research.

Corporate

- Comp (company): commercial entities primarily operating with a profit motive although some so-called non-profit organizations could potentially be classified as companies. Examples: IBM, HP

- Lawf (law firm): business entities formed by one or more lawyers to engage in the practice of law. Examples: Baker and McKenzie LLP (http://www.bakernet.com/BakerNet/default.htm).

Government

- Govt (government): includes all levels of government as well as the UN. Example: U.S. Department of Energy, Los Alamos National Laboratory, Centers for Disease Control and Prevention

- Milo (military organization): Example: U.S. Army Research Laboratory, Weapons and Materials Research Directorate.

Medical

- Hosp (hospital): organizations whose primary function is to provide health care although they may also do research. Example: Mayo Clinic, Memorial Sloan-Kettering Cancer Center, St. Jude Children Research Hospital

Other

- Poli (policy institute): policy is the primary function of organizations of "poli" type while they may also engage in research and perhaps even some development. Example: American Institutes of Research.

- Ngov (non-governmental and/or non-profit organization): organizations primarily focused on development and social/political progress, but nevertheless produce research documents. Example: Red Cross.

APPENDIX D

Field Classification Systems

Background on All Science Journal Classification (ASJC) System

Journals and conference proceedings (titles) in Scopus are classified under four broad field clusters (life sciences, physical sciences, health sciences and social sciences and humanities) which are further divided into 27 major fields and 334 minor fields. Titles may belong to more than one field, so the sum of an entity's output across all fields may add up to more than 100 percent.

Articles within each title inherit the ASJC four digit codes assigned to the titles they belong to automatically during loading time. Depending on the judgments of the Scopus Content Advisory Board, a title can be categorized in multiple fields.

Highly multidisciplinary journals such as Nature, Science, Proceedings of the National Academy of Sciences, and so forth are categorized in a separate field category called General / Multidisciplinary.

These fields do not necessarily map onto the department, program, or school divisions of a particular institution, nor that of other field classification systems, such as that the National Center of Education Statistics (NCES) Classification of Instructional Programs (CIP) or the National Science Foundation's Research and development Fields.

Scopus 27 Field Classification

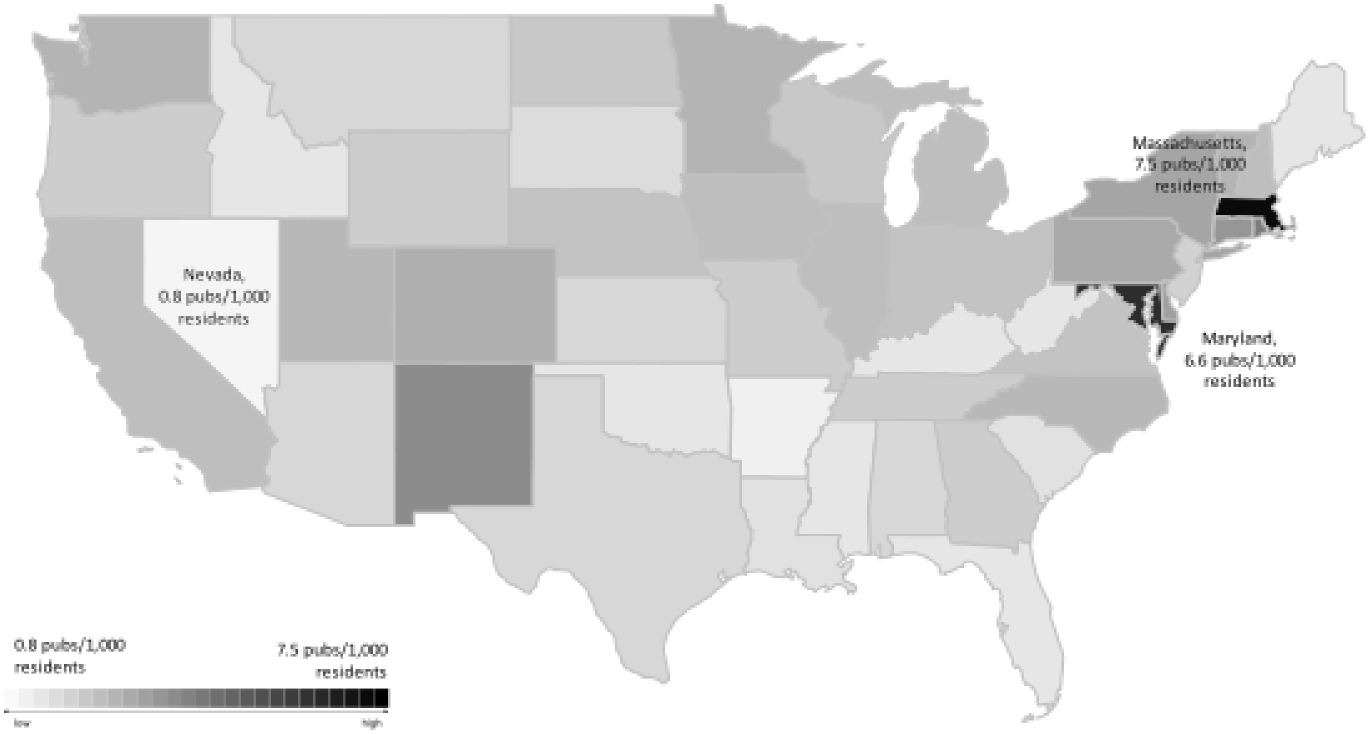
Name of Field	Broad Cluster	Shortened Name
General (multidisciplinary journals like Nature and Science)	All	General
Agricultural and Biological Sciences	Life Sciences	Agricultural & Biological Sci
Arts and Humanities	Social Sciences	Arts & Humanities
Biochemistry, Genetics and Molecular Biology	Life Sciences	Biochem & Mol Bio
Business, Management and Accounting	Social Sciences	Business, Mgmt, & Accounting
Chemical Engineering	Physical Sciences	Chemical Eng
Chemistry	Physical Sciences	Chemistry
Computer Science	Physical Sciences	Computer Sci
Decision Sciences	Social Sciences	Decision Sci
Earth and Planetary Sciences	Physical Sciences	Earth & Planetary Sci
Economics, Econometrics and Finance	Social Sciences	Economics & Finance
Energy	Physical Sciences	Energy
Engineering	Physical Sciences	Engineering
Environmental Science	Physical Sciences	Environmental Sci
Immunology and Microbiology	Life Sciences	Immunology & Microbio
Materials Science	Physical Sciences	Materials Sci
Mathematics	Physical Sciences	Mathematics
Medicine	Health Sciences	Medicine
Neuroscience	Life Sciences	Neuroscience
Nursing	Health Sciences	Nursing
Pharmacology, Toxicology and Pharmaceutics	Life Sciences	Pharmacology & Toxicology
Physics and Astronomy	Physical Sciences	Physics & Astronomy
Psychology	Social Sciences	Psychology
Social Sciences	Social Sciences	Social Sciences
Veterinary Sciences	Health Sciences	Veterinary Sci
Dentistry	Health Sciences	Dentistry
Health Professions	Health Sciences	Health Professions

APPENDIX E

Summary Tables

The following pages provide tables for the top ten states and their performance along several of the main indicators of interest throughout the report.

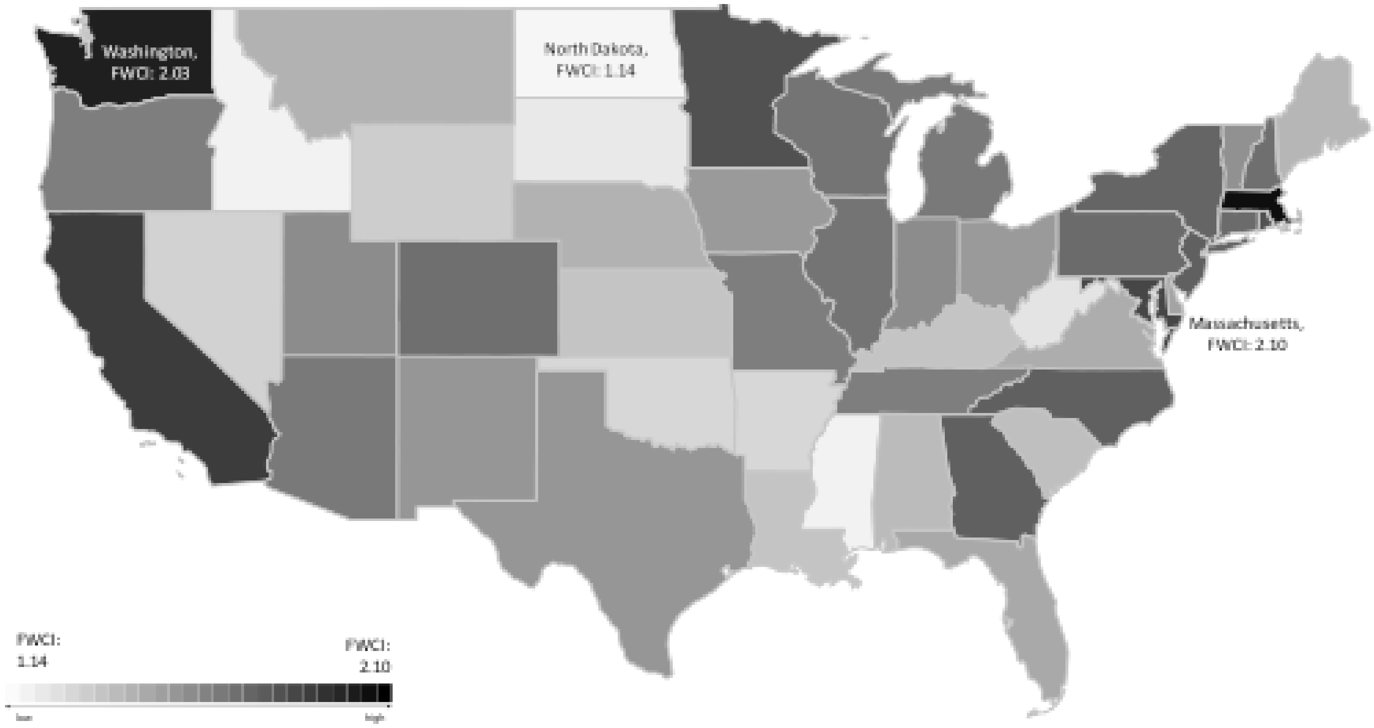
Publications per 1,000 Residents (2013)



Source: Scopus® and U.S. Census Bureau

Rank	State	Publications per 1,000 residents	Rank	State	Publications per 1,000 residents
1	Massachusetts	7.5	6	Delaware	3.2
2	Maryland	6.6	7	New York	3.1
3	Rhode Island	4.2	8	Pennsylvania	3
4	New Mexico	3.8	9	Colorado	2.9
5	Connecticut	3.5	10	Minnesota	2.8

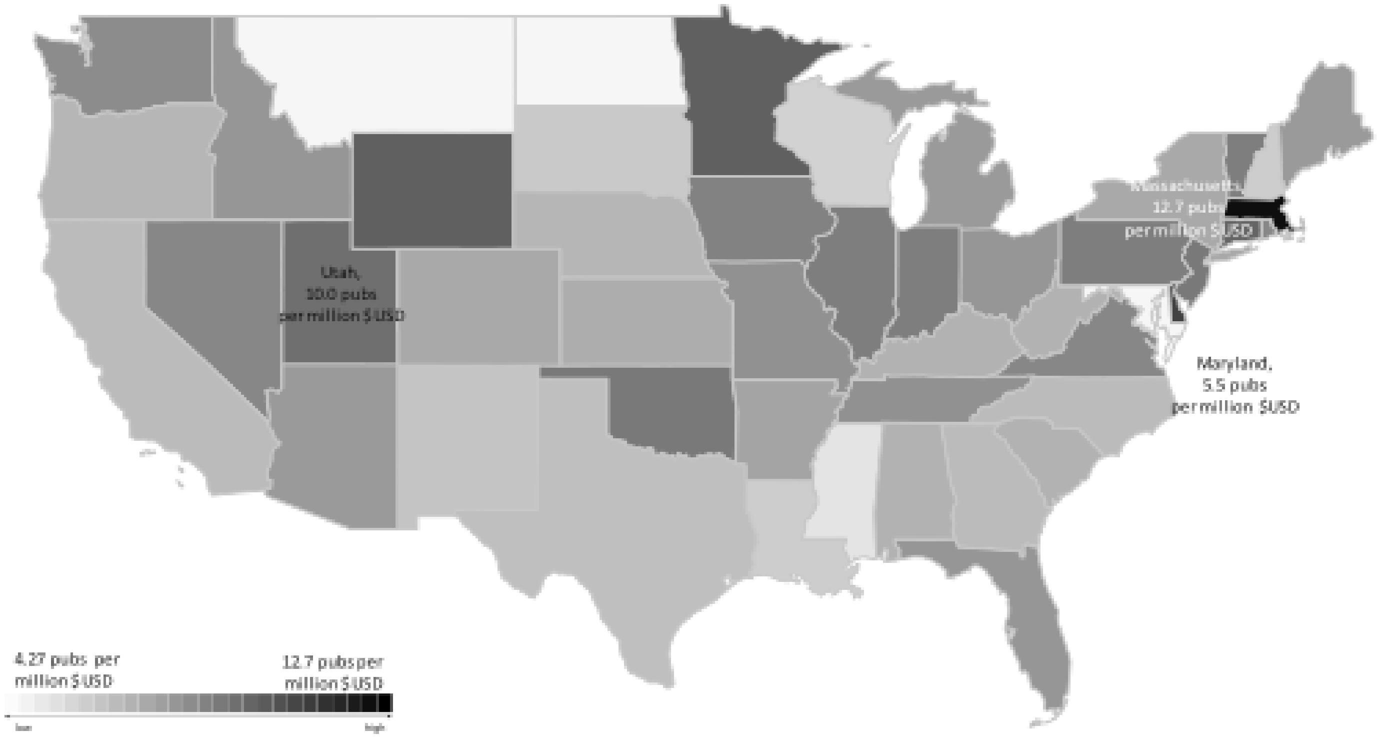
Field-Weighted Citation Impact (FWCI) for U.S. States (2004-2013)



Source: Scopus®

Rank	State	FWCI	Rank	State	FWCI
1	Massachusetts	2.11	6	Rhode Island	1.85
2	Washington	2.03	7	North Carolina	1.8
3	California	1.94	8	New Jersey	1.79
4	Maryland	1.91	9	Georgia	1.79
5	Minnesota	1.86	10	New York	1.77

Publications by the Academic Sector per Million $ USD Research and Development for U.S. States, in 2013 dollars (2004–2013)



Source: Scopus® and NSF Higher Education Research and Development Survey

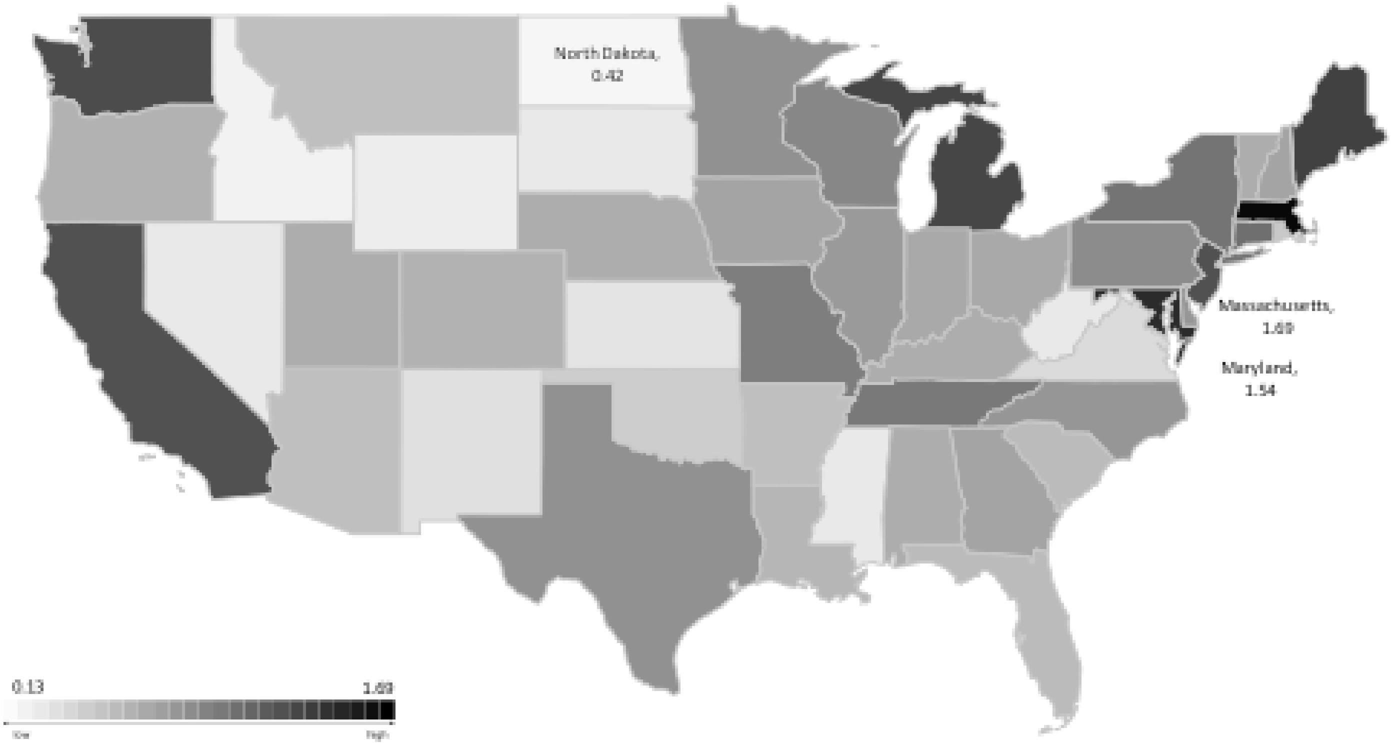
Rank	State	Publications per million $ USD R&D	Rank	State	Publications per million $ USD R&D
1	Massachusetts	12.7	6	Utah	10
2	Delaware	11.4	7	New Jersey	9.6
3	Minnesota	10.5	8	Oklahoma	9.6
4	Wyoming	10.3	9	Pennsylvania	9.6
5	Connecticut	10.3	10	Indiana	9.5

Percentage of Total State Output from Corporate Institutions (2004–2013)

Source: Scopus®

Rank	State	Corporate publications as % of state total	Rank	State	Corporate publications as % of state total
1	New Jersey	20.80%	6	Indiana	7.20%
2	Delaware	13.90%	7	Texas	6.70%
3	California	13.20%	8	Connecticut	6.40%
4	New York	10.90%	9	Massachusetts	6.30%
5	Washington	7.20%	10	Virginia	6.30%

Ratio of National Patent Citation Share to National Publication Share (2004–2012)



Source: LexisNexis® patent database and Scopus®

Rank	State	Ratio of patent citation share to publication share	Rank	State	Ratio of patent citation share to publication share
1	Massachusetts	1.69	6	California	1.35
2	Maryland	1.54	7	New Jersey	1.35
3	Maine	1.45	8	Connecticut	1.21
4	Michigan	1.4	9	New York	1.18
5	Washington	1.38	10	Tennessee	1.16

Ranking of states (1-50) along select indicators of research performance

A: Number of publications, 2004–2013
B: Compound annual growth rate (CAGR) in publications, 2004–2013
C: Publications per 1,000 residents, 2013
D: Field-weighted citation impact (FWCI), 2004–2013
E: CAGR in FWCI, 2004-2013
F: Publications by the academic sector per million $ USD (in 2013 dollars), 2004–2013
G: Publications by the academic sector per 1,000 net assignable square feet (NASF), 2011
H: Publications by the academic sector per faculty, 2013
I: Ratio of national download share to national publication share, 2004–2013
J: Ratio of national patent citation share to national publication share, 2004–2013

State	A	B	C	D	E	F	G	H	I	J
Alaska	48	4	33	41	3	50	24	30	48	50
Alabama	25	37	37	36	4	30	26	37	29	25
Arkansas	40	22	49	44	42	26	41	49	44	35
Arizona	23	29	34	18	35	25	13	12	42	36
California	1	42	19	3	39	38	21	5	20	6
Colorado	16	23	9	13	6	27	10	7	36	30
Connecticut	21	36	5	12	23	5	14	3	2	8
Delaware	39	43	6	30	9	2	20	8	25	17
Florida	9	7	48	31	31	21	19	20	22	33
Georgia	13	16	31	9	33	36	40	26	21	21
Hawaii	38	24	21	29	48	39	11	16	47	45
Iowa	27	47	15	27	43	13	22	29	30	20
Idaho	43	27	42	49	7	20	48	48	49	48
Illinois	7	41	17	15	28	11	29	18	31	18
Indiana	17	18	24	22	46	10	4	24	32	23
Kansas	32	15	35	38	10	29	35	38	41	41
Kentucky	31	19	43	40	50	31	43	46	12	28
Louisiana	29	48	41	39	47	44	46	40	18	31
Massachusetts	3	14	1	1	38	1	2	1	1	1
Maryland	5	44	2	4	16	49	9	2	3	2
Maine	44	46	45	35	14	23	45	47	15	3
Michigan	10	20	18	17	40	24	8	13	7	4
Minnesota	18	25	10	5	41	3	38	32	6	15
Missouri	20	31	28	21	12	18	30	22	4	11
Mississippi	36	17	47	48	20	46	49	50	38	44
Montana	45	26	38	33	30	47	36	44	45	34
North Carolina	11	5	14	7	45	37	25	21	5	16
North Dakota	47	2	25	50	2	48	47	42	35	49
Nebraska	35	40	22	34	15	35	50	34	26	26
New Hampshire	37	45	16	14	49	43	18	14	24	19
New Jersey	15	49	32	8	37	7	7	19	34	7
New Mexico	24	50	4	26	21	41	15	15	50	40
Nevada	41	33	50	43	34	16	42	31	33	43
New York	2	35	7	10	44	28	17	17	16	9
Ohio	8	39	23	28	18	22	5	25	11	22
Oklahoma	33	21	46	45	8	8	37	43	37	38
Oregon	26	32	27	19	11	34	32	27	14	29
Pennsylvania	6	28	8	11	24	9	6	9	9	13
Rhode Island	34	10	3	6	29	15	1	10	8	37
South Carolina	30	13	40	37	25	32	23	41	13	32
South Dakota	50	1	39	47	1	42	44	45	39	46
Tennessee	19	8	29	20	5	19	16	28	19	10
Texas	4	9	36	25	26	40	27	23	23	14
Utah	28	6	13	23	22	6	31	11	28	27
Virginia	12	34	20	32	19	14	28	35	43	39
Vermont	46	30	11	24	17	12	3	36	17	24
Washington	14	12	12	2	27	17	12	4	10	5
Wisconsin	22	38	26	16	32	45	33	33	27	12
West Virginia	42	11	44	46	13	33	34	6	40	42
Wyoming	49	3	30	42	36	4	39	39	46	47

ELSEVIER

THE COUNCIL OF
STATE GOVERNMENTS