THE INNOVATION IMPACT OF U.S. UNIVERSITIES

Rankings and Policy Conclusions

FULL REPORT

J.H. Cullum Clark
George W. Bush Institute - SMU Economic Growth Initiative, Director

Kristina Murri
Southern Methodist University, Department of Economics, Doctoral Student

Vinit Nijhawan
Opus Faveo Innovation Development LLC, Fellow; Boston University, Lecturer

Christian T. Blackwell
Opus Faveo Innovation Development LLC, Managing Partner

David Overton
Opus Faveo Innovation Development LLC, Partner

Steve Ingram
Opus Faveo Innovation Development LLC, Vice President

June 2020

George W. Bush Institute

SMU

opus faveo innovation development

About the George W. Bush Institute:

Housed within the George W. Bush Presidential Center, the George W. Bush Institute is an action-oriented, nonpartisan, policy organization with the mission of developing leaders, advancing policy, and taking action to solve today's most pressing challenges. Through three Impact Centers — Domestic Excellence, Global Leadership, and an Engagement Agenda — the Bush Institute delivers measurable results that save and improve lives. To learn more, visit www.BushCenter.org.

Opus Faveo Innovation Development:

Opus Faveo Innovation Development is an innovation strategy and venture development firm. Through its Institutional and Corporate Innovation strategy practice, the firm provides actionable solutions to leadership in academia, government and the private sector, increasing innovation impact through stakeholder engagement, rigorous analysis, and effective communication and outreach programs.

Table of Contents

Tables

Figures

THE INNOVATION IMPACT OF U.S. UNIVERSITIES[1]

Summary

America's long-term economic growth demands a stepped-up commitment to promoting the innovation impact of the nation's top-tier universities and other research institutions. For research institutions themselves, this commitment means prioritizing research, empowering great researchers, building efficient and outcomes-focused technology transfer operations, instilling cultures of innovation and entrepreneurship, and engaging with surrounding business and innovation communities. For America as a whole, it means increasing research funding and paying more attention to the worldwide competition for human talent, including for high-skilled immigrants.

American universities play a pivotal role in fueling innovation, which in turn drives economic growth and raises living standards in the United States. U.S. universities spend approximately $75 billion per year on research, amounting to 13 percent of America's total spending on research and development (R&D).[2] Much of this spending funds research activities in science, technology, engineering, and mathematics (STEM) fields.

Universities conduct a majority of the country's basic research, while the private sector largely focuses on product development, which often relies on discoveries from basic research. The volume and quality of R&D activity in turn drive the pace of technological progress in the economy and society as a whole.

The COVID-19 crisis has dramatically underscored the importance of great research institutions to America's well-being and economic future. Major research institutions are at the center of efforts to understand and combat the novel coronavirus, focusing new research programs on the emergency at a scale and pace reminiscent of their national defense mobilization during WWII. The economic aftershocks of the COVID-19 crisis threaten the financial models that underpin

---

[1] The authors wish to thank Jim Stewart (Opus Faveo), Sarah Beth Luckey (a data scientist at a Dallas-area firm and recent SMU master's graduate and George W. Bush Institute researcher), Alex McElya (an undergraduate student at the College of William & Mary), and Tommy Hessel (an undergraduate student at Duke University) for their invaluable research help on this study; Tom Fomby, Kathy Hayes, Dan Millimet, James Quick, Tom DiPiero, Matt Myers, Kimberly Jones-Ross, and numerous other SMU colleagues for their crucial methodological advice and wise counsel; and Ken Hersh, Holly Kuzmich, Matt Rooney, Kristin Spanos, Anu Chatterjee, Ioanna Papas, Jessica Wheeler, and countless colleagues at the George W. Bush Institute for their support and editorial feedback. The report's conclusions, as well as its inevitable errors, are the responsibility of the authors alone.

[2] Department of Education, National Center for Education Statistics data.

America’s world-leading universities, raising urgent questions for policy- makers. But institutions that build competitive research operations around life science, biotechnology, and other vital STEM fields are likely to be successful in overcoming growing challenges to traditional ways of doing business in higher education.

This report offers a new set of rankings of U.S. research universities and research institutions for innovation impact. We rank institutions for overall innovation impact and separately for productivity in converting research inputs measured in terms of research spending to innovation impact output. Our aim in publishing rankings is to highlight high-performing institutions — particularly standout performers in innovation impact productivity — so that other institutions, as well as policymakers and other leaders, can learn from their example. We also look closely at *why* some universities are exceptionally productive in generating innovation impact through their research activities.

In this report, innovation impact means the dissemination of research findings in STEM fields beyond the walls of academia in ways that directly drive technological progress in the wider economy and society. To be clear, this report does not address the extent to which universities pursue innovative methods in their teaching activities or in non-STEM academic research, though we fully support the broader teaching and research missions of U.S. universities.

Rankings

We have constructed our rankings based on data from the Association of University Technology Managers (AUTM) for the years 2013 to 2017, plus data on patent citations, academic paper citations, graduate numbers, and other university attributes from publicly available websites. Our rankings reflect a more expansive concept of innovation impact than any other rankings in the literature. We base our rankings on composite scores that combine nine variables measuring the success of universities in:

1) technology commercialization,
2) entrepreneurship based on intellectual property and technologies licensed from the university,
3) research impact on other researchers and inventors, and
4) production of STEM graduates, at the Ph.D., master’s, and bachelor’s levels.

Our rankings include 195 institutions, based on the availability of AUTM data for the years 2013-2017. Our separate rankings for aggregate innovation impact and innovation impact productivity reflect the observation that some universities might have very large overall innovation impact output but only moderate productivity, while other smaller institutions might be especially productive but generate only medium-sized overall innovation impact because their available research inputs are more modest. This study identifies a number of universities that exemplify each of these patterns.

Table 1 shows the top 25 universities in our ranking for overall innovation impact. The University of California and the University of Texas are by far the first- and second-ranked institutions in the rankings, both in terms of research inputs and in terms of innovation impact. Like some other state university systems, they report data to AUTM at the system-wide level rather than for individual campuses, so we treat each of them as a single institution in this report.

Sixteen of the top 25 universities for innovation impact are large state institutions. In addition to the University of California and University of Texas systems, leading public institutions for innovation impact include the Universities of Washington, Michigan, Florida, and Minnesota. Nine of the top 25, led by the 3rd-ranked Massachusetts Institute of Technology (MIT), are private universities. Leading private institutions also include Columbia University, Stanford University, the University of Pennsylvania, and Johns Hopkins University.

Table 1

UNIVERSITY RANKING FOR INNOVATION IMPACT

Top 25 of 195 ranked institutions[3]

1	University of California System
2	University of Texas System
3	Massachusetts Institute of Technology (MIT)
4	University of Washington
5	University of Michigan
6	University of Florida
7	Columbia University
8	University of Minnesota
9	Stanford University
10	University of Pennsylvania
11	Johns Hopkins University
12	University of Illinois at Urbana-Champaign
13	University System of Maryland
14	University of Wisconsin–Madison
15	Purdue University
16	Northwestern University
17	New York University (NYU)
18	University of Pittsburgh
19	Cornell University
20	North Carolina State University
21	Harvard University
22	Ohio State University
23	Duke University
24	University of Utah
25	State University of New York

[3] Appendix 2 sets forth our comprehensive ranking of 195 institutions for innovation impact.

Table 2 shows the top 10 institutions in our rankings for productivity in generating innovation impact separated into five different groups: large, mid-sized, and smaller comprehensive research universities, plus pure medical schools and pure research/health care institutions (including research hospitals).

We separate our productivity rankings into five groups because we believe it makes more sense to compare productivity levels among institutions of similar size and mission than among institutions that differ widely in both respects. We distinguish among large, mid-sized, and smaller comprehensive research universities based on their total research budgets, not on student numbers or other measures of size. Note that the institutions in our group of smaller research universities are small only by comparison, as institutions reporting data to AUTM primarily consist of relatively large universities.

This report includes brief case studies of the top performers in the large, mid-sized, and smaller research university categories in terms of innovation impact productivity: The University of Florida, Drexel University, and Brigham Young University. Each of our case studies provides strong evidence that the best-in-class performance of these institutions in innovation impact productivity has resulted from intentional effort rather than from chance.

Note that we use the terms "university" and "institution" interchangeably in this report, even though a handful of the institutions in our rankings typically do not refer to themselves as "universities." This reflects the fact that all institutions we discuss in this report participate in the Association of University Technology Managers.

We suggest two key takeaways from the rankings. First, the leading universities in innovation impact productivity terms are in many cases quite different from the institutions that generate the greatest overall innovation impact. Second, a number of leading state universities play a critical role, fully competitive with private institutions that tend to dominate popular media rankings of U.S. universities in generating innovation impact and driving technological progress in America's economy.

Table 2

UNIVERSITY RANKINGS FOR INNOVATION IMPACT PRODUCTIVITY[4]

COMPREHENSIVE RESEARCH UNIVERSITIES

Largest Universities:

1	University of Florida
2	University of Utah
3	California Institute of Technology
4	University of Chicago
5	North Carolina State University
6	Columbia University
7	Northwestern University
8	New York University (NYU)
9	Purdue University
10	University of Georgia

Mid-Sized Universities:

1	Drexel University
2	University of New Mexico
3	Princeton University
4	Carnegie Mellon University
5	University of Central Florida
6	University of New Hampshire
7	University of Houston
8	Washington State University
9	Rice University
10	Temple University

Smaller Universities:

1	Brigham Young University
2	University of Wisconsin - WiSys
3	Northern Illinois University
4	Duquesne University
5	Creighton University
6	Ball State University
7	Stevens Institute of Technology
8	University of North Carolina at Charlotte
9	University of North Florida
10	East Carolina University

OTHER INSTITUTIONS:

Pure Medical Schools:

1	University of North Texas Health Science Center
2	Georgia Health Sciences University
3	Medical University of South Carolina
4	Mayo Fdn. for Medical Educ. and Research
5	Baylor College of Medicine
6	Mount Sinai School of Medicine of NYU
7	Medical College of Wisconsin Research Fdn.

Pure Research/Health Care Institutions:

1	Cold Spring Harbor Laboratory
2	Whitehead Institute for Biomedical Research
3	Jackson Laboratory
4	Hospital for Special Surgery
5	The Wistar Institute
6	City of Hope National Medical Center
7	Moffitt Cancer Center
8	Salk Institute for Biological Studies
9	National Jewish Health
10	Cedars-Sinai Medical Center

[4] Appendix 3 sets forth our comprehensive rankings for innovation impact productivity by institution type.

Explaining success

We investigate determinants of university success in creating innovation impact and innovation impact productivity through a variety of statistical methods. We analyze the influence of numerous factors, which we group into four categories: (1) scale of the university and its research effort; (2) attributes of the metro area where the university is located; (3) other non-scale attributes of the university such as widely cited measures of faculty "quality" and whether a university has a medical, business, or engineering school; and (4) policy variables, meaning resource allocation decisions that universities could reasonably change.

We add to the existing literature on university technology innovation by broadening the concept of innovation impact, updating the literature with more recent data than most prior studies use, and adding novel explanatory variables — notably, the share of foreign-born people in metro-area population and the professional background of the head of the university's technology transfer office (TTO).

Our analysis points to the following conclusions:

- Our data strongly show diseconomies of scale in generating innovation impact. Universities with larger research spending tend to produce more innovative output than universities with smaller research spending, but larger size predicts lower productivity in converting research inputs to innovation impact outputs.
- Once one controls for the size of a university's research spending, other measures of size, such as endowment size and total budget, have little effect on innovation impact.
- Universities in larger metro areas tend to produce more innovation impact than those in smaller metro areas, a finding consistent with prior literature.
- The share of foreign-born people in a metro area's population has a strong association with the innovation impact and productivity of local institutions. Metros with a larger proportion of immigrants host universities with greater innovation impact, all else equal. To our knowledge, this report is the first to study this relationship.
- Universities recognized for exceptionally high faculty quality tend to generate greater innovation impact, another finding consistent with prior literature that focuses on narrower measures of innovation impact.
- We find little consistent difference between public and private universities in innovation impact and productivity, once we control for size. This result contrasts with some studies focused on narrower measures of innovation impact, which have tended to find greater productivity at private universities.
- We conclude, consistent with prior literature, that having a larger TTO predicts greater success in technology commercialization and entrepreneurship. But we further find that universities with larger TTOs achieve exceptional innovation impact even through

channels over which the TTO exerts no direct control, such as research impact on other researchers and inventors and the training of STEM graduates.

- Universities in which the TTO head is a trained engineer generate greater innovation impact, all else equal, while the business and startup experience of the TTO head seems to make little difference.
- Finally, the share of research spending funded by industry partners is negatively associated with innovation impact productivity, again consistent with several past studies.

KEY FINDINGS:

- **Higher research spending predicts lower productivity in generating innovation impact.**
- **Universities in larger metro areas tend to produce more innovation impact than those in smaller metro areas.**
- **Universities in metro areas with larger immigrant population shares tend to achieve more innovation impact, independent of metro area population.**
- **The size, professional background, and policies of university technology transfer offices (TTOs) have surprisingly wide-ranging effects on innovation impact.**
- **The share of research spending funded by industry partners is negatively associated with innovation impact productivity.**

Universities control their own fate in generating innovation impact to a significant degree through their allocation of resources to research and also through policies and cultural factors related to innovation, commercialization, and entrepreneurship. **The universities that achieve the greatest innovation impact are the ones which choose to do so.**

Policy conclusions

Our study offers clear takeaways for university leaders, as well as policymakers, business leaders, philanthropists, and communities, with the aim of improving the innovation impact productivity of university research and promoting technological progress and growth in America's economy.

SUMMARY OF POLICY CONCLUSIONS:

For university leaders:

1) **Prioritize research.**
2) **Compete hard for and retain star faculty researchers.**
3) **Run an efficient, outcomes-focused technology transfer operation.**
4) **Instill a culture of innovation and entrepreneurship throughout the university.**
5) **Engage closely with the surrounding business and innovation communities.**
6) **Avoid overreliance on sponsored research funding from industry.**
7) **Monitor, quantify, and transparently disclose innovation impact results.**

For policymakers, business leaders, philanthropists, and communities:

1) **Increase public sector support for university research.**
2) **Understand how institutions vary in their innovation impact productivity.**
3) **Compete hard for talent — including immigrant talent.**
4) **Invest in integrated physical spaces that connect researchers with entrepreneurs, investors, and other potential nonacademic partners.**
5) **Support technology transfer operations and other enablers of innovation impact.**

Origins and objectives of this project

Opus Faveo Innovation Development started studying the innovation impact of U.S. universities in 2014. Beginning that year, the firm developed the concept of innovation impact through interviews with leaders and staff at universities across the United States, as well as in Canada and Mexico. The firm developed an unpublished set of rankings based on AUTM data. It also conducted a survey with respondents from 92 large research universities on the subject in that year, with rich results that helped to inform this study. Opus Faveo's interest in university innovation impact reflects its long experience working with early-stage companies to commercialize innovative technologies. It also reflects the firm's conviction that universities, companies, and indeed governments often have considerable room for improvement in creating cultures and processes that are conducive to generating innovation impact.

The George W. Bush Institute-SMU Economic Growth Initiative joined the project because of its focus on policies to maximize economic growth in America. The Initiative has recently launched a program addressing economic vitality and opportunity in American cities and metro areas and believes research institutions play a central role in driving economic growth and prosperity in their hometowns and beyond.

***

Section I of this report describes the growing commitment by U.S. universities to innovation, their rising innovation impact, and the tremendous benefits university innovation activities provide for universities themselves, local economies, the national economy, and society as a whole.

Section II outlines our approach. We detail how our ranking system differs from other prominent approaches, why we focus on the variables we use in this study, how we construct our rankings, and how we evaluate productivity in converting research inputs to innovation impact outputs.

Section III presents our rankings of U.S. universities, both for overall innovation impact and for innovation impact productivity.

Section IV summarizes our findings on factors that influence universities' success in generating innovation impact.

Section V provides brief case studies of three exceptionally productive institutions — The University of Florida, Drexel University, and Brigham Young University.

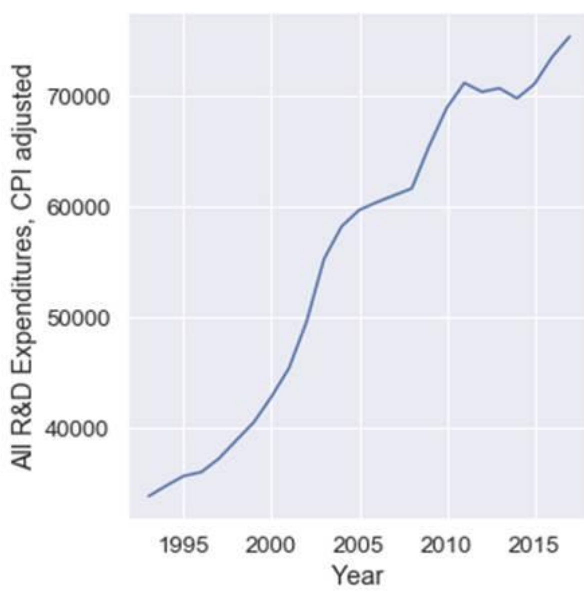
Section VI concludes.

Section I: The innovation impact of U.S. universities

Universities play a vital role in fueling innovation, which drives long-term economic growth and rising living standards in the U.S. economy and society. The contribution of universities to economic growth starts with producing educated graduates. The share of the nation's adult population with a bachelor's degree or higher, as well as the share with a graduate or professional degree, has increased steadily in recent decades, adding to the economy's stock of skilled human capital. An increasing stock of highly educated, technically skilled workers is essential to economic growth in today's specialized and technologically advanced workplace.

But university research makes a vital contribution to economic growth, too. Between 2013 and 2017, U.S. universities spent approximately $75 billion per year on research, amounting to 14 percent of total higher education spending in the United States.[5] Total research spending has risen from $54 billion in 2008, increasing slightly as a percentage of the U.S. economy over the past decade. Figure 1 shows the long-term growth of research spending by U.S. universities, adjusted for inflation.

Figure 1
TOTAL RESEARCH SPENDING BY U.S. UNIVERSITIES[6]
(USD in millions)



[5] Department of Education, National Center for Education Statistics data.
[6] Data is in 2017 dollars, in millions. Department of Education, National Center for Education Statistics data, adjusted for changes in the U.S. Consumer Price Index, Bureau of Labor Statistics.

University research spending also constitutes approximately 13 percent of America's total spending on research and development (R&D). This statistic, however, understates the central role of university research. Universities conduct a majority of the country's basic research, while the private sector largely focuses on product development, which often relies on discoveries from basic research.

From 2013 to 2017, U.S. universities spent approximately $75 billion per year on research, amounting to 13 percent of America's total investment in R&D.

Universities disseminate innovative research findings to the rest of the economy through a multitude of channels. The best-known channel is publication through professional journals, books, websites, and other media. Another important channel is through patent applications by universities and individual researchers. Academic researchers frequently initiate and conduct their research and disseminate results through direct collaboration with private-sector firms and entrepreneurs, including sponsored research arrangements.

Alternatively, universities often generate their own spinout businesses, which disseminate research findings through their commercialization efforts. Finally, universities disseminate research findings by sending out graduates who have become knowledgeable about cutting-edge research through their academic studies.

The rise of modern-day intellectual property commercialization

The last four decades have seen a tremendous increase in the higher education sector's investment in patenting and commercializing intellectual property generated by university researchers. The Bayh-Dole Act of 1980 permitted U.S. universities to assert ownership of intellectual property financed partly by government funds for the first time. Between 1980 and 2017, the number of universities with dedicated technology transfer offices (TTOs) focused on patenting and commercialization activities rose from 25 to more than 225, and the professional staff engaged in these activities increased even faster.[7] In the words of Dan Berglund, former president of the State Science & Technology Institute, "The amount of interest in encouraging the commercialization of university-developed technology has just exploded."[8]

---

[7] Carlsson B. & Fridh A.C. (2002), "Technology transfer in United States universities," *Journal of Evolutionary Economics*, Vol. 12, No. 1, pp. 199-232; Association of University Technology Managers (AUTM) data.
[8] Quoted in Friedman J. & Silberman J. (2003), "University technology transfer: Do incentives, management, and location matter?" *Journal of Technology Transfer*, Vol. 28, No. 1 (January), pp. 17-30.

More generally, many universities have stepped up their commitment to research activities in STEM fields. This commitment is visible in the number of postdoctoral researchers employed at U.S. universities, which has more than tripled over the past four decades[9] and in the proliferation of state-of-the-art science and engineering facilities across university campuses.

In the survey Opus Faveo conducted in 2014 with 92 large universities, 51 percent rate the importance of intellectual property commercialization to their university's mission as "high," while 38 percent rate its importance as "medium" and 11 percent as "low." Based on the survey, the top priorities of these universities related to intellectual property include commercializing patents, increasing the number of license agreements with outside businesses, launching more spinout companies, and raising more funds from industry-sponsored research.

U.S. universities create approximately 1,000 spinout companies and earn more than $2.9 billion in license revenues per year.

Increased research, patenting, and commercialization activities have led to large increases in innovation impact outputs, based on a variety of measures.

- Total patents issued each year to U.S. universities and their faculty rose more than four-fold from 1980 to 2017, growing as a share of all U.S. patents issued to American inventors.
- The number of new spinout companies launched by university TTOs increased from virtually zero in the 1970s to approximately 200 per year in the early 1990s and to about 1,000 per annum over the five years from 2013 to 2017.
- Total income to universities from licensed intellectual property rose from approximately $200 million in 1990 to more than $2.5 billion by 2015, a sixfold increase, adjusted for inflation.[10]

Figures 2, 3, and 4 show the aggregate growth in issued patents, spinout companies, and license income, respectively. (Each reflects aggregate data for institutions that report to the Association of University Technology Managers, or AUTM.)

[9] National Science Foundation data, as cited in "Foreign postdocs in the U.S.: What are the numbers?", PostdocinUSA website, available at https://postdocinusa.com.
[10] AUTM data, as cited in DeVol R., Lee J., and Ratnatunga M. (2017), "Concept to Commercialization: The best universities for technology transfer," Milken Institute report (April); United States Patent and Trademark Office data.

Figure 2

TOTAL PATENTS ISSUED TO U.S. UNIVERSITIES[11]

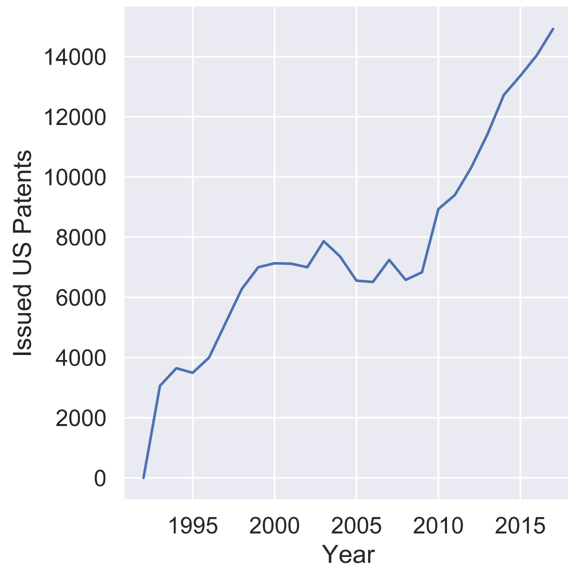
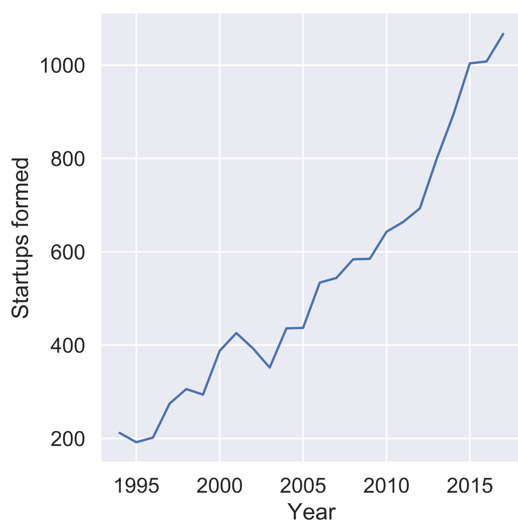


Figure 3

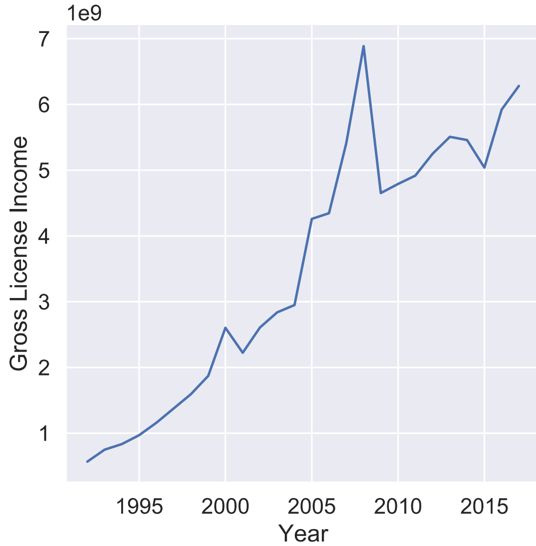
TOTAL SPINOUT COMPANIES LAUNCHED BY U.S. UNIVERSITIES[12]



[11] Association of University Technology Managers dataset.

[12] Ibid.

Figure 4
TOTAL LICENSE INCOME EARNED BY U.S. UNIVERSITIES[13]



Benefits from innovation activities

Increased innovation activity has brought significant benefits to U.S. universities, the localities in which they reside, the national economy, and society as a whole.

Universities: Commercializing intellectual property has paid dividends in numerous forms. A 2009 study found that total annual license income earned by universities that report data to the Association of University Technology Managers (AUTM) amounted to 2.9 percent of annual research expenditures — a compelling return, considering that this income stream is hardly the main objective of universities' research mission.

Based on the updated analysis we present in this report, the total return from licensed intellectual property has improved over the last decade. The 225 universities for which we have data earned aggregate license income of $2.98 billion per year on average between 2013 and 2017, amounting to 4 percent of total research spending during the period. A number of America's largest universities, typically spending between $500 million and $1.6 billion per year on research, have created license income streams of $50 million to $250 million a year, generating returns in excess of 10 percent.

[13] Ibid.

Innovative research activities also play an increasingly important role in attracting high-quality faculty and students. In the 2014 Opus Faveo survey, 75 percent of universities said that commercialization success is "very important," "important," or "somewhat important" in recruiting faculty members, while 46 percent said it's "very important" or "important."

Meanwhile, 53 percent say technology commercialization is "very important," "important," or "somewhat important" in attracting students, which is unsurprising when one considers the priority many universities place on offering research opportunities to their students.

Our survey indicates that 75 percent of large U.S. universities view commercialization success as "very important," "important," or "somewhat important" in recruiting faculty members, while 53 percent see it as "very important," "important," or "somewhat important" in attracting students.

Moreover, successful patenting and commercialization activity seems to enhance a university's core missions in basic research and teaching. Contrary to early fears that a rising emphasis on commercialization would detract from the quality of basic research, two studies have debunked the idea of a tradeoff between patenting and research quality.[14] A series of studies have further reported evidence for positive relationships at the level of whole universities between patent applications and publication quantity,[15] as well as between issued patents and publication quantity.[16]

In this report, we additionally find a positive correlation between productivity in converting research spending to literature citations for university faculty — a standard measure of research

---

[14] Zucker L.G. and Darby M.R. (1996), "Star scientists and institutional transformations: Patterns of invention and innovation in the formation of the biotechnology industry," Proceedings of the National Academy of Sciences, Vol. 93, No. 23, pp. 12709-16; Sampat B.N. (2003), "Private parts: Patents and academic research in the twentieth century," Georgia Tech School of Public Policy working paper, available at https://pdfs.semanticscholar.org/ab8a/94f8722825ac3571bcb05d697636620a7c70.pdf.

[15] Fisch C.O. (2015), "University patenting: A comparison of 300 leading universities worldwide*," Journal Technology Transfer,* Vol. 40, No. 2 (April), pp. 318-45.

[16] Breschi S. et al. (2005), "From publishing to patenting: Do productive scientists turn into academic inventors?" *Revue d'Economie Industrielle*, No. 110, 2nd trimester, pp. 75-102; Bresci S. et al. (2008), "University patenting and scientific productivity: A quantitative study of Italian academic inventors," *European Management Review*, Vol. 5, No. 2 (Summer), pp. 91-109; Crespi G. et al. (2011), "The impact of academic patenting on university research and its transfer," *Research Policy*, Vol. 40, No. 1 (February), pp. 55-68; Wong P. and Singh A. (2010), "University patenting activities and their link to the quantity and quality of scientific publications," *Scientometrics*, Vol. 83, No. 1.

quality — and productivity in converting research spending into spinout companies. And, the universities that are outperformers in these two categories also turn out to be outperformers in producing bachelor's and master's graduates in STEM fields, which suggests that success in patenting and commercialization tends to go hand in hand with success in a university's core teaching mission as well.

Productivity in innovation impact positively correlates with productivity in research and teaching impact, refuting the premise of a tradeoff between commercialization and the traditional teaching mission of universities.

Localities: Studies in Europe and the United States have found that a disproportionate share of technology spillovers from university research to the private sector occur locally. For instance, citations of a university's work in both patents and other academic papers disproportionately come from other researchers or companies residing relatively close to the university.[17]

Studies of U.S. metropolitan statistical areas (MSAs) and German cities and towns have found that localities with a relatively rich portfolio of research-intensive universities have experienced greater R&D activity, innovation impact, and growth among local firms than other places.[18] Another study reported that cities in which the Swedish government established new STEM-focused research universities in the 1970s and 1980s enjoyed stronger productivity growth in the local private-sector economy in subsequent years than other cities did.[19]

Finally, a university's research and teaching work spills over to its local economy by producing STEM graduates who frequently opt to stay in the area for the long term. A 2008 Brookings Institution study on the local economic impact of "Eds and Meds" institutions reported evidence that while many graduates obviously leave the locality where they received their education, a

---

[17] Calcagnini G. & Favaretto I. (2016), "Models of university technology transfer: Analyses and policies," *Journal of Technology Transfer*, Vol. 41, pp. 655-60; Arundel A. and Geuna A. (2004), "Proximity and the use of public science by innovative European firms," *Economics of Innovation and New Technology,* Vol. 13, pp. 559-80; Jaffe A., Trajtenberg M., and Henderson R. (1993), "Geographic localization of knowledge spillovers as evidenced by patent citations," *Quarterly Journal of Economics*, Vol. 108, pp. 577-98.
[18] Anselin L., Varga A., and Acs Z. (1997), "Local geographic spillovers between university research and high technology innovations," *Journal of Urban Economics*, Vol. 42, pp. 422-48; Audretsch D.B. & Lehmann E.E. (2005), "Mansfield's missing link: The impact of knowledge spillovers on firm growth," *Journal of Technology Transfer*, Vol. 30, pp. 207-10.
[19] Andersson R., Quigley J.M., and Wilhelmsson M. (2006), "Urbanization, productivity, and innovation: Evidence from investment in higher education," Working Paper No. W05-001, Institute of Business and Economic Research, Program on Housing and Urban Policy, University of California at Berkeley.

state that increases its output of college graduates will experience a rise in its stock of graduates equal to 30 percent of the original increase after 15 years, all else equal.[20]

The national economy: Between 2011 and 2015, the 225 research institutions in our dataset produced an average of 62,542 doctoral graduates and 399,129 bachelor's or master's degree graduates per year in STEM fields, amounting to more than 10 percent of the individuals entering (or re-entering) the U.S. labor force each year. Growing numbers of STEM graduates — together with high-skilled immigrants — have contributed to a doubling in the share of the U.S. workforce engaged in R&D activities since the 1980s.[21] U.S. universities constitute 46 of the top 100 universities in the world and eight of the top 10 for the quality and quantity of patenting activity, according to an international ranking published by Thomson Reuters.[22] They make up eight of the top 14 for producing spinout companies, based on data from the media site Global University Venturing.[23]

While we cannot be confident about how much the innovation impact of U.S. universities has added to America's economic growth, we can obtain some idea from two calculations economists have made. First, economists generally agree that technological progress and a rising stock of human capital — both of which owe a great deal to America's universities — have accounted for at least 70 percent of the nation's long-term growth of 2.0 percent in Gross Domestic Product (GDP) per capita over the last century.[24]

Second, a 2016 study of the European Union found that the most important driver of differences in innovation across European countries has been cross-country differences in the number of STEM Ph.D.s and technical publications.[25] It follows that America's lead over European countries in these measures helps to explain the considerable edge the United States maintains in income levels.

Social benefits: University research has spawned a wide variety of products with significant societal benefits, including the automobile seatbelt from Cornell University, Global Positioning System technology from the Massachusetts Institute of Technology (MIT), nuclear reactors from the University of Chicago, beta-carotene-rich golden rice from Louisiana State University, fluoride toothpaste from Indiana University, Factor IX hemophilia drugs from the University of Washington, the cancer drug Cisplatin from Michigan State University, the glaucoma drug

[20] DeVol R., Lee J., and Ratnatunga M. (2017).
[21] Jones C.I. (2016), "The facts of economic growth," in *Handbook of Macroeconomics*, Vol. 2, available at http://dx.doi.org/10.1016/bs.hesmac.2016.03.002.
[22] Ewalt D.M. (2018), "Reuters Top 100: The world's most innovative universities - 2018," available at https://www.reuters.com/article/us-amers-reuters-ranking-innovative-univ/reuters-top-100-the-worlds-most-innovative-universities-2018-idUSKCN1ML0AZ.
[23] "Europe's old schools hatch new firms," *Wall Street Journal*, 10 October 2019.
[24] Ibid.
[25] Calcagnini G. & Favaretto I. (2016).

Trusopt from the University of Florida, antiretroviral drugs from Yale University, the calcium supplement Citracal from the University of Texas Southwestern Medical Center, pacemakers from the University of Minnesota, laser cataract surgery from the University of California at Los Angeles, genome sequencing techniques from Tufts University, the spreadsheet from Harvard University, web browsers from the University of Illinois at Urbana-Champaign, web traffic-conducting technology from MIT, and the Google search engine from Stanford University.

Cold Spring Harbor Laboratory, a premier private, nonprofit research institution, illustrates the social benefits from cutting-edge research well. The laboratory played a key role in the discovery of DNA and has long been among the premier research centers engaged in elucidating the genetics and molecular biology of cancer. In 2016, the FDA approved SPINRAZA®, a drug for the deadly childhood disease spinal muscular atrophy, that researchers at Cold Spring Harbor Laboratory discovered using the lab's novel RNA-splicing technology. SPINRAZA was the first FDA-approved drug to alter the underlying biology of a neurodegenerative disease.

For all these reasons, America has a vital interest in the innovation impact and productivity of its research universities.

Section II: Our approach

Overview

In this report, "innovation impact" means the dissemination of research findings in science, technology, engineering, and mathematics (STEM) fields beyond the walls of academia in ways that directly drive technological progress in the wider economy and society. We distinguish "innovation impact" from the societal benefits universities produce through non-STEM teaching and research activities.

We calculate a composite innovation impact score for each university, comprising nine innovation impact variables grouped into four categories:

- **Commercialization impact:**
  - ✓ New patents issued
  - ✓ New licenses
  - ✓ License income
- **Entrepreneurship impact:**
  - ✓ Spinout companies
  - ✓ Licenses to spinouts
- **Research impact:**
  - ✓ Paper citations
  - ✓ Patent citations
- **Teaching impact:**
  - ✓ New STEM doctoral graduates
  - ✓ New STEM bachelor's and master's graduates

Our rankings reflect a broader definition of innovation impact than three widely cited rankings in the literature, from the Milken Institute,[26] Thomson Reuters-Clarivate Analytics,[27] and the venture capital-focused media organization PitchBook.[28] The Milken Institute's approach uses the first four variables in our set (issued patents, new licenses, license income, and spinout companies) but does not incorporate variables associated with research impact or teaching

[26] DeVol R., Lee J., and Ratnatunga M. (2017), "Concept to Commercialization: The best universities for technology transfer," Milken Institute report (April).
[27] Ewalt D.M. (2018), "Reuters Top 100: The world's most innovative universities - 2018," available at https://www.reuters.com/article/us-amers-reuters-ranking-innovative-univ/reuters-top-100-the-worlds-most-innovative-universities-2018-idUSKCN1ML0AZ.
[28] "PitchBook Universities: 2019," 5 September 2019, available at https://pitchbook.com/news/articles.

impact. The Thomson Reuters-Clarivate Analytics ranking relies primarily on metrics associated with Clarivate's rich dataset on patenting and patent citations, while PitchBook's ranking focuses on the universities attended by venture capital-backed startup founders.

Our approach reflects a broader definition of innovation impact than other published studies do, consistent with a variety of data on how university leaders tend to think in setting goals for their institution's innovation activities. We include not only commercialization and entrepreneurship measures but also measures of research impact and teaching impact.

Our method, we suggest, is complementary to these existing ranking systems, in that our composite score measures a broader set of innovation activities than they capture.

We also suggest that our concept of innovation impact more closely aligns with the way top university leaders typically think in setting goals for their institution's innovation activities. For instance, our 2014 survey, as well as surveys by other researchers,[29] shows that universities rank licensing technologies and launching spinouts well ahead of patenting activities on their list of intellectual property-related objectives. Survey evidence also demonstrates that many star researchers highly value opportunities to participate in spinout companies based on their work, so universities should and do consider spinouts a significant piece of their recruiting efforts.[30]

Also, our data shows that success in patent citations — while certainly a measure of high-impact innovative research — has a relatively low correlation with success in the other eight metrics, so it would be inappropriate to infer that universities that score high on patent citations are likely to be outperformers in the other measures of innovation impact.

At the same time, academic publications represent a crucial channel through which universities exert social impact beyond their walls. As the literature on local and national economic impact shows, it's often the published output of a university's researchers that most closely predicts knowledge spillovers to the wider economy, rather than its TTO's commercialization activities as such.

A Carnegie Mellon study found that what most distinguishes universities with outsized economic impact on their local economy is the "breadth of involvement" of the whole university in

---

[29] Thursby J.G. et al. (2001), "Objectives, characteristics, and outcomes of university licensing: A survey of major U.S. universities," *Journal of Technology Transfer*, Vol. 26, Nos. 1-2 (January), pp. 59-72.
[30] Markman G.D., Siegel D.S., and Wright M. (2008), "Research and technology commercialization," *Journal of Management Studies*, Vol. 45, No. 8 (December), pp. 1401-23.

innovation activities, including publishing, collaboration with industry, and skills development in students. According to the authors, "the most engaged universities demonstrate these kinds of diverse, integrated commitments across administrative and academic units."[31]

Finally, in response to our 2014 survey's question on how universities evaluate the success of their innovation activities, one of the top answers was the number of well-prepared graduates they produce.

Consequently, we believe it is appropriate to include "research impact" and "teaching impact" outputs such as patent citations, paper citations, and STEM graduates alongside "commercialization impact" and "entrepreneurship impact" outputs in a broad composite of innovation impact.

A second respect in which our approach differs from the three best-known ranking systems is that we explicitly separate the overall *innovation impact* of universities from their *productivity* in converting inputs — in the form of research spending — into outputs, such as patents, licenses, widely cited papers, and graduates. In contrast, ranking systems created by the Milken Institute and Thomson Reuters-Clarivate Analytics mix innovation impact output variables (stated in absolute levels) with innovation impact productivity variables (stated in ratios) to generate composite scores.

We suggest that separating innovation impact and innovation impact productivity into separate measures draws a useful distinction. Some universities, typically very large institutions, generate enormous levels of innovation impact in the form of large volumes of patents, licenses, license dollars, spinouts, paper citations, and graduates, but achieve relatively low innovation impact productivity in converting inputs to outputs. Other, smaller universities are extraordinarily productive in creating innovation impact outputs from modest-sized research spending, even though their overall output is at best mid-sized relative to that of other institutions.

A third difference is that our main ranking approach combines our nine innovation impact measures through principal component analysis (PCA), which effectively lets the data inform us about how to weight the nine variables in our composite scores, rather than assigning arbitrary weightings. We explain our use of PCA in Appendix 1 on methods. (To assess the robustness of our results, we also rank the universities in our dataset based on a simple weighted average method, closer to that used in prior studies, and wind up with very similar results.)

Our report also builds on a substantial body of academic literature focused on factors explaining why some universities are more successful than others in generating innovation impact. The most

[31] Paytas J., Gradeck R., and Andrews L. (2004), "Universities and the Development of Industry Clusters," Carnegie Mellon University Center for Economic Development report.

notable conclusions from this literature are that: (1) very large universities seem to be less productive in converting research inputs to innovation impact outputs than smaller universities, and (2) factors predicting success include being in a large metro area, having high-quality faculty based on widely accepted measures, operating a relatively large technology transfer office, and relying relatively little on industry sponsorship for research funding.

This study, we suggest, adds to the existing literature in four important ways.

First, our study of factors influencing the success of university technology innovation activities again defines innovation impact more broadly. We show that variables which previous researchers have found to be significant predictors of commercialization and entrepreneurship impact predict research and STEM teaching impact as well and thus predict success in our broad composite measure of innovation impact.

Second, we update the analysis, studying the effects of the main explanatory variables cited in the literature with more recent data. These variables include university size, metro area size, metro area median income, faculty quality, invention disclosures, size of the TTO, and share of research spending from industry. Our study uses AUTM data from 2013 to 2017, while most published studies rely on AUTM data from the 1990s or early 2000s. We also replicate certain methods used in widely cited studies of older data, such as using data envelopment analysis (DEA) to study the innovation impact productivity of universities. For the most part, our study reinforces the findings of earlier work.

Third, we introduce some new predictive variables that have not appeared in previous literature, specifically the foreign-born share of the local population and whether the TTO head is a trained engineer. Both factors turn out to have significant positive effects on innovation impact.

Fourth, we include a novel analysis of the interrelationships among our nine innovation impact output measures. This analysis suggests a number of nontrivial relationships that deserve further study.

Variables and data

<u>Innovation impact variables</u>. The first four of our nine variables are standard measures of innovation impact in the literature. We include the number of licenses to spinout companies (a less typical measure) alongside the number of spinouts because it provides a second measure of entrepreneurial activity by universities, and because our survey confirms that universities place a high priority on fostering such entrepreneurial activity.

As for our research variables, both the total number of papers citing a university's published work and the total number of patents citing the university's research represent standard measures of the externally validated impact of a university's research on other researchers and inventors. We view both variables as capturing quality as well as quantity, in contrast to the total number of papers published, which the Thomson Reuters-Clarivate Analytics ranking uses.

We draw the data for the first five variables from the AUTM dataset. For the two literature citation variables, we rely on citation counts estimated by Google Scholar and Google Patents between 2013 and 2017.[32] Our data on STEM graduates, both at the Ph.D. and master's/ bachelor's levels, comes from annual National Science Foundation and Department of Education data.[33]

One limitation of our approach is that we unavoidably exclude institutions that decline to report data to AUTM. Prominent institutions that do not participate in the AUTM survey include Yale University, Colgate University, and a number of respected liberal arts colleges, such as Williams College, Amherst College, and Pomona College.

Another issue the AUTM dataset raises is that a handful of state university systems — most prominently, the University of California, University of Texas, and University of Maryland systems — report data at the system level rather than at the level of individual campuses. We treat each of these systems as a single institution. The chief implication of this constraint is that the University of California and University of Texas systems rank far larger in terms of both research spending and innovation impact than all other institutions. If all data were available at the campus level, very large campuses like the University of California at Berkeley and the University of Texas at Austin would undoubtedly rank high in our research input and innovation impact rankings, but they likely wouldn't look any larger in spending or innovation impact than certain other large state institutions like the Universities of Michigan, Minnesota, and Florida.

The most notable feature of the data for our nine innovation impact variables is that, on every measure, a few large institutions are dramatically larger than all the rest. For instance, each of the top 10 institutions for number of licenses signed averaged more than 138 licenses per year between 2013 and 2017, more than 10 times the median rate of 13. Drexel University and Brigham Young University (BYU), two outstanding performers in terms of productivity in

[32] Specifically, we enter the official name of the university in quotation marks into the Google Scholar or Google Patents search box, set the date range, and include all patent offices covered by Google's search system. Google then gives an estimated citation count. In a small number of cases, we had to make minor adjustments to the university title to capture how the university refers to itself in academic literature and patents. Note that Google Scholar does not permit us to restrict our count to papers in STEM fields. In practice, however, STEM papers constitute a large majority of papers identified by our method.

[33] Available from the National Center for Education Statistics' Integrated Postsecondary Education Data System (IPEDS) surveys.

converting research inputs to innovation impact outputs, signed only 28 and 30 licenses per year, on average.

Similarly, the 10th-ranked institution's innovation impact output was some eight to 20 times that of the median institution for issued patents, spinouts, licenses to spinouts, paper citations, and patent citations. The dominance of the leading institutions is even more pronounced in terms of license income. The top 10 institutions for license income earned an average of $86 to $327 million per year, with the 10th-ranked institution earning more than 50 times the median income of $1.6 million.

Table 3 summarizes our data. All figures represent annual averages over the years 2013 to 2017.

Table 3
SUMMARY OF INNOVATION IMPACT DATA

	Highest Value	**10th - 2nd Highest Values**	**Median Value**	**No. of Institutions**	**Top Institution**
Research spending ($m)	$4,999	$1,018 - $2,676	$160	217	Univ. of California System
Licenses signed	315	138 - 275	13	209	Univ. of Washington
License income ($m)	$327	$86 - $235	$2	211	City of Hope Med. Ctr.
Patents issued	457	114 - 297	14	214	Univ. of California System
Spinout companies	81	16 - 29	3	216	Univ. of California System
Licenses to spinouts	72	24 - 45	3	208	Univ. of California System
Paper citations (000s)	1,100	253 - 654	18	225	Univ. of California System
Patent citations	43,608	3,065 - 13,812	145	225	Cold Spring Harbor Lab.
STEM Ph.D. graduates	3,883	907 - 2,456	160	225	Univ. of California System
STEM bachelor's/master's grads	22,953	5,378 - 17,494	1,184	225	Univ. of California System

Relationships among our nine innovation impact variables. As Table 4 shows, our nine innovation impact variables are positively correlated with one another. All 36 pairwise correlations are positive, indicating universities that have relatively high innovation impact output on one of the nine measures are likely to have relatively high innovation impact output on the other eight as well. Pairs of variables with especially high correlations include spinout companies and patents issued (with a correlation of 0.9), STEM bachelor's/master's graduates and STEM Ph.D. graduates (0.9), licenses to spinouts and patents issued (0.8), paper citations and spinout companies (0.8), STEM Ph.D. graduates and spinout companies (0.8), and STEM bachelor's/master's graduates and spinout companies (0.8).

Table 4
CORRELATIONS AMONG THE NINE INNOVATION IMPACT VARIABLES[34]

	Licences	License Income	Patents Issued	Spinout Firms	Licenses to Spinouts	Paper Citations	Patent Citations	Ph.D. Grads	Bach/Mast Grads
Licenses	1								
License Income	0.3	1							
Patents Issued	0.7	0.4	1						
Spinout Firms	0.7	0.4	0.9	1					
Licenses to Spinouts	0.8	0.4	0.8	0.9	1				
Paper Citations	0.6	0.4	0.7	0.8	0.7	1			
Patent Citations	0.2	0.2	0.3	0.3	0.3	0.3	1		
Ph.D. Grads	0.7	0.3	0.7	0.8	0.8	0.7	0.2	1	
Bach/Masters Grads	0.6	0.2	0.7	0.8	0.7	0.7	0.2	0.9	1

It may be that these correlations simply reflect the scale of universities, with larger universities achieving relatively large innovation impact output on all nine variables. We suggest it also makes sense to evaluate correlations among nine productivity scores, where each score is the university's output on one of the nine variables divided by its total research spending. Table 5 shows the correlations among these nine productivity scores.

As Table 5 demonstrates, institutions that attain relatively high productivity on any of the nine measures also tend to be outperformers on most of the other eight. Of the 36 pairwise correlations, 22 are positive.

[34] Table 5 reports correlations for 2013-2017 annual averages for each variable at the level of whole institutions.

Table 5

CORRELATIONS OF INNOVATION IMPACT PRODUCTIVITY AMONG THE NINE INNOVATION IMPACT VARIABLES[35]

	Licences	License Income	Patents Issued	Spinout Firms	Licenses to Spinouts	Paper Citations	Patent Citations	Ph.D. Grads	Bach/Mast Grads
Licenses	1								
License Income	0.1	1							
Patents Issued	0.3	0.0	1						
Spinout Firms	0.4	0.0	0.6	1					
Licenses to Spinouts	0.5	0.0	0.6	0.8	1				
Paper Citations	0.0	0.1	0.3	0.1	0.1	1			
Patent Citations	0.0	0.0	0.0	0.0	0.0	0.1	1		
Ph.D. Grads	-0.1	-0.1	0.2	0.1	0.1	0.3	-0.1	1	
Bach/Masters Grads	0.1	-0.1	0.5	0.2	0.3	0.5	0.00	0.2	1

This analysis has two implications. First, the high correlations in innovation impact across our nine variables validate our approach of combining the nine to construct composite scores. Our overall composite scores combine closely interconnected activities associated with innovation impact rather than create a total score out of unrelated "apples and oranges."

Second, the generally positive correlations we report in Tables 4 and 5 strongly suggest that relative success in terms of commercialization impact and entrepreneurship impact reinforce rather than compete with university activities focused on research impact and teaching impact, at least insofar as research and teaching activities involve STEM fields.

In general, universities that are unusually productive at converting research inputs to innovation impact on one of our nine output measures are unusually productive on most of the other measures as well. High productivity on our commercialization and entrepreneurship measures is positively correlated with high productivity in research impact and teaching impact.

[35] For Table 6, we divide each institution's 2013-2017 annual average for each innovation impact variable by the institution's average research spending over the same period to compute productivity ratios. The table reports correlations across these ratios, which means a positive figure indicates that universities with higher than average productivity in converting research spending to one of the innovation impact outputs tend to have higher productivity in the other outputs as well.

Explanatory variables. Our data for university research spending, as well as for invention disclosures, patent applications, and the share of spending funded by industry, come from the AUTM dataset.

To analyze the relationships between a university's location and its innovation impact productivity, we study several variables at the level of Metropolitan Statistical Areas (MSAs), as defined by the U.S. Census Bureau. These include each MSA's population, median age, population share with a bachelor's degree or higher, median household income, and housing affordability — in most cases, consistent with a number of prior studies. We also consider the foreign-born share of each metro area's population, a variable we have not seen in prior literature.

We address the influence of a number of university attributes, in addition to research spending and invention disclosures. These include endowment size, total budget, the number of members of the prestigious National Academies of Sciences, Engineering, Medicine, and Inventors on each university's faculty,[36] whether a university is a member of the Association of American Universities (AAU) or is included in the Top American Universities list published by the Center for Measuring University Performance (CMUP), whether a university is public or private, whether it has a business school or an engineering school, and the number of international students as a share of a university's student body.

We also classify each institution as a comprehensive research university without a medical school (where "comprehensive" means it educates undergraduates, trains graduate students, and conducts research), a comprehensive research university with a medical school, a pure medical school, or a pure research/health care institution. Institutions in the third category conduct research, train medical students, and typically treat patients, while they do not educate undergraduates. The fourth category includes a number of institutions that conduct research and in some cases treat patients, but don't offer degree programs, such as Cold Spring Harbor Laboratory and Cleveland Clinic. Our study examines the effect of a university's classification under this method on its innovation impact.

As for what we call "policy" variables — that is, resource allocation decisions that universities can change more easily than (say) their location or total size — we include several that have appeared in numerous past studies: technology transfer office (TTO) staff size, whether the university has a seed fund, and whether it has an "accelerator."[37] We also consider the effect of

[36] Election to one of the National Academies by one's peers is a highly prestigious honor for researchers, and the number of members of the National Academies at a university is a widely cited measure of the university's faculty quality.

[37] An "accelerator" is a program supporting early-stage, innovation-driven, growth-focused companies, typically for a short duration such as 12 weeks through education, mentorship, financing, and sometimes, office space. Prominent

several additional variables we have not seen in prior literature, including whether the TTO head is a trained engineer, whether she has business or startup experience, and whether the university has a teaching program on entrepreneurship.

We summarize the data sources for our explanatory variables in Appendix 1.

The one policy variable we would have liked to include but could not is the extent of incentives universities make available to individual faculty inventors through shares of royalty income or other mechanisms. Most universities provide little public information on such incentives. The handful of studies addressing the effect of researcher incentives have typically relied on proprietary surveys of around 20 institutions. We prioritized achieving a much larger sample size in this study, so gathering proprietary data on incentives proved impractical.

Again, a few institutions are far larger than all the rest on most measures of scale. The University of California and University of Texas systems spent an average of $5.0 billion and $2.7 billion per year on research from 2013 to 2017, respectively, while the next eight each spent between $1.0 billion and $1.6 billion. The median institution spent $160 million per year. High-performing Drexel and BYU spent $107 million and $33 million, respectively.

The number of National Academies members ranged from 59 to 535 for the top 10 institutions on this measure, compared to four at the median university. Forty-nine of the institutions in our dataset are members of the AAU, while 113 made the CMUP's Top American Universities list.

As for our "policy" variables, the 10 largest TTOs range in size from 42 to 67 staff, while the median TTO has seven people. The TTO head is a trained engineer at 24, or 12 percent, of the 199 institutions for which we have data. Eighty-one institutions have a seed fund, 85 have an accelerator, and 135 have an entrepreneurship program, amounting to 41, 43, and 68 percent of the institutions in the dataset.

The share of research spending funded by industry among the institutions in the dataset ranges from 0 to 73 percent, while industry funds five percent of research spending at the median university. The industry funding ratio exceeds 15 percent at just 21 institutions, including several pure research/health care institutions.

Certain correlations among the explanatory variables are worth noting. The correlation between total research spending and endowment size is approximately 0.52, which means the overall size of an institution's available resources predicts its research spending to some degree but not

---

examples include Y Combinator in the San Francisco Bay area and Techstars in Boulder, Colorado. This study counts universities as having an accelerator, if and only if they directly control the entities providing startup companies these services.

perfectly. Universities have a considerable degree of choice in determining the scale of their research efforts.

The correlation between number of members in the National Academies and research spending is approximately 0.80, suggesting a tight relationship between research spending and this measure of faculty quality. (Even so, each of these two variables generally predicts innovation impact when we hold the other constant, as we show in Section IV.)

The pairwise correlations among metro area population, household income, educational attainment, and foreign-born population share are all very high. In particular, the correlation between metro area population and the foreign-born share of metro area population is 0.79. Finally, having a seed fund or an accelerator is positively correlated with research spending, as well as with membership in the AAU and inclusion in the CMUP's Top American Universities list.

Constructing our rankings

We construct our scores for innovation impact for each university by calculating 2013-17 annual averages for each of the nine output measures to smooth out fluctuations in the data, standardizing the annual average for each measure to make the distributions for the nine variables comparable, and aggregating the nine standardized variables into a composite score using principal component analysis (PCA), a standard statistical technique. The chief benefit of using PCA is it essentially allows the data to dictate what the implicit weighing factor on each of the nine variables should be.

As a check, we also calculate composite scores taking a simple weighted average of the nine variables, as each of the other ranking approaches in the literature do.

The section on "Constructing our rankings" in Appendix 1 explains our methods in greater detail.

Measuring productivity

We evaluate the productivity of institutions in converting research inputs to innovation impact outputs in three ways. Our preferred method is to divide each university's composite PCA score by its total research spending. (We multiply the quotient by 10^8 to arrive at more readable numbers.)

We view this ratio as a reasonable measure of productivity, based on two considerations. One is that the numerator effectively preserves scale relationships across universities. If one university has twice as much output as another university on all nine measures, then it will have twice as high a PCA score.

The other consideration is that the denominator — research spending — is in our view a reasonable proxy for total research inputs. We would readily agree that the true "production function" of university research uses multiple inputs, some of which universities employ without paying for directly, so research spending as reported to AUTM is an imperfect measure. However, AUTM requires all participating institutions to report research spending in a well-defined, consistent way. Even if research spending is an imperfect proxy for aggregate inputs, we conclude it is sufficiently comparable across institutions to allow for cross-institutional productivity comparisons.

Our second method for evaluating innovation impact productivity is to divide each university's composite innovation impact score based on our simple weighted average method by its research spending.

Finally, we evaluate productivity using data envelopment analysis (DEA), following the example of several widely cited academic studies.[38] DEA is a statistical technique that defines the production possibility frontier of a production function — that is, the curve depicting how much in outputs can be produced from given quantities of inputs — simply according to the best output-to-input relationships observed in the dataset. It then categorizes each "producer" as either fully efficient or somewhat inefficient, based on whether it is operating on the production possibility curve. Further, it quantifies the extent of inefficiency for each "inefficient" producer by connecting the dots between fully efficient producers, calculating how much a fully efficient firm with the same inputs as a given inefficient producer would produce and measuring how far below this point the inefficient producer is.

We base our DEA analysis on a production model in which the inputs include not only research spending but also invention disclosures, university endowment, total university budget, number of members in the National Academies, and institution type (with or without medical school, pure medical institution, or pure research/health care institution), and outputs that include each of our nine innovation impact measures.

We explain DEA further in the "Measuring productivity" section in Appendix 1.

One benefit of DEA is that it permits us to treat the issue of diseconomies of scale differently than we do with our first two methods. Suppose that a production process is characterized by

[38] Thursby J.G. and Kemp S. (2002); Foltz J.D. et al. (2012); Ho H.M. et al. (2014).

declining returns to scale, as we find for innovation impact at universities. Because DEA simply connects the dots to form an upper envelope around the data rather than positing a linear relationship between inputs and potential output, it allows for the possibility that a large producer may be quite productive given its large scale, even though it achieves a much lower ratio of output to input than the best-performing smaller producers.

On the other hand, DEA necessarily identifies numerous producers as fully efficient, which may give too much credit in some cases. It is possible, for instance, that some large universities which DEA scores as fully efficient despite their relatively low output-to-input ratio really are inefficient in converting research resources to innovation impact outputs. For such institutions, our methods do not resolve which interpretation is "correct."

Section III: Rankings

Innovation impact rankings

Table 6 sets forth our ranking of the top 25 U.S. universities for innovation impact. The table provides each university's PCA score, recalibrating scores such that the top-ranked University of California System earns an adjusted score of 100, which allows comparison across universities for scale. Table 6 also shows the innovation impact rank of each institution based on our alternative method using simple weighted averages across our output variables. Our two methods generate very similar rankings.

We additionally include the rankings of each institution for commercialization impact (patents issued, licenses, and license income), entrepreneurship impact (spinout companies and licenses to spinout companies), research impact (paper citations and patent citations), and teaching impact (STEM Ph.D. graduates and STEM bachelor's/master's graduates), all based on our alternative weighted average method.[39]

Appendix 2 provides a complete version of this table, with all included institutions.

As Table 6 shows, the leading universities for innovation impact create far greater innovation impact as we measure it in this report than most other institutions. The University of California and University of Texas systems achieve innovation impact significantly above even the next several institutions, reflecting their vast scale. The 10th-ranked University of Pennsylvania scores more than five times higher than the median institution in our ranking, even though most of the 195 institutions in our dataset are relatively large in terms of research spending.

Sixteen of the top 25 institutions are public research universities, while nine are private research universities. As Appendix 1 shows, several pure medical institutions and research/health care institutions rank relatively high, even though our scoring method holds them back for not educating undergraduates. For instance, the leading pure research institution for innovation impact, Cold Spring Harbor Laboratory, ranks 45th overall, while the top two pure medical institutions — Mayo Foundation for Medical Education and Research and City of Hope National Medical Center — rank 47th and 49th, respectively.

[39] Note that our PCA method necessarily uses all nine variables to compute composite scores, so we cannot use PCA to develop rankings for each of the four categories without creating significant data interpretation problems.

Table 6

RANKING OF TOP 25 UNIVERSITIES FOR INNOVATION IMPACT[40]

		Innovation Impact Score (PCA)	Total Research Spending ($m)	Innovation Impact Productivity Score	Innovation Impact Rankings (weighted average method)				
					Overall Rank	Comm. Rank	Entrep. Rank	Resrch. Rank	Teaching Rank
1	University of California System	100.00	$4,998.8	2.00	1	1	1	1	1
2	University of Texas System	55.03	$2,675.9	2.06	2	2	2	4	2
3	MIT	31.25	$1,639.4	1.91	3	4	3	9	56
4	University of Washington	29.56	$1,197.9	2.47	6	3	6	18	10
5	University of Michigan	28.70	$1,362.5	2.11	5	10	7	10	7
6	University of Florida	28.11	$565.1	4.97	7	7	9	28	4
7	Columbia University	27.24	$753.8	3.61	4	8	5	5	27
8	University of Minnesota	24.92	$916.2	2.72	8	15	15	15	6
9	Stanford University	24.53	$946.1	2.59	9	11	8	12	39
10	University of Pennsylvania	23.25	$908.1	2.56	11	13	10	14	35
11	Johns Hopkins University	22.86	$1,632.0	1.40	12	16	16	6	29
12	University of Illinois at U-C	21.02	$1,014.9	2.07	13	20	17	11	22
13	University System of Maryland	20.30	$1,018.2	1.99	15	35	14	26	3
14	University of Wisconsin - Mad.	19.32	$1,120.6	1.72	18	14	35	24	16
15	Purdue University	19.15	$611.4	3.13	17	28	18	27	11
16	Northwestern University	18.56	$554.1	3.35	14	6	22	19	59
17	New York University (NYU)	18.09	$546.5	3.31	16	9	31	22	32
18	University of Pittsburgh	17.83	$732.4	2.43	21	21	20	30	23
19	Cornell University	17.29	$801.6	2.16	20	22	27	16	50
20	North Carolina State University	17.12	$464.4	3.69	23	29	12	36	28
21	Harvard University	17.08	$827.9	2.06	19	32	29	7	53
22	Ohio State University	16.81	$924.7	1.82	22	46	36	20	8
23	Duke University	16.77	$897.7	1.87	24	19	34	13	64
24	University of Utah	16.45	$386.8	4.25	26	23	11	48	48
25	State University of New York	16.36	$949.3	1.72	25	34	26	33	13
	Median institution:	4.17	$160.0	2.68					

A number of highly respected private universities rank somewhat lower for innovation impact than they do in other ranking systems, such as the Thomson Reuters-Clarivate Analytics 2018 ranking or the well-known U.S. News & World Report ranking. For instance, Stanford University and Harvard University rank 9th and 21st for innovation impact, while ranking first

[40] Appendix 2 sets forth our comprehensive ranking of 195 institutions for innovation impact. The right side of Table 6 shows innovation impact rankings in each of our four categories: commercialization, entrepreneurship, research, and teaching.

and third in the Thomson-Reuters 2017 ranking and invariably appearing in the top five in the annual U.S. News & World Report ranking. This difference in part reflects the fact that they are smaller institutions than a number of the largest state universities, with far fewer graduates. From 2013 to 2017, more than 30 state universities produced more STEM Ph.D. graduates, as well as STEM bachelor's and master's graduates than Stanford or Harvard.

On the other hand, Stanford and Harvard, plus other premier private institutions like the University of Pennsylvania and Johns Hopkins University, rank very high in paper and patent citations, which is why they rank high in our research impact ranking, as well as in the Thomson Reuters ranking, which relies heavily on patent citations.

In a handful of cases, the choices institutions have made about how to report data to AUTM modestly influence the rankings. For instance, the Johns Hopkins University Applied Physics Laboratory reports separately from the rest of Johns Hopkins University. If the two reported their data as one institution, Johns Hopkins University would report research spending roughly equivalent to that of the University of Texas System and would rank approximately 8th in innovation impact, instead of 11th and 125th. If Harvard University included the data from its associated hospitals, which report separately, its research spending would approach $1 billion and its innovation impact ranking would rise several spots.

Our five rankings on the right side for overall impact, commercialization impact, entrepreneurship impact, research impact, and teaching impact demonstrate that, with few exceptions, the universities that rank high overall for innovation impact rank high in each of the other four categories as well. The University of California System ranks first in all four categories.

Several private universities — MIT, Columbia University, Stanford University, the University of Pennsylvania, Johns Hopkins University, Northwestern University, Harvard University, and Duke University — rank somewhat lower in teaching impact than in the other three categories, as they are considerably smaller than the largest state universities in student numbers. A handful of institutions, meanwhile, rank significantly higher in one category than they do in the others, such as Northwestern University and New York University in commercialization, the University of Utah and North Carolina State University in entrepreneurship, Harvard University in research, and the University of Maryland System and Ohio State University in teaching.

Innovation impact productivity rankings

Table 7 presents our rankings for the top 10 institutions for innovation impact productivity in each of five categories. Our categorization breaks down the 162 comprehensive research universities into three equal-sized groups of 54, each based on total research spending. Institutions in the group of largest universities had 2013-2017 average annual research spending between $333 million and $5 billion. The mid-sized institutions spent between $100 million and $333 million, while the smaller institutions spent less than $100 million. We treat pure medical institutions and research/health care institutions as two additional, separate groups. We separate institutions in this way because we believe it makes more sense to compare institutions on productivity to other institutions of roughly similar size and mission than to institutions that differ widely in both respects.

Appendix 3 presents the complete version of this table, with all 195 included institutions.

Table 7 includes the innovation impact productivity score for each institution, calculated as our PCA innovation impact score divided by total research spending.[41] We also include each institution's rank within its group based on our alternative weighted average method, and again, the rankings do not change much under the alternative method.

As Table 7 illustrates, the five groups differ significantly from one another in innovation impact productivity, in the scores of both their top performers and their median institutions. Within the group of smaller comprehensive research universities, first-ranked Brigham Young University (BYU) has a productivity score of 30.21, far above any other institution in our study. And Drexel University, the productivity leader in the mid-sized group, scores far higher than any member of the largest university group.

The highest-performing pure medical institutions and research/health care institutions, which are relatively small institutions compared to the universities in the "large" group, also achieve relatively high innovation impact productivity levels.

Very large scale in terms of research spending does not translate into high productivity in our study. As Table 6 shows, the University of California and University of Texas systems have productivity scores of 2.00 and 2.06, respectively — just below the median level for the large university group.

A similar size relationship holds at the level of median institutions in each group. Productivity scores for the median institutions in the large, mid-sized, and smaller research university groups are 2.09, 2.81, and 5.13, respectively.

These results suggest that there are declining returns to scale in the conversion of research inputs into innovation impact outputs. We revisit this issue in additional ways in Section IV.

[41] We multiply each resulting figure by 10^8 to arrive at more intuitive quantities.

Table 7

UNIVERSITY RANKINGS FOR INNOVATION IMPACT PRODUCTIVITY

		Innovation Impact Productivity Score	Rank Based on Weighted Avg
Largest Universities:			
1	University of Florida	4.97	1
2	University of Utah	4.25	2
3	California Institute of Technology	3.93	17
4	University of Chicago	3.80	3
5	North Carolina State University	3.69	6
6	Columbia University	3.61	4
7	Northwestern University	3.35	5
8	New York University	3.31	8
9	Purdue University	3.13	11
10	University of Georgia	3.01	12
	Median of group:	2.09	
Mid-Sized Universities:			
1	Drexel University	7.85	1
2	University of New Mexico	6.77	2
3	Princeton University	5.68	3
4	Carnegie Mellon University	5.42	4
5	University of Central Florida	4.78	5
6	University of New Hampshire	4.57	8
7	University of Houston	4.34	6
8	Washington State University	4.27	7
9	Rice University	4.12	9
10	Temple University	3.70	10
	Median of group:	2.81	
Smaller Universities:			
1	Brigham Young University	30.21	1
2	University of Wisconsin - WiSys	20.30	2
3	Northern Illinois University	15.83	3
4	Duquesne University	15.43	4
5	Creighton University	14.39	5
6	Ball State University	12.56	12
7	Stevens Institute of Technology	12.49	6
8	University of North Carolina at Charlotte	10.09	8
9	University of North Florida	9.91	7
10	East Carolina University	9.45	9
	Median of group:	5.13	

Table 7 (cont.)

UNIVERSITY RANKINGS FOR INNOVATION IMPACT PRODUCTIVITY[42]

		Innovation Impact Productivity Score	Rank Based on Weighted Avg
Pure Medical Schools:			
1	University of North Texas Health Science Center	6.15	1
2	Georgia Health Sciences University	3.33	2
3	Medical University of South Carolina	2.21	3
4	Mayo Foundation for Medical Education and Research	1.55	4
5	Baylor College of Medicine	1.49	5
6	Mount Sinai School of Medicine of NYU Medical Center	1.46	6
7	Medical College of Wisconsin Research Foundation	1.06	7
	Median of group:	1.55	
Pure Research/Health Care Institutions:			
1	Cold Spring Harbor Laboratory	10.87	1
2	Whitehead Institute for Biomedical Research	6.08	2
3	Jackson Laboratory	4.41	3
4	Hospital for Special Surgery	3.27	4
5	The Wistar Institute	3.02	6
6	City of Hope National Medical Center	2.58	5
7	Moffitt Cancer Center	2.36	7
8	Salk Institute for Biological Studies	2.30	8
9	National Jewish Health	2.28	9
10	Cedars-Sinai Medical Center	1.91	10
	Median of group:	1.40	

The full rankings in Appendix 3 further demonstrate that the distribution of innovation impact productivity scores is far wider for smaller institutions than for the largest ones. Within the large university group, productivity scores range only from 1.15 to 4.97. In contrast, the smaller university group has productivity scores ranging from 0.00 to 30.21. The mid-sized group has scores from 1.20 to 7.85, while the pure research/health care institution group ranges from 0.20 to 10.87.

[42] Our main innovation impact productivity scores in Table 7 represent each institution's overall PCA innovation impact score divided by average annual research spending for 2013-2017, multiplied by 10^8 to simplify figures. The cutoffs between the largest, mid-sized, and smaller research universities are $333 million and $100 million in average annual research spending.

We suggest that the relatively compact distribution of innovation impact productivity levels for the largest institutions reflects the reality that this group consists of institutions far more similar to one another in mission and operations than the other groups. Among the smaller university group, by contrast, there is tremendous diversity in missions and in the extent to which each institution prioritizes STEM research and innovation impact.

Comparing our rankings with those of the Milken Institute highlights the effect of ranking institutions separately for innovation impact output and for innovation impact productivity. The Milken Institute report assigns high ranks to the University of Utah (1st) and CalTech (9th), two universities that score extremely high in our rankings for productivity but only moderately high (24th and 32nd) for innovation impact. It ranks BYU, 50th in our ranking for innovation impact, fourth overall, reflecting its exceptional productivity.

In contrast to the Milken Institute rankings, our innovation impact rankings identify institutions with very large output but middle-of-the-pack productivity, such as MIT, Johns Hopkins University, and the University of Texas and University of California systems. And they identify a number of smaller institutions in addition to BYU that are particularly productive, such as Drexel University, Carnegie Mellon University, the University of Central Florida, and the University of Northern Illinois.

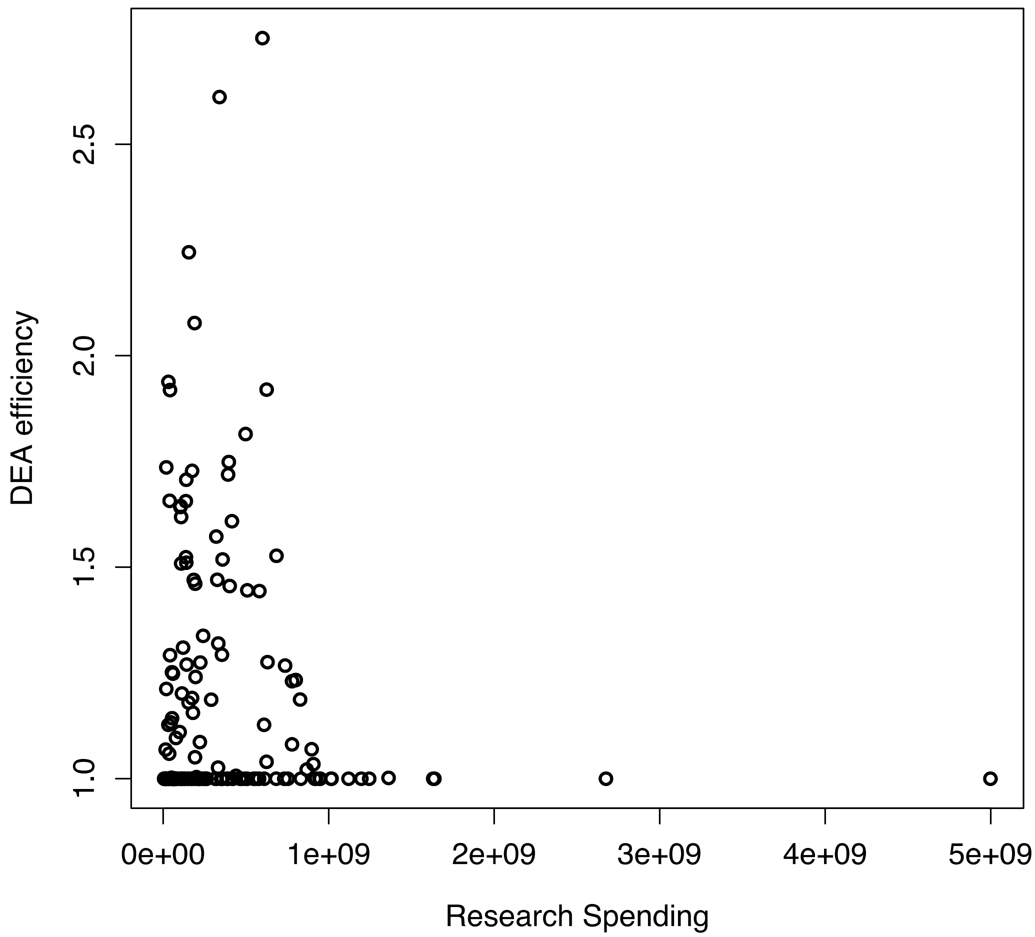
Figure 5 shows the results of our data envelopment analysis (DEA). For each institution, DEA assigns a value greater than or equal to 1. DEA categorizes institutions with a score of 1 as fully efficient, meaning they are operating on the production possibility frontier in converting multiple inputs into our nine separate outputs. Based on DEA, institutions with a score x above 1 are inefficient and have the potential to increase their innovation output by a factor of $(x - 1)$ by increasing their efficiency to the level implied by the possibility frontier.[43]

As we note in our discussion of the DEA method in Section II, DEA necessarily identifies many institutions as fully efficient. In our analysis, 106 of the 175 institutions for which we are able to calculate DEA efficiency scores are fully efficient. Most of the other institutions are relatively large or mid-sized. Of these institutions, this analysis estimates that the median university could improve its "production" of all nine outputs by 29 percent by moving to the efficient frontier, while the bottom-ranked institutions could improve their production by more than 100 percent.

Appendix 4 provides the DEA productivity scores for all universities in the dataset.

[43] Specifically, DEA calculates that inefficient institutions could increase their output of *each* of the nine innovation impact variables by a factor of $(x - 1)$ using current inputs, where the inputs for each university include its research spending, university endowment, number of members in the National Academies, and institution type (with or without medical school, pure medical institution, or pure research/health care institution).

Figure 5
PRODUCTIVITY SCORES FROM DATA ENVELOPMENT ANALYSIS (DEA)



The key difference between our main productivity scores and the efficiency scores generated by DEA is that DEA necessarily finds that a number of the largest universities in the dataset are fully efficient. For instance, it tells us that the University of California and University of Texas systems are fully efficient for the simple reason that there are no other institutions with comparable inputs but larger output to prove they are not.

This study presents substantial evidence for diseconomies of scale in turning research inputs into innovation impact output. It may be that America's very largest universities are doing as well as possible, given the constraints facing very large institutions, or it may be that they could do considerably better through improved policies. In the next section, we argue for the latter hypothesis.

Section IV: Explaining success in creating innovation impact productivity

We analyze determinants of success in creating innovation impact productivity by several methods in this section. First, we evaluate the influence of variation in a series of single variables on innovation impact productivity, one at a time. Second, we consider a number of multivariate models of innovation impact, which effectively measure the effect of variation in each explanatory variable while holding the other included variables constant. Third, we develop models to account for whether an institution is fully efficient, as measured in our data envelopment analysis (DEA).

Single-variable analysis

Scale. A variety of evidence in this study suggests diseconomies of scale in converting research inputs to innovation impact output. The correlation between total research spending and our main measure of innovation impact productivity is -0.25.

Figure 6 shows a scatterplot of innovation impact productivity (based on both our main PCA measure and our alternative weighted-average measure) against average annual research spending. The data illustrate, first, that innovation impact productivity tends to fall off with increasing size, and second, that productivity varies much more widely among smaller institutions than among large ones.

To explore the relationship between scale (measured by average annual research spending) and innovation impact productivity in greater detail, we analyze how size affects productivity in producing each of our nine innovation output variables separately. Table 8 shows the mean output per $100 million of average annual research spending for each of our five groups of institutions.

Figure 6
RESEARCH SPENDING AND PRODUCTIVITY

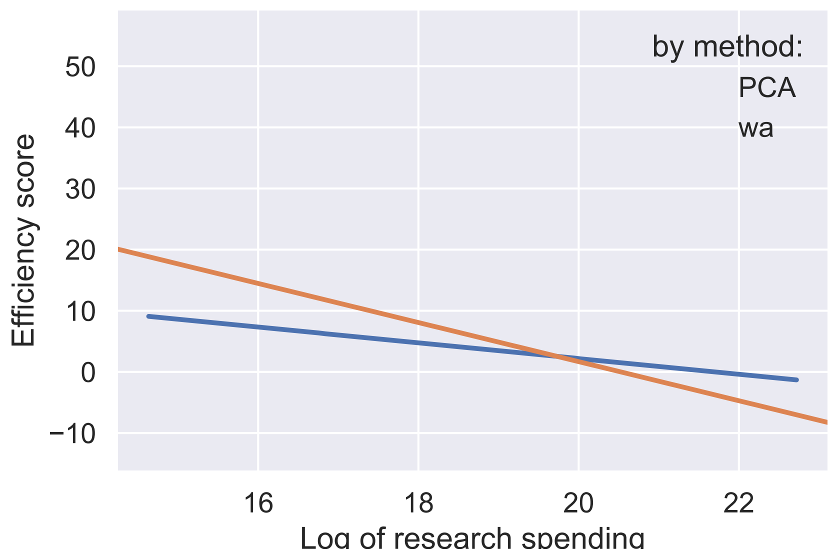


Table 8
PRODUCTIVITY IN GENERATING
EACH OF NINE INNOVATION IMPACT OUTPUTS[44]

	Comprehensive Research Universities			Medical	Res./Healthcare
(per $100m of research spend)	Large	Mid-sized	Smaller	Institutions	Institutions
Licenses	10.5	12.5	16.7	11.12	8.6
License income ($m)	3.7	4.4	1.8	4.7	11
Patents issued	10.4	11.3	14.5	6.3	6.3
Spinout firms	1.5	1.8	3.2	1.4	0.8
Licenses to spinout firms	1.9	2.7	4.3	1.7	1.2
Paper citations	16,962	16,031	31,622	6,785	5,848
Patent citations	202	137	128	140	896
Ph.D. graduates	86	158	260	84	n/a
Bach's/Master's graduates	475	891	2,780	136	n/a
No. of institutions	54	54	54	7	26

[44] For each institution, we divide its 2013-2017 annual average for a given innovation impact output variable by its average annual research spending, then multiply by $100 million to calculate more intuitive figures for innovation impact productivity. The section on comprehensive research universities divides institutions according to average annual research spending, with cutoff points of $100 million and $333 million.

As the table shows, mean output per $100 million of research spending is higher at mid-sized universities than at large universities, and higher at smaller universities than at mid-sized ones, for six of our nine innovation impact measures. Regarding the exceptions, the larger and mid-sized groups are approximately even in productivity with respect to paper citations. The mid-sized group has a notable productivity advantage over the large group in producing license income, on average, but the smaller group appears to be exceptionally unproductive on this measure. The one innovation impact measure which shows consistent evidence of *increasing* returns to scale is patent citations.

Results for the medical institution and research/health care institution groups do not point to clear conclusions. Both groups have relatively low average productivity in producing patents, spinout companies, licenses to spinout companies, and paper citations, perhaps reflecting different priorities. But they both have remarkably high productivity in creating license income, and research/health care institutions are extremely productive in generating patent citations, on average.

The evidence we present here argues for declining returns to scale in commercialization impact, entrepreneurship impact, and teaching impact, but is inconclusive on the effects of scale on productivity in generating research impact.

The evidence we present in this report suggests significant diseconomies of scale in converting research inputs to innovation impact outputs. Innovation impact productivity tends to fall off with increasing institution size for each of our nine innovation impact output measures, with the exception of patent citations. The relationship between scale and productivity in generating license income is ambiguous.

Metro areas. To evaluate the effects of a university's location on its innovation impact productivity, we separate each of our five groups into the highest-productivity quartile and the three lower-productivity quartiles and consider the extent to which the high-productivity groups separate from the rest on a series of metro-area attributes. Breaking down the dataset into our five groups partially controls for university size and mission. We focus on the first quartile, because the primary purpose of this report is to learn from the experience of top-performing institutions.

Table 9 presents this analysis for metro-area size and foreign-born share of the local population. For instance, the section on metro-area size takes the metro-area populations for all the institutions in the group and calculates the group mean. As the table shows, universities in the highest-productivity quartile tend to be in larger metro areas than those in the bottom three quartiles, in every group except that of pure medical institutions. Universities in the top-performing quartile also tend to be in localities with a larger foreign-born population share, though this effect is less pronounced in this single-variable analysis than the metro-area size effect.

Table 9

METRO-AREA ATTRIBUTES AND INNOVATION IMPACT PRODUCTIVITY

	Comprehensive Research Universities			**Medical**	**Res./Healthcare**
	Large	**Mid-sized**	**Smaller**	**Institutions**	**Institutions**
MSA size (million):					
Total	3.7	3.3	2.1	5.3	6.7
Top quartile	6.0	4.5	3.1	3.9	9.7
Bottom 3 quartiles	2.8	2.9	1.8	5.9	5.6
Ratio of top quartile to bottom 3	*2.12*	*1.52*	*1.74*	*0.66*	*1.75*
% foreign-born in MSA:					
Total	13.7%	11.7%	8.8%	13.6%	17.3%
Top quartile	16.1%	13.8%	8.7%	11.8%	20.1%
Bottom 3 quartiles	12.8%	11.0%	8.8%	14.4%	16.3%
Ratio of top quartile to bottom 3	*1.26*	*1.26*	*0.99*	*0.82*	*1.23*

Similar analysis on metro-area educational attainment levels, median household income, median age, and housing prices shows very little separation between the highest-productivity groups and the less productive groups.[45] In other words, there does not seem to be any difference on average on these metrics between the cities where the top-performing institutions are located and the cities where the rest are located.

University attributes. Table 10 presents a similar analysis for university endowment size and the number of members in the four National Academies. Viewed in isolation, it appears that the most productive institutions tend to have smaller endowments than other institutions, reinforcing the premise of diseconomies of scale. The top-performing institutions also have fewer National Academies members than other institutions in every group except mid-sized comprehensive universities, where the top performers have far more National Academies members.

[45] Data available upon request.

Table 10

UNIVERSITY ATTRIBUTES AND INNOVATION IMPACT PRODUCTIVITY

	Comprehensive Research Universities			Medical	Res./Healthcare
	Large	**Mid-sized**	**Smaller**	**Institutions**	**Institutions**
Endowment size ($m):					
Total	$5,586	$1,643	$367	$725	n/a
Top quartile	$3,298	$2,840	$338	$132	n/a
Bottom 3 quartiles	$6,429	$1,224	$377	$1,021	n/a
Ratio of top quartile to bottom 3	*0.51*	*2.32*	*0.9*	*0.13*	
National Academies members:					
Total	47.1	7.4	0.9	3.4	2.6
Top quartile	25.8	18.5	0.4	0	0.2
Bottom 3 quartiles	54.5	3.5	1.1	4.8	3.6
Ratio of top quartile to bottom 3	*0.47*	*5.29*	*0.36*	*0.00*	*0.06*

It's important to remember, however, that this analysis views each explanatory variable one at a time. Controlling for research spending and other variables in the multivariate regression setting, the apparent negative effect of large endowment size largely disappears, while the number of National Academies members turns out to influence productivity positively.

Based on similar analysis for AAU membership, inclusion in the CMUP Top Universities list, and presence of a business school or engineering school, we find little evidence for separation between high-productivity institutions and other institutions on these characteristics.[46]

University policy. Table 11 shows results for a series of what we call "policy" variables — that is, choices that universities can change relatively easily, compared to the variables we've considered so far. The first section shows, perhaps surprisingly, that top-performing institutions devote a smaller share of their total budget to research than other institutions, except in the pure research/health care institution group. The next section suggests that the most productive institutions in three groups — large comprehensive universities, medical institutions, and research/health care institutions — source a smaller share of their research spending from industry than other institutions do, while the opposite seems to be the case for mid-sized and smaller comprehensive universities.

[46] Data available upon request.

Table 11

POLICY VARIABLES AND INNOVATION IMPACT PRODUCTIVITY

	Comprehensive Research Universities			Medical	Res/Healthcare
	Large	**Mid-sized**	**Smaller**	**Institutions**	**Institutions**
Research as % of total budget:					
Total	0.23	0.21	0.10	0.24	0.29
Top quartile	0.20	0.21	0.06	0.07	0.48
Bottom 3 quartiles	0.25	0.20	0.12	0.35	0.24
Ratio of top quartile to bottom 3	*0.80*	*1.05*	*0.50*	*0.20*	*2.00*
% of research funded by industry:					
Total	0.07	0.05	0.08	0.10	0.11
Top quartile	0.06	0.06	0.09	0.04	0.05
Bottom 3 quartiles	0.07	0.05	0.07	0.12	0.13
Ratio of top quartile to bottom 3	*0.81*	*1.19*	*1.26*	*0.32*	*0.41*
TTO staff size per $100m research:					
Total	2.50	4.70	10.50	4.50	6.00
Top quartile	3.90	4.80	16.20	12.50	4.60
Bottom 3 quartiles	2.20	4.60	9.40	4.00	6.00
Ratio of top quartile to bottom 3	*1.77*	*1.04*	*1.72*	*3.13*	*0.77*
TTO head is trained engineer					
Total	0.23	0.16	0.08	0.00	0.06
Top quartile	0.29	0.23	0.20	0.00	0.00
Bottom 3 quartiles	0.21	0.14	0.04	0.00	0.08
Ratio of top quartile to bottom 3	*1.40*	*1.66*	*5.41*		*0.00*
Patent budget per $100m research ($000s):					
Total	$631	$501	$637	$418	$610
Top quartile	$855	$688	$1,535	$498	$437
Bottom 3 quartiles	$587	$434	$466	$413	$639
Ratio of top quartile to bottom 3	*1.46*	*1.59*	*3.29*	*1.21*	*0.68*
Patent applications per $100m research:					
Total	21.7	24.1	40.3	15.2	21.2
Top quartile	29.5	33.7	107.2	26.7	20.5
Bottom 3 quartiles	20.3	20.7	27.8	14.5	21.3
Ratio of top quartile to bottom 3	*1.45*	*1.63*	*3.86*	*1.84*	*0.96*
% of group with seed fund:					
Total	0.54	0.50	0.36	0.29	0.15
Top quartile	0.71	0.57	0.54	0.00	0.14
Bottom 3 quartiles	0.48	0.48	0.30	0.40	0.16
Ratio of top quartile to bottom 3	*1.50*	*1.20*	*1.79*	*0.00*	*0.91*

The next five sections show that the most productive institutions seem to have larger TTO resources per $100 million of research spending, a greater tendency to employ trained engineers as TTO heads, bigger patenting budgets per $100 million of research spending, more patent applications per $100 million of research spending, and a greater tendency to have seed funds.

Viewing our "policy" variables one at a time, we find that top-quartile universities in converting research inputs to innovation impact outputs have larger TTOs, bigger patenting budgets, and more patent applications per $100 million of research. They are more inclined to employ trained engineers as their TTO head and to have seed funds than less productive institutions, and they fund a smaller proportion of their research spending through industry sponsorships.

Multivariate analysis

In this section, we report results from 12 multivariate regression models. Each model specification treats our main innovation impact output score as the dependent variable. The model specifications vary from one another, however, in the combination of explanatory variables we include in the analysis. In all cases, we estimate models by ordinary least squares regression analysis. All of these model specifications perform relatively well in explaining variation in innovation impact across institutions, with adjusted R^2 statistics ranging from 0.47 to 0.88.

All but two of our model specifications include research spending as an explanatory variable, which means our results show the effect of variation in other variables holding research spending constant. So, our regression models effectively address the relationship between a series of explanatory variables and innovation impact productivity.

We show our full regression results in Appendix 5.

Scale. We include research spending as an explanatory variable in 10 of our 12 model specifications. The effect of variation in research spending on innovation impact is always positive and virtually always highly significant. Based on our results, a $100 million increase in research spending is associated with an increase of approximately two points in our innovation impact score, all else equal. For an institution in the middle of our ranking, this is equivalent to saying that increasing research spending by some 50 to 100 percent would raise the institution's innovation output by about 50 percent and its place in the rankings by roughly 20 spots.

Our regression results indicate that, once we control for research spending and other variables in the models, endowment size has little influence on innovation impact. This result implies that larger financial resources influence innovation impact primarily through greater research spending, not that they don't affect innovation impact at all.

We also include the square of research spending in five of our models, which allows us to capture curvature in the effect of variation in research spending on innovation impact. In economic terms, this allows us to evaluate whether there are economies or diseconomies of scale in converting research spending to innovation impact output.

The coefficients on this "quadratic" term are negative and statistically significant in four of five models, pointing to declining returns to scale. This analysis allows us to refine our estimate of the effect of increasing research spending by $100 million. For a university with current research spending of $100 million, our results suggest that a $100 million increase would be associated with an increase in the university's innovation impact score of at least two points. But the marginal effect of raising spending by $100 million is much smaller if a university already spends $1 billion a year (1.2 points) and smaller still if a university is already spending more than $2 billion, as the Universities of California and Texas are.

Metro areas. The effect of metro-area population on innovation impact is generally positive but statistically insignificant, controlling for the foreign-born share of the population and other variables. Other metro-area variables we consider in this study, including educational attainment levels, median household income, median age, and housing prices, have no consistent effects on innovation impact.

On the other hand, the foreign-born share of metro-area population is positively associated with the innovation impact of local universities in nine of the 10 model specifications in which we include it, with statistically significant effects in some but not all models. This result suggests that, while large metro-area size predicts greater innovation impact in local universities in our single-variable analysis, this effect works only insofar as large metro areas have diverse populations with relatively large immigrant communities. Controlling for the foreign-born population share, the positive effect of large size becomes insignificant.

Based on our results, a university in a metro area with a foreign-born population share of (say) 20 percent will have an innovation impact score roughly 0.7 points higher than an otherwise similar institution in a metro area with a 10 percent foreign-born share, equivalent to about 20 spots in our ranking.

Both large size and a large foreign-born population share in a metro area are associated with greater innovation impact for universities located there, all else equal. Almost all of the largest metros in the United States have relatively large immigrant population shares — and they host a number of America's premier universities. But smaller metros with large foreign-born population shares also tend to host high innovation impact universities, arguably reflecting the dynamism that immigrant communities bring to these cities and their local institutions.

University attributes. The most notable result relating to non-size university attributes is that faculty quality, as proxied by the number of members in the National Academies, has a significant positive effect on innovation impact in a number of our model specifications. So, after controlling for research spending, it matters who is leading the research.

Membership in the AAU and inclusion in CMUP's Top American Universities list have no effect on innovation impact, controlling for research spending and other variables.

Our data show a slight edge for public universities over private ones, all else equal, but this effect is insignificant. Similarly, having a business school seems to have a modest but statistically insignificant effect. Having an engineering school or an entrepreneurship program makes no consistent difference to innovation impact.

Comprehensive universities with medical schools seem to perform moderately better than those without medical schools, all else equal, though this effect is also insignificant in all model specifications. Unsurprisingly, pure medical institutions and research/health care institutions perform moderately below comprehensive research universities, as our composite impact score penalizes them for not educating undergraduates.

We include "invention disclosures," an AUTM variable measuring the number of inventions submitted by faculty researchers to the TTO or internal patenting office in four of our model specifications. Unsurprisingly, it has a highly significant association with innovation impact.

One could interpret this result two ways. One interpretation is that inventions are another innovation output, which we could have included in our composite measure, and as such, they are highly correlated with our nine innovation impact metrics. Another interpretation is that inventions are an intermediate step in the innovation production process. In the latter case, one could say that our model specifications which include invention disclosures control not only for research input but also for productivity in turning research inputs into the intermediate step, so that the coefficients on other variables describe the determinants of success in going from this intermediate step to the final "good" of innovation impact.

University policy. TTO size has a highly significant positive effect on innovation impact. Based on our results, a university with a TTO staff of (say) 20 will achieve an innovation impact score approximately 1.1 points higher than an otherwise similar peer with a staff of 10, equivalent to about 10 spots in our ranking.

The effect of having a trained engineer as the TTO head is always positive in our results, and significant in most models in which we include this variable. Universities with an engineer as the TTO chief achieve innovation impact scores approximately 1.9 points higher than others, equivalent to at least 15 spots in our ranking, all else equal.

On the other hand, having a TTO head with startup experience makes no difference to innovation impact.

Seemingly small differences in the technology transfer office's size, professional makeup, and policies make a surprisingly large difference to a university's innovation impact. They influence not only an institution's success in generating patents, technology licenses, and spinout companies but also its research and teaching impact.

Having a seed fund has a positive effect in two of the six models in which we include it — one of them significant — but a small negative effect in the other four. In view of the positive effect we show in the single-variable analysis, we conclude that seed funds likely contribute to innovation impact. But again, institutions with a substantial technology transfer effort generally have seed funds, so the marginal effect of having one is ambiguous after controlling for other variables. Having an accelerator seems to have positive but insignificant effects.

Finally, the effect of sourcing a relatively large share of a university's research funding from industry is significantly negative in every model specification in which we include this variable, all else equal.

Separate effects on our nine innovation impact measures. We've also conducted a series of multivariate regression studies on the determinants of success for each of our nine innovation impact variables separately.[47] While these models largely confirm the relationships we summarize in the foregoing analysis, they provide several additional conclusions worth highlighting:

- **Scale**: This analysis provides evidence for declining returns to scale in research spending for every variable except patent citations, for which the evidence suggests *increasing* returns to scale. Endowment size positively predicts paper citations, even controlling for total research spending, but no other variable.
- **Metro areas**: Metro-area population positively affects license income, controlling for foreign-born population share. The foreign-born share has especially large effects on issued patents and spinout companies.
- **University attributes**: The number of members in the National Academies has particularly strong positive effects on issued patents and paper citations. Public comprehensive universities have a decided edge over private ones in producing STEM graduates at all levels, even after controlling for research spending and other measures of scale.
- **University policy**: TTO size has significant positive effects not just on our commercialization and entrepreneurship variables but also on patent citations. Having a trained engineer as TTO head is positively associated with STEM Ph.D. graduates, all else equal, while having a seed fund is positively associated with STEM bachelor's and master's graduates. A relatively large share of industry funding has a consistently negative effect on all nine innovation impact variables in every single model in which we include it.

The share of research spending funded by industry sponsors is negatively associated with innovation impact in both our single-variable and multivariate analyses. It is also negatively associated with success on all nine of our innovation impact measures when we analyze them separately.

Data envelopment analysis (DEA)

In Appendix 6, we show results for two logistic regression models in which the dependent variable is binary: either an institution is "fully efficient" in our DEA analysis, or it is not. These models estimate how our various explanatory variables influence the probability that a university is fully efficient.

[47] We've omitted these regression tables from the report in the interest of space. Results are available upon request.

While the results we report generally do not reach statistical significance, they are directionally consistent with the effects we find throughout this study. Having a larger TTO, a trained engineer as the TTO head, and a seed fund are associated with a higher probability of operating on the DEA production possibility frontier. Both metro area size and foreign-born population share are positively associated with the probability of operating on the production possibility frontier as well.

Having a larger share of research spending funded by industry is slightly associated with a higher probability of operating on the DEA production possibility frontier, inconsistent with all other results for this variable in our study.

Discussion

Why university innovation activities suffer declining economies of scale is a question that deserves further study. We suggest two possibilities, each admittedly speculative. First, very large institutions may have the resources to pursue marginal projects that smaller institutions cannot, which may yield societal benefits but pull down their innovation impact productivity as we measure it. For instance, it may be that the biggest universities are the only institutions that can host very large-scale labs focused on unusually complex challenges, and that these operations inherently have low productivity because of the complexity of what they're addressing.

Second, research activities at the largest institutions may be more subject to waste and bureaucratic inefficiencies than those at smaller universities.

The evidence for increasing returns to scale on the one output measure of patent citations may reflect a bias among inventors towards citing publications from especially large, well-known institutions.

The evidence we present on the positive effects of being in a large metro area is consistent with a vast literature on the economic benefits of large, dense, diverse cities. Big cities give rise to a broad diversity of firms, vibrant labor markets, and prolific intermingling of ideas. Abundant evidence indicates that large cities enjoy higher rates of innovation and labor productivity than smaller places, and that this advantage seems to be growing as the world economy becomes more knowledge centric.[48]

---

[48] See, for instance, Marshall A. (1890), *Principles of Economics*, London: Macmillan; Florida R.L. (2014), *The Rise of the Creative Class,* New York: Basic Books, and Florida R.L. (2017), *The New Urban Crisis,* New York: Oneworld Publications; and Combes P.P. and Gobillon L. (2015), "The empirics of agglomeration economies," in

Our new findings on the benefits to a university of being in a metro area with a relatively large foreign-born population, moreover, are consistent with numerous studies on the economic vibrancy immigrant populations bring to American cities, including work by the George W. Bush Institute.[49] Immigrants are roughly twice as likely as native-born U.S. citizens to file a patent application, commercialize an invention, or start a successful technology company. They are somewhat more likely to become a small-business owner.[50]

Regarding other university attributes, our results tell a somewhat different story than past studies that have found an edge for private institutions over public ones in producing innovation impact. We find modest evidence for a public university advantage. One reason we come to a different conclusion is that we include STEM Ph.D. graduates and STEM bachelor's/master's graduates in our measure of innovation impact, and our data indicate that public universities are more productive in producing graduates, controlling for research spending scale. But we also find no evidence for a private university edge in any of our other seven variables.[51] One explanation might be that large public and private institutions may have increasingly converged towards one another academically, culturally, and financially in recent decades, becoming more similar despite their sometimes very different historical origins.

Our findings on the positive association between the number of National Academies members and innovation impact point to the importance of star researchers to innovation impact.

As for our policy variables, there are numerous reasons why the size and sophistication of a university's technology transfer operation (TTO) might exert a significant influence on the institution's innovation impact. One simple reason: the evidence suggests that intellectual property management and technology transfer present difficult challenges. Past studies have shown that inadequate staffing often leads to poor marketing of university inventions, that most innovative work by faculty researchers never makes it to the TTO, and that the interactions

---

Duranton G., Henderson J.V., and Strange W.C., eds., *Handbook of Regional and Urban Economics*, 5, Amsterdam: Elsevier, Chapter 5.

[49] George W. Bush Institute (2017), *America's Advantage: A Handbook on Immigration and Economic Growth* (Third Edition).

[50] Wadhwa V. et al. (2007), "America's new immigrant entrepreneurs: Part 1," (January), available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=990152; Hunt J. and Gauthier-Loiselle M. (2010), "How much does immigration boost innovation?" *American Economic Journal: Macroeconomics*, Vol. 2, No. 2; Hunt J. (2011), "Which immigrants are most innovative and entrepreneurial? Distinctions by entry visa," *Journal of Labor Economics*, Vol. 29, No. 3; Kalick D.D. (2012), *Immigrant Small Business Owners: A Significant and Growing Part of the Economy*, Fiscal Policy Institute report, available at http://fiscalpolicy.org/wp-content/uploads/2012/06/immigrant-small-business-owners-FPI-20120614.pdf.

[51] Data from multivariate regressions with single innovation impact output measures as the dependent variable are available upon request.

between university administrations and individual researchers — including the incentives universities make available to innovative faculty members — vary widely across institutions.[52]

Our 2014 survey indicates that the biggest challenges facing universities in their innovation efforts include building a good understanding among faculty researchers concerning university commercialization programs, creating awareness of the university's work on the part of established businesses and entrepreneurs, and finding good licensees.

Our results raise fresh questions about how the size and professional makeup of a university's technology transfer office might influence variables the TTO does not directly touch, such as patent citations and STEM graduates. We suggest two hypotheses. One is that an effective technology transfer operation attracts unusually innovative researchers who not only publish widely cited papers but in turn attract talented students and raise the intellectual level of the whole university.

Another hypothesis is that it is not just an effective TTO in itself but also the overall university culture in which an effective TTO comes into being that drives a university's innovation impact. The vast differences in TTO activities we see in this study, even among America's largest universities, suggest that some institutions simply prioritize innovation activities more than others do. The University of Utah, CalTech, Columbia University, and Stanford University — all in the top third of large universities for innovation impact productivity — operate unusually large TTOs, and all besides Stanford run seed funds and accelerators. Each is known for being especially well connected to innovative businesses and venture capital firms in their localities. The performance of these institutions shows that a very large university can achieve innovation impact productivity levels as much as 1.5 to 2 times higher than the median level through purposeful action.

Our case studies on The University of Florida, Drexel University, and Brigham Young University in Section V provide further evidence for the hypothesis that a broad-based culture of innovation and entrepreneurship can generate superior innovation impact.

A final subject that deserves more study is the negative effect of having relatively large industry funding as a share of total research spending. This study is not designed to address why this relationship holds. That said, it may be that industry funding tends to push researchers towards highly applied projects that lead to fewer widely cited papers, patents, licenses, and spinout companies than projects more focused on transformational basic research. Also, universities

---

[52] Thursby J.G. and Kemp S. (2002); Swamidas P.M. (2009), "Why do university innovations rarely produce income?" "Bottlenecks in university technology transfer," *Journal of Technology Transfer*, Vol. 34, No. 4 (August), pp. 343-63.

often negotiate sponsored research arrangements that fully transfer resulting intellectual property to the industry sponsor, with little or no license income available to the university from commercialized technologies. Our findings raise fundamental questions about university strategy, as our 2014 survey indicated that many institutions place a high priority on increasing their industry-sponsored research.

Section V: Case studies

The University of Florida

The University of Florida ranks first among the group of largest universities in our study for productivity in turning research inputs to innovation impact outputs. It ranks sixth in our ranking for innovation impact, even though it ranks only 36th in total research spending. It generated an average of 123 issued patents and 15 spinouts per year from 2013 through 2017, placing it among the top performing U.S. universities on these measures. It was also a strong performer in license income, earning an average of $36 million per annum, equal to 6.4 percent of research dollars.

Additionally, The University of Florida ranks 4th overall in teaching impact. It produced one third as many STEM Ph.D.s each year as the entire University of California system between 2013 and 2017, despite having a research budget only about one-tenth as large.

The University of Florida has famously earned more than $280 million in royalties since 1967 from its invention of Gatorade. But the university is very far from being a one-hit innovator. Its biotechnology effort has produced more than 60 companies, including more than a dozen that have been acquired by major pharmaceutical, food, agricultural biotechnology, and energy enterprises.

The University of Florida operates one of the largest and most respected technology transfer offices (TTOs) in the United States. Indeed, the university has claimed to have "the best tech transfer team in the world." The TTO has a staff of 42 and a leader with an engineering background.

Based on our interview with the TTO's chief, the TTO operates as a "high-volume shop" and takes a highly "business-like" approach to its activities. The TTO relies heavily on process management tools borrowed from the business world to achieve consistency in its patenting and licensing activities.

The university has also launched an initiative called "UF Innovate" to create tighter linkages among its TTO, its seed fund sources, its two incubators, and the outside business community.

The University of Florida operates one of the premiere technology transfer offices in the United States. The university is a top performer in issued patents and spinouts and also produces an exceptional number of STEM Ph.D. graduates given its size.

The university's top leadership is highly supportive of the TTO's work and strongly supports a culture of innovation and entrepreneurship throughout the university community. University leadership generally does not engage in technology transfer activities in a hands-on way but has recently pushed to increase the university's emphasis on creating "blockbuster" spinout companies.

Consistent with our findings on the benefits of being in a large, diverse metro-area economy, the university acknowledged to us that one its challenges in meeting its goals for innovation impact is its location in the relatively small Gainesville area, distant from large urban business centers and entrepreneurial networks.

Drexel University

Drexel University ranks first among our mid-sized research university group for innovation impact productivity. From 2013 through 2017, Philadelphia-based Drexel averaged 41 issued patents and five spinout companies per year. It produced an average of 447 STEM Ph.D.s per annum. The more than 30 spinout companies launched since 2014 cover a wide range of technologies, including wireless infrastructure, energy storage, AI-enabled software development, smart fabrics, health care management software, tissue engineering, diagnostics, and pharmaceutical products for rare diseases. One Drexel University spinout firm has developed the sports nutrition snack Dragon Gel, which Drexel believes could be "the next Gatorade."

Drexel's TTO employs seven professionals, in line with the median institution in our dataset. But this figure understates the university's commitment to innovation impact. The university operates the Drexel Ventures University Accelerator, the Drexel Ventures Ben Franklin Seed Fund, and the Proof-of-Concept Academy. According to an interview we conducted with a longtime Drexel researcher, the university generously supports innovative researchers with funding and lab space and offers unusually favorable financial terms to inventors. Our interview with Drexel's TTO staff indicates that the TTO prioritizes a flexible, individualized approach in how it works with faculty researchers.

Drexel's emphasis on innovation in part reflects its heritage, as it was established as an engineering school. But the university's technology transfer policies and innovation ecosystem are also part of a much more recent, broad-based commitment to innovation and entrepreneurship. As the university's president from 1995 to 2009, Dr. Constantine "Taki" Papadakis led a comprehensive turnaround of what had previously been an ailing institution. In addition to leading significant innovation in the university's academic programs and significantly raising the caliber of its faculty and students, he created a leading medical school and school of public health, partly through the acquisition and turnaround of a nearby bankrupt medical institution. The university's engineering school grew tremendously on his watch.

Our interviews confirm that Papadakis, an engineer with substantial experience in industry as well as academia instilled a culture of innovation throughout the university community. Although Papadakis died in office in 2009, our interviews indicate that current President John Fry has continued to place heavy emphasis on innovation and technology commercialization.

Drexel's efforts to promote innovation have included increasing its integration with the wider innovation community in Philadelphia. It set up lab space in the University City research and business facility operated by the much larger University of Pennsylvania a few blocks away, alongside researchers from Penn, four other universities, startup businesses, and venture capital firms. Later, Drexel created the Excite Center to catalyze transdisciplinary interactions among its faculty, its students, and outside innovators in the community. It now operates the ic@3401 incubator space that houses several dozen startup companies.

Drexel has also created the Charles D. Close School of Entrepreneurship, one of America's top free-standing, interdisciplinary, degree-granting entrepreneurship schools. The university recently established an institute focused on innovative ideas on the future of cities. It assigns an associate dean for research to each of its schools as an advocate for commercialization. And it has built close relationships with innovative research institutions in Israel and China.

Drexel University shows what a university can achieve in terms of innovation impact when it prioritizes innovation throughout the institution and engages broadly in its home city — particularly when it's located in a large, diverse metro area with other innovative institutions and deep business and financial talent.

Drexel's experience illustrates the innovation impact a university can achieve when it prioritizes innovation across its operations over a sustained period of years. It also shows the benefits of being in a large, culturally diverse city with a deep bench of entrepreneurial and financial talent, provided the institution makes a concerted effort to connect with the wider business community.

Brigham Young University

BYU leads our smaller research university group for innovation impact productivity. Its composite score for innovation impact from 2013 through 2017 is roughly even with those of several respected institutions spending some 10 to 20 times more per year on research.

During the five years starting in 2013, BYU averaged 32 issued patents, 12 spinout companies, and $2.7 million in license income per year — a remarkable return on its modest annual research spending of about $30 million. Recent licenses cover technologies for improved contact lens coatings, a handheld liquid chromatography device for scientific research, and a camera designed to enable the "Internet of Things." The numerous spinout companies developed by BYU faculty and students prominently include Qualtrics, a leader in customer experience management solutions that has raised significant capital from venture capital firms.

BYU operates a small TTO with just three licensing professionals, but it enjoys a vast campus-wide innovation ecosystem. According to BYU, the University Growth Fund is the largest venture/private equity fund based at a higher education institution. The business school's Rollins Center for Entrepreneurship and Technology provides space for inventors and startup entrepreneurs, mentoring, startup competitions, and frequent lectures on technology-focused entrepreneurship. BYU operates at least nine Innovation Lab spaces, covering not only life sciences and computer science but also animation, the arts, and social innovation. An interdisciplinary Creativity, Innovation, and Design Group offers design help to inventor-entrepreneurs. The campus features thriving student clubs focusing on entrepreneurship, venture investing, and design thinking. The university also is known for offering particularly generous financial terms to both faculty and student inventors.

Based on our interviews, the TTO's three-person staff are highly knowledgeable about technology and experienced in commercialization. They function well at their current size partly through substantial outsourcing. The TTO believes it prioritizes licensing more than most peer institutions do.

BYU's cultural emphasis on innovation runs through its formal academic programs as well. The university recently introduced an undergraduate minor in design thinking. The School of Life Sciences offers a two-course sequence focused on starting a biotechnology company, as well as the year-long Crocker Innovation Fellowship Program, in which students take multiple classes on innovation, earn a stipend, and engage in a paid internship with a nearby life science firm.

Our interviews suggest that BYU also benefits from an exceptional degree of cohesion and common purpose among its faculty, reflecting the university's unique position as an institution of the Church of Jesus Christ of Latter-day Saints.

BYU, finally, has exceptionally tight interconnections with the wider technology and business community, across the whole Silicon Slopes region stretching from Provo through Salt Lake City to Park City. BYU's engineering school is a leader in working closely with local firms to create hands-on learning opportunities for students.

Brigham Young University has created a vast, campus-wide ecosystem focused on innovation and entrepreneurship. It provides numerous dedicated spaces for inventor-entrepreneurs, mentoring programs, innovation and entrepreneurship academic programs across its curriculum, close connections with the startup community in Salt Lake City as well as Provo, and unusually generous financial terms for faculty and student inventors.

Although BYU is in the relatively small metro area of Provo, it benefits from its close connections with the booming and increasingly diverse Salt Lake City metro area. It also benefits from its cooperative relationship with the Salt Lake-based University of Utah, which has a research budget more than 10 times larger than BYU and ranks second in our large university group for innovation impact productivity.

Section VI: Conclusions

Conclusions for universities

Generating high innovation impact is in significant measure a choice that some universities have made. Our case studies on The University of Florida, Drexel University, and Brigham Young University show that the extraordinary successes these institutions have achieved over the past decade in turning research inputs to innovation impact are no accident. In each case, leaders have made persistent, purposeful investments in building a culture of innovation and entrepreneurship throughout the institution.

More generally, our data demonstrate that some universities place a far higher priority on promoting innovation impact than most others do. Among large public research universities, the Universities of Florida, Washington, Michigan, Minnesota, and Utah, as well as New York University and North Carolina State University run very large research budgets, operate effective TTOs, promote innovation-minded campus cultures, and achieve relatively high innovation productivity. The same is true, in some cases at smaller scale, of the most productive private institutions — for instance, MIT, Columbia University, Stanford University, the University of Pennsylvania, Northwestern University, Princeton University, Rice University, and the University of Chicago.

A number of considerably smaller institutions besides BYU, such as Northern Illinois University and Creighton University, achieve significant innovation impact with much smaller resources. Cold Spring Harbor Laboratory is the leading example of a pure research/health care institution that has prioritized innovation impact and achieved remarkable innovation impact productivity.

This report shows that university leaders should not fear that prioritizing technology innovation, commercialization, and entrepreneurship will detract from their traditional missions in teaching and basic research. On the contrary, we show that success in generating innovation impact reinforces the teaching and research activities of universities, at least in STEM fields.

Our analysis also shows that most institutions could achieve very significant increases in innovation impact by moving towards the productivity levels of high-performing peers. Among the institutions in our large university group, for instance, the median university in terms of productivity would increase its innovation output by 34 percent if it reached the productivity level of the bottom institution in the first quartile. Improving from the third quartile cutoff level to the first would mean increasing innovation impact by 59 percent. The room for improvement is roughly the same in the mid-sized and smaller university groups.

Our report suggests seven takeaways for university leaders who aim to maximize the innovation impact of their institutions:

1) **Prioritize research**: More research spending likely means greater innovation impact. (This report does not address whether achieving high innovation impact *should* be a higher priority than other possible spending priorities.)

2) **Compete hard for and retain star faculty researchers**: Institutions with relatively large numbers of members of the National Academies generate high innovation impact, even controlling for total research spending.

3) **Run an efficient, outcomes-focused technology transfer operation**: First of all, this means paying close attention to the size, professional makeup, and policies of the technology transfer office (TTO). It also means operating a well-funded seed fund, interacting well with faculty and staff, forging deep connections with the business and finance community in the university's home city and beyond, and offering competitive financial terms to faculty and student inventors.

4) **Instill a culture of innovation and entrepreneurship throughout the university**: MIT, Stanford University, Drexel University, and BYU demonstrate the benefits of a culture that prizes technological innovation, commercialization, and startup entrepreneurship. With their innovation spaces, accelerators, entrepreneurship programs, and strong connections to outside investors and entrepreneurs, they are magnets for innovation-minded researchers and students.

5) **Engage closely with the surrounding business and innovation community**: While it helps to be in a big, diverse city with many entrepreneurs and a substantial immigrant population, universities can amplify these benefits through purposeful engagement. Again, BYU exemplifies purposeful connection building throughout the Silicon Slopes region, while Drexel University has successfully reached beyond its walls to build strong relationships with the University of Pennsylvania and the Philadelphia venture capital community.

6) **Avoid overreliance on sponsored research funding from industry**: The most successful institutions in terms of innovation impact generally fund no more than five to seven percent of their research spending from industry sources. When government support for research is no longer growing and tuition growth faces obvious constraints, it is unsurprising that university leaders would look to industry. But this report strongly

suggests they should do all they can to sustain broad diversity in funding sources. Also, AUTM data indicates that total industry-sponsored research spending at U.S. universities has expanded only five percent over the past five years, suggesting that universities focusing on this funding source are engaged in a zero-sum game.

7) **Monitor, quantify, and transparently disclose innovation impact results**: BYU publishes brief but transparent annual reports on how they are doing, including much of the data they report to the Association of University Technology Managers (AUTM). All universities focused on maximizing their innovation impact should do the same. Research universities not reporting annual data to AUTM should start reporting it, and all research universities should become considerably more cognizant of how they are positioned relative to peer institutions in generating innovation impact of all kinds.

One other note: We urge AUTM to become more global, moving beyond its current reporting institutions in the United States and Canada. In view of the central importance of technological innovation to worldwide economic growth, AUTM should aim to build comparable data on research activities and innovation impact from research universities throughout the world.

Conclusions for policymakers, business leaders, philanthropists, and communities

For America's economy as a whole, higher innovation impact from universities would likely bring a greater pace of technological progress and faster economic growth.

Over the last four decades, applied research by the private sector has risen as a percentage of America's GDP, while basic university research funded by the federal government has declined in relation to the economy. The United States now ranks 28th of 30 Organization for Economic Co-operation and Development nations in government funding of university research as a share of GDP, far behind Germany, Switzerland, Denmark, Sweden, and numerous other countries. China's public sector investment in university research, meanwhile, is rapidly growing.[53]

Leading economists such as Robert Gordon estimate that the rate of productivity growth, which is closely connected to technological progress, has slowed over this period of waning public sector investment in basic research.[54] While correlation doesn't necessarily imply causality, it is plausible that increasing basic research might induce a reacceleration in long-term productivity growth.

[53] Atkinson R.D. and Foote C. (2019), "U.S. funding for university research continues to slide," Information Technology and Innovation Foundation report (October).
[54] Gordon R.J. (2016), *The Rise and Fall of American Growth*, Princeton: Princeton University Press.

This report also suggests that local government, business, and philanthropic leaders can strengthen their hometown economies by promoting the innovation impact of local universities.

Our report suggests five takeaways for policymakers, business leaders, philanthropists, and communities:

1) **Increase public sector support for university research**: Both federal spending on basic research and state government support for public universities play irreplaceable roles in funding university innovation activities. This report suggests that most research institutions could increase innovation impact, if they had more resources to invest in research.

2) **Understand how institutions vary in their innovation impact productivity**: Smaller universities can achieve remarkable productivity in converting research inputs to innovation impact outputs. Supporting smaller institutions committed to building a broad-based culture of innovation and entrepreneurship can be a very good investment. More generally, funders should consider the extent to which the institutions they support not only do great research but are also effective in achieving innovation impact beyond the university's walls.

3) **Compete hard for talent — including immigrant talent**: Metro areas with relatively large foreign-born population shares tend to host universities with high innovation impact. Localities can promote the innovation impact of local institutions by pursuing a highly welcoming approach to diverse populations, especially immigrants. While the competition for talent among localities for talent may seem like a zero-sum game, the federal government can create positive-sum conditions by welcoming more skilled immigrants from abroad.

4) **Invest in integrated physical spaces connecting researchers with entrepreneurs, investors, and other potential nonacademic partners**: This report points to clear benefits from bringing faculty researchers into close proximity with nonacademic entrepreneurs, venture capital firms, and other investors. Policymakers, business leaders, and funders of all kinds can contribute to the creation of innovation spaces that catalyze such connections.

5) **Support technology transfer operations and other enablers of innovation impact**: Funders should consider supporting expansion of TTOs and other innovation-promoting activities. The federal government should expand successful programs to support academic technology transfer such as the National Science Foundation Innovation Corps (I-Corps™), National Institutes of Health's REACH, Small Business

Innovation Research (SBIR), and Small Business Technology Transfer (STTR). State governments should replicate programs like the Massachusetts Technology Transfer Center.

More generally, we hope this report encourages additional research on how America and its research institutions can generate greater innovation impact. Our analysis raises questions about why very large universities experience declining returns to scale in converting research inputs to innovation impact outputs, why metro areas with high foreign-born population shares host universities with relatively high innovation impact, and why the share of research spending funded by industry is negatively associated with innovation impact. We also hope this report encourages more detailed case studies on the innovation programs of high-performing institutions.

Appendix 1

OUR APPROACH IN DETAIL

Prior literature

Media and think tank rankings

The three most widely cited ranking systems are the Milken Institute's ranking of "the best U.S. universities for technology transfer,"[55] the ranking of "the world's most innovative universities" published by Thomson Reuters-Clarivate Analytics,[56] and the PitchBook Universities ranking published by the venture capital-focused media firm PitchBook.[57]

The Milken Institute's 2017 ranking is based on a composite score that combines four variables — patents issued, new licenses, license income, and spinout companies — together with four productivity measures, defined as each of these four variables divided by a university's total research spending.[58] The Milken Institute's method captures commercialization and entrepreneurship activities but not research or teaching activities. Incorporating both output and productivity measures into a composite score makes sense if one wishes to think of generating high innovation impact output and doing so efficiently as two related sides to a single coin but is comparable to ranking companies according to a composite that includes total profits stated in dollars alongside profit margins stated in percentage terms.

The Milken Institute's ranking turns out to be relatively similar to ours, though their list of top performers includes both: (1) universities with very high innovation impact and better-than-average innovation impact productivity and (2) universities with medium-sized innovation impact but extraordinary innovation impact productivity. Our approach distinguishes between these two patterns.

Thomson Reuters-Clarivate Analytics bases their global ranking on a composite score combining 10 variables primarily related to patenting and patent citations, drawing on Clarivate Analytics' rich worldwide dataset on patents. This method also combines output and efficiency measures,

[55] DeVol R., Lee J., and Ratnatunga M. (2017).
[56] Ewalt D.M. (2018), "Reuters Top 100: The world's most innovative universities - 2018," available at https://www.reuters.com/article/us-amers-reuters-ranking-innovative-univ/reuters-top-100-the-worlds-most-innovative-universities-2018-idUSKCN1ML0AZ.
[57] "PitchBook Universities: 2019," 5 September 2019, available at https://pitchbook.com/news/articles.
[58] Specifically, Milken calculates average levels for each university of the four innovation impact output variables based on AUTM data for 2012 through 2015, then calculates efficiency measures for each of the four variables by dividing them by the university's four-year average research spending. Milken calculates the natural log of each of the resulting eight variables, recalibrates each natural log to set the top performer on each variable to 100, then multiplies each transformed output variable by its transformed counterpart efficiency variable. Finally, Milken weights the resulting license income and spinout quantities by 0.35 each and the resulting license number and issued patents quantities by 0.15 each to yield a final composite score.

though in this case all but one of them relate to patents. (One relates to total academic papers published.)[59]

One merit of this ranking is that it ranks universities from around the world according to a consistent methodology, which reliance on AUTM data does not allow.

The rank-order of U.S. universities within Thomson Reuters-Clarivate Analytics' global ranking differs significantly from our ranking. This divergence is unsurprising, as their method focuses entirely on what we call "research" variables, assigning no weight to the other three categories of variables. It is also consistent with our observation that success in patent citations has only a weak correlation with success in the other eight variables we use to construct our composite.

The PitchBook ranking system focuses on the universities attended by individual entrepreneurs who have founded startup companies backed by venture capital funds. Drawing on PitchBook's deep database of venture capital deals, PitchBook ranks leading universities according to a composite score that combines the number of company founders from each university, the number of companies they've founded, and the capital raised by these companies.

Although the PitchBook rankings focus on a very specific form of innovation impact, it turns out that the universities that score high on PitchBook's ranking tend to score high on our broader measure of innovation impact as well. Of the top 25 universities in PitchBook's 2019 ranking, fully 16 are among the top 25 in our ranking for innovation impact. A 17th institution in PitchBook's top 25 — Brigham Young University — ranks 50th in our ranking for innovation impact but first for innovation impact productivity.

Academic literature

A significant body of work by academic economists focuses on the determinants of success in university technology transfer. Most of these studies rely on AUTM data for U.S. universities and measure innovation impact according to "commercialization" and "entrepreneurship" variables available in the AUTM dataset: patent applications, issued patents, new licenses,

[59] Thomson Reuters-Clarivate Analytics starts with 10 variables from Clarivate's "Derwent World Patents Index" and related Clarivate data. They cross-reference articles published from 2012 through 2016 and patents citing these papers and issued before April 2018. The 10 variables capture a university's total patent applications, its efficiency in converting its patent applications to issued patents, the percentage of its patents which it files in multiple countries, how often other researchers and inventors cited its patents, how often other patents cited its publications, and the total number of papers published. Thomson Reuters-Clarivate Analytics rank all qualifying universities on each variable separately, then sums the ranks to arrive at a composite score, assigning slightly different weights to different variables.

license income, and spinout companies.[60] One study also uses paper citations, patent citations, new STEM Ph.D. graduates, and new STEM master's/bachelor's degree graduates, as we do.[61]

The explanatory variables these studies focus on fall into the same four categories we emphasize: (1) university size (total research spending, total budget, endowment);[62] (2) geographic attributes (metro area population, educational attainment levels, and household income levels);[63] (3) non-size university attributes (measures of faculty quality, public vs. private, medical school vs. no medical school);[64] and (4) "policy" variables (TTO size, TTO age, share of research spending funded by industry, revenue shares for individual inventors).[65]

Two prior studies have found diseconomies of scale in university innovation activities, as we do.[66] Studies that have analyzed the effect of a university's location on its innovation impact have in some cases reported that larger city size predicts greater innovation impact, though they have not found much evidence that a city's median income levels have a significant effect.[67] Regarding other university attributes, prior literature generally finds that measures of faculty "quality" predict innovation impact, all else equal.[68] Two studies have found that private universities are more productive in turning research inputs to innovation outputs, other things

---

[60] See, for instance, Foltz J.D. et al. (2000), "Universities and agricultural biotech patent production," *Agribusiness*, Vol. 16, No. 1, pp. 82-95; Thursby et al. (2001); Thursby J.G. and Kemp S. (2002), "Growth and productive efficiency of university intellectual property licensing," *Research Policy*, Vol. 31, pp. 109-24; Carlsson B. & Fridh A.C. (2002); Friedman J. and Silberman J. (2003); Siegel D.S. et al. (2003), "Assessing the impact of organizational practices on the productivity of university technology transfer offices," *Research Policy*, Vol. 32, No. 1, pp. 27-48; Markman (2005*)*; Siegel D. et al. (2008), "Assessing the relative performance of university technology transfer in the U.S. and UK: A stochastic distance function approach," *Economics of Innovation and New Technology*, Vol. 17, Nos. 7-8, pp. 717-29; Curi C. et al. (2012), "University technology transfer: How (in)efficient are French universities?" *Cambridge Journal of Economics,* Vol. 36 (April), pp. 629-54; Ho, M.H. et al. (2014), "A new perspective to explore the technology transfer efficiencies in U.S. universities," *Journal of Technology Transfer*, Vol. 39, pp. 247-75; Fisch C.O. et al. (2015); Yeo B. (2017), "What drives university technological innovation and commercialization?" Twenty-third American Conference on Information Systems, Boston.

[61] Foltz J.D. et al. (2012), "Efficiency and technological change at U.S. research universities," *Journal of Production Analysis*, Vol. 37, pp. 171-86.

[62] Most studies at least include total research spending. See, for example, Siegel D.S. et al. (2008); Foltz J.D. et al. (2012); and Ho M.H. et al. (2014).

[63] See, for instance, Siegel D.S. et al. (2008).

[64] See, for instance, Thursby J.G. et al. (2001); Friedman J. and Silberman J. (2003); Siegel D.S. et al. (2008); and Foltz J.D. et al. (2012).

[65] See, for instance, Thursby J.G. et al. (2001); Thursby J.G. and Kemp S. (2002); Carlsson B. and Fridh A.C. (2002); Friedman J. and Silberman J. (2003); Siegel D.S. et al. (2008); Curi C. et al. (2012); Foltz J.D. et al. (2012); Ho M.H. et al. (2014); and Yeo B. (2017).

[66] Siegel D.S. et al. (2008); Foltz J.D. et al. (2012).

[67] Varga A. (2000), "Local academic knowledge transfers and the concentration of economic activity," *Journal of Regional Science,* Vol. 40, pp. 289-309; Siegel D.S. et al. (2008); Curi C. et al. (2012).

[68] Sharma M. et al. (2006), "The role of university technology transfer offices in university technology commercialization: Case study of the Carlson University foundry program," *Journal of Services Research*, Vol. 6 (July), pp. 109-39; Siegel D.S. et al. (2008).

equal,[69] while the literature is inconsistent on whether universities with medical schools are more or less productive than those without medical schools.[70]

As for what we call "policy" variables, numerous papers have reported that TTO size is positively associated with greater success in technology commercialization.[71] Several find that TTOs that have been in existence longer predict greater innovation impact, while others find that universities offering greater shares of license income to individual inventors achieve greater innovation output.[72] Finally, two studies report evidence that deriving a relatively large share of research funding from industry negatively influences innovation productivity, at the levels of both individual researchers[73] and universities as a whole.[74]

Variables and data

Innovation impact variables

Our study includes nine measures of innovation impact: (1) patents issued by year, (2) licenses signed, (3) license income, (4) spinout companies launched, (5) licenses signed with spinouts, (6) citations of a university's papers in other papers, (7) citations of a university's papers in patents, (8) Ph.D. graduates in STEM fields, and (9) bachelor's and master's graduates in STEM fields.

We draw the data for the first five variables from the AUTM dataset. For the two literature citation variables, we rely on citation counts estimated by Google Scholar and Google Patents. from 2013 through 2017.[75] Our data on STEM graduates, both at the Ph.D. and

---

[69] Thursby J.G. & Kemp S. (2002); Foltz J.D. et al. (2012).
[70] Studies finding that having a medical school enhances innovative productivity include Siegel D.S. et al. (2008) and Curi C. et al. (2012). Studies finding the opposite include Thursby J.G. and Kemp S. (2002) and Foltz J.D. et al. (2012).
[71] Thursby J.G. et al. (2001); Thursby J.G. and Kemp S. (2002); Carlsson B. and Fridh A.C. (2002); Sharma M. et al. (2006); Siegel D.S. et al. (2007), "Technology transfer offices and commercialization of university intellectual property: Performance and policy implications," *Oxford Review of Economic Policy*, Vol. 23, No. 4 (1 Dec), pp. 640-60; Foltz J.D. et al. (2012); Yeo B. (2017).
[72] Thursby J.G. and Kemp S. (2002); Carlsson B. and Fridh A.C. (2002); Foltz J.D. et al. (2012); Friedman J. and Silberman J. (2003); DiGregorio D. & Shane S. (2003), "Why do some universities generate more startups than others?" *Research Policy*, Vol. 32, pp. 209-227; Markman G.D. et al. (2005), "Innovation speed: Transferring university technologies to market," *Research Policy*, Vol. 34, No. 7 (September), pp. 1058-75.
[73] Blumenthal D. et al. (1996), "Participation of life-science faculty in research relationships with industry," *New England Journal of Medicine*, Vol. 335 (December 5), pp. 1734-9.
[74] Foltz J.D. et al. (2008).
[75] Specifically, we enter the official name of the university in quotation marks into the Google Scholar or Google Patents search box, set the date range, and include all patent offices covered by Google's search system. Google then gives an estimated citation count. In a small number of cases, we had to make minor adjustments to the university title to capture how the university refers to itself in academic literature and patents. Note that Google Scholar does not permit us to restrict our count to papers in STEM fields. In practice, however, STEM papers constitute a large majority of papers identified by our method.

bachelor's/master's levels, comes from annual National Science Foundation and Department of Education data.[76]

Explanatory variables

Almost all data at the level of MSAs is from U.S. Census datasets, principally the American Community Survey. One exception, our housing affordability data, comes from the research group Demographia.[77]

Most data on university attributes and technology transfer policies comes from the websites of each individual university, with certain exceptions. Data on university endowment size is from the National Association of College and University Business Officers (NACUBO) dataset. Our data on the number of faculty members who are members of the National Academies comes from the websites of the four National Academies.[78] The membership lists of the AAU and the CMUP Top American Universities list, two of the three measures commonly used to designate some institutions as "Tier One" universities, come from the respective organizations' websites.[79]

Constructing our rankings

In our main ranking system, we compute composite "innovation impact" scores for each university in four steps.

First, for each university, we calculate the 2013-17 annual average for each of the nine innovation impact output measures, in order to smooth out the year-to-year fluctuations in the data.[80]

---

[76] National Science Foundation data, available at https://ncsesdata.nsf.gov/gradpostdoc/2016/index.html; and Department of Education, National Center for Education Statistics, IPEDS data.

[77] "14th Annual Demographia International Housing Affordability Survey: 2018," available at www.demographia.com/dhi2018.pdf.

[78] We estimate the number of members of the "National Academies" at each university by searching the membership lists on the websites of each of the four National Academies for university affiliation, then summing each university's total across the four academies.

[79] The AAU is an association of 62 prestigious comprehensive research universities. The CMUP Top American Universities list includes what it determines to be the top 50 public universities, the top 50 private universities, the top 25 public medical and specialized research universities, and the top 25 private medical and specialized research universities.

[80] Because of "lumpiness" concerns, we consider an institution's data for each of the nine variables as valid only if we have data for two or more of the five years between 2013 and 2017. Institutions appear in our main rankings only if we have valid data for all nine variables. Of the 225 institutions in our dataset, 30 fall out because of deficiencies in the data for the five variables drawn from AUTM data, leaving 195 institutions in the ranking.

Second, we convert the annual average for each of the nine output variables into standardized "z scores." That is, for each of the nine measures, we subtract the mean value for the 195-institution dataset from an institution's five-year average, then divide the difference by the standard deviation of the distribution of yearly averages for the 195 institutions. A university's nine z-scores thus summarize how many standard deviations ahead or behind the 195-university mean the university performed on each of the innovation impact variables between 2013 and 2017. We standardize the annual averages in this way in order to prevent variables with particularly wide distributions from dominating our composite scores at the expense of variables with narrower distributions. For example, the top-performing universities in license income are so far ahead of middle- or even upper-middle-ranked institutions that our methods for aggregating across variables would implicitly overweight this variable in determining overall top performers, if we didn't standardize the data through z-scores.

Third, we convert the z-scores for each variable into scores between 0 and 100, where the highest-performing institution on a given variable earns a score of 100 and the lowest-performing one earns a score of 0. This conversion assigns every institution a positive number for each variable, which makes comparison across universities more intuitive. The second and third steps preserve scale relationships from the underlying data, in that an institution scoring (say) 20 for a given variable has twice the innovation impact output on this measure as an institution scoring 10.

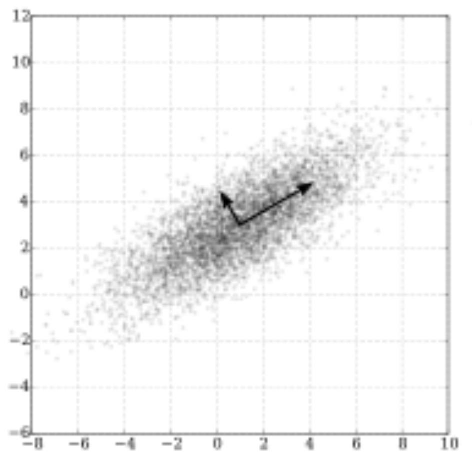
Fourth, we aggregate the nine single-variable scores for each university to arrive at a composite score, using two different methods. Our preferred method, which we use to generate the rankings in Tables 1 and 4, is principal component analysis (PCA). PCA, a method widely used in academic studies in economics and statistics, involves transforming a dataset of multiple *correlated* variables into a set of linearly *uncorrelated* variables ("principal components"). PCA transforms the data in such a way that one transformed variable, the first principal component, captures in one dimension as much of the variation in the data as possible, the second transformed variable captures as much of the remaining variation as possible, after controlling for variation in the first principal component, and so on.[81]

Figure 7 illustrates graphically how PCA works, using a two-variable dataset that's easy to visualize. The PCA method fits the longer, upward-sloping line through the scatterplot of points such that variation along this line accounts for as much as possible of the variation in the data. The shorter, downward-sloping line then accounts for all remaining variation in the data after controlling for variation along the first line. Likewise, PCA needs nine transformed variables to

[81] The Wikipedia entry for principal component analysis provides a detailed explanation of the method, as well as a substantial list of references. These include the 1901 paper in which PCA's inventor Karl Pearson first describes it (Pearson K. [1901], "On lines and planes of closest fit to systems of points in space," *Philosophical Magazine*, Vol. 2, No. 11, pp. 559-72) and a variety of more recent "textbook" explanations, such as Jolliffe I.T. (2002), Principal Component Analysis, Springer Series in Statistics, 2nd ed., Springer, NY, XXIX, 487, ISBN 978-0-387-95442-4.

capture all the variation across universities in our nine-variable dataset. But in some cases, as with our data, variation in the first principal component accounts for most of the underlying variation.

Figure 7
GRAPHICAL ILLUSTRATION OF PRINCIPAL COMPONENT ANALYSIS (PCA)[82]



The benefits of combining our nine output variables using PCA, relative to combining them through a simple weighted average using arbitrarily selected weighing factors, are, first, that the first principal component necessarily captures more of the variation across universities in the nine-variable dataset than a simple weighted average would, and second, that PCA essentially allows the data to tell us what the implicit weighing factor on each of the nine variables should be. Suppose we start from the premise that each of our nine impact variables is correlated with an unobservable variable that intrinsically sums up the innovation impact of each institution. If eight of our observable variables are highly correlated with one another but the ninth has a relatively low correlation with each of the other eight, PCA will implicitly assign a lower weight to the ninth factor than to the other eight in generating the first principal component. In effect, the method assumes the ninth variable is a weaker approximation than the others of the unobservable "innovation impact" variable.

To calculate the composite score for each university in our preferred method, we take the first principal component of the nine-variable dataset consisting of the transformed innovation impact

[82] The graph, from the Wikipedia entry for PCA, shows the PCA of a two-variable Gaussian distribution centered at (1,3) with a standard deviation of 3 in roughly the (0.866, 0.5) direction and of 1 in the orthogonal direction. The diagonal vectors depicted in the figure are the eigenvectors of the covariance matrix scaled by the square root of the corresponding eigenvalue, and shifted so their tails are at the mean (Source: Wikipedia Commons).

output variables from the first three steps and recalibrate the values for each institution such that the top university in the rankings receives a score of 100. It turns out that the first principal component accounts for fully 64.1 percent of the variation in the dataset, reflecting the relatively high correlations among our nine innovation impact measures.

As a check, we alternatively calculate a composite innovation impact score for each university using a simple weighted average method. In this case, we assign equal weights to issued patents, signed licenses, and license income to arrive at a composite commercialization impact score, equal weights to spinout companies and licenses to spinout companies to arrive at a composite entrepreneurship impact score, equal weights to paper and patent citations to arrive at a composite research impact score, and equal weights to STEM Ph.D. graduates and STEM bachelor's/master's graduates to arrive at a composite teaching impact score. We then calculate each university's overall composite score as the unweighted average of these four scores.

A benefit of this method is that it allows us to report rankings in each of the four categories of commercialization impact, entrepreneurship impact, research impact, and teaching impact. In principle, we could calculate scores for each of the four categories using PCA, but PCA would weight component variables differently than it does with the full nine-variable dataset, raising problematic issues of data interpretation.

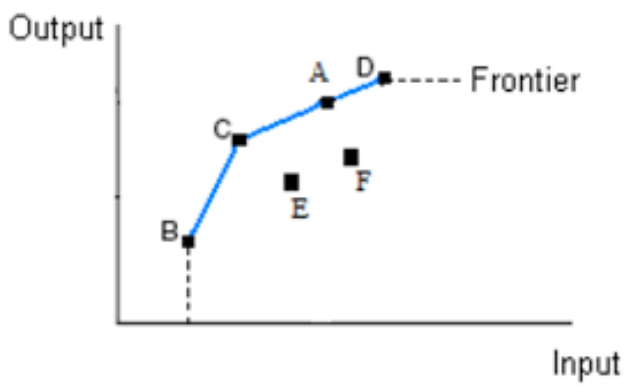
Measuring productivity

Figure 8 illustrates how data envelopment analysis (DEA) works through a simple case of a production function with a single input and a single output. Each dot represents the input-output combination for a single producer. DEA draws a curve through the leftmost producer with the smallest input, and then through the next producer to the right which has higher input and higher output than the first, and so on, until it has drawn a curve that "envelops" from above all the dots in the dataset. For a production process with two inputs and one output (or one input and two outputs), DEA would draw a two-dimensional "surface" rather than a one-dimensional curve through and over the three-dimensional "cloud" of datapoints. For our university research production process featuring nine innovation outputs and six inputs, it draws a 14-dimensional "manifold" through and over the 15-dimensional cloud of input-output combinations, each one representing a different institution.

One advantage of DEA is that it can handle a production process with multiple inputs and multiple outputs. For purposes of this study, this means we can calculate a single measure of productivity for each institution in producing the nine separate outputs in a way that is not dependent on our methods for constructing composite innovation impact scores.

DEA also allows us to define innovation impact productivity in a different way than we do in our first two methods, as the productivity of each institution in producing the nine outputs *from multiple inputs*. In particular, our application of DEA evaluates the productivity of each institution in converting research spending, as well as a series of metro area and university attributes we've identified in this study as playing an important role in determining innovation impact into the nine outputs.

Figure 8
GRAPHICAL ILLUSTRATION OF DATA ENVELOPMENT ANALYSIS (DEA)[83]



[83] Illustration is from Molinos M. et al. (2016), "Benchmarking the energy performance of office buildings: A data envelopment analysis approach," *Recta*, Vol. 17, pp. 179-190, and was downloaded from Google Images based on a search for DEA images.

Appendix 2

FULL RANKING FOR INNOVATION IMPACT

		Innovation Impact Score (PCA)	Total Research Spending ($m)	Innovation Impact Productivity Score	Innovation Impact Rankings (simple weighted average method) Overall Rank	Comm. Rank	Entrep. Rank	Res. Rank	Teaching Rank
1	University of California System	100.00	$4,998.8	2.00	1	1	1	1	1
2	University of Texas System	55.03	$2,675.9	2.06	2	2	2	4	2
3	MIT	31.25	$1,639.4	1.91	3	4	3	9	56
4	University of Washington	29.56	$1,197.9	2.47	6	3	6	18	10
5	University of Michigan	28.70	$1,362.5	2.11	5	10	7	10	7
6	University of Florida	28.11	$565.1	4.97	7	7	9	28	4
7	Columbia University	27.24	$753.8	3.61	4	8	5	5	27
8	University of Minnesota	24.92	$916.2	2.72	8	15	15	15	6
9	Stanford University	24.53	$946.1	2.59	9	11	8	12	39
10	University of Pennsylvania	23.25	$908.1	2.56	11	13	10	14	35
11	Johns Hopkins University	22.86	$1,632.0	1.40	12	16	16	6	29
12	University of Illinois at Urbana-Champaign	21.02	$1,014.9	2.07	13	20	17	11	22
13	University System of Maryland	20.30	$1,018.2	1.99	15	35	14	26	3
14	University of Wisconsin at Madison	19.32	$1,120.6	1.72	18	14	35	24	16
15	Purdue University	19.15	$611.4	3.13	17	28	18	27	11
16	Northwestern University	18.56	$554.1	3.35	14	6	22	19	59
17	New York University (NYU)	18.09	$546.5	3.31	16	9	31	22	32
18	University of Pittsburgh	17.83	$732.4	2.43	21	21	20	30	23
19	Cornell University	17.29	$801.6	2.16	20	22	27	16	50
20	North Carolina State University	17.12	$464.4	3.69	23	29	12	36	28
21	Harvard University	17.08	$827.9	2.06	19	32	29	7	53
22	Ohio State University	16.81	$924.7	1.82	22	46	36	20	8
23	Duke University	16.77	$897.7	1.87	24	19	34	13	64
24	University of Utah	16.45	$386.8	4.25	26	23	11	48	48
25	State University of New York	16.36	$949.3	1.72	25	34	26	33	13
26	University of Southern California	16.05	$684.8	2.34	27	37	23	29	15
27	University of New Mexico	15.81	$233.6	6.77	29	48	4	78	88
28	University of Colorado	15.30	$737.4	2.07	28	53	19	42	14
29	University of North Carolina at Chapel Hill	14.89	$779.2	1.91	31	51	13	37	26
30	Texas A&M University System	14.87	$867.8	1.71	30	42	46	71	5
31	University of South Florida	14.73	$508.3	2.90	37	26	32	76	36
32	California Institute of Technology	14.17	$360.1	3.93	40	18	28	32	138
33	Indiana University	14.13	$475.2	2.97	33	59	39	21	12
34	Arizona State University	14.04	$471.0	2.98	34	31	21	34	33
35	Carnegie Mellon University	13.76	$253.7	5.42	32	12	37	40	66
36	Penn State University	13.70	$832.4	1.65	36	65	38	31	9
37	University of Arizona	13.60	$610.1	2.23	38	43	25	35	38
38	University of Chicago	13.33	$351.3	3.80	35	81	62	3	106
39	Georgia Institute of Technology	12.79	$779.0	1.64	42	39	33	39	31
40	Rutgers/The State University of New Jersey	12.77	$631.0	2.02	41	30	60	38	18

FULL RANKING FOR INNOVATION IMPACT (cont.)

		Innovation Impact Score (PCA)	Total Research Spending ($m)	Innovation Impact Productivity Score	Innovation Impact Rankings (simple weighted average method)				
					Overall Rank	Comm. Rank	Entrep. Rank	Res. Rank	Teaching Rank
41	University of Massachusetts System	12.22	$625.1	1.96	43	36	45	43	21
42	University of Georgia	11.73	$389.1	3.01	48	24	53	60	60
43	Princeton University	11.46	$201.8	5.68	39	27	82	8	124
44	University of Missouri System	11.11	$322.5	3.44	47	44	65	53	17
45	Cold Spring Harbor Laboratory	10.77	$99.0	10.87	10	119	110	2	168
46	University of Iowa	10.64	$440.3	2.42	49	70	30	52	46
47	Mayo Foundation for Medical Educ. and Research	10.58	$683.4	1.55	50	25	41	25	162
48	Michigan State University	10.20	$581.8	1.75	51	50	91	51	19
49	City of Hope National Medical Center	10.08	$390.7	2.58	45	5	59	174	169
50	Brigham Young University	10.06	$33.3	30.21	52	74	24	87	73
51	Vanderbilt University	10.01	$625.5	1.60	53	33	43	57	85
52	Iowa State University	9.84	$352.1	2.80	46	45	66	17	52
53	University of Virginia	9.60	$397.2	2.42	55	52	40	55	71
54	University of Central Florida	9.60	$200.8	4.78	54	57	48	92	37
55	University of Nebraska	9.32	$421.2	2.21	56	64	50	50	44
56	Case Western Reserve University	9.14	$321.1	2.85	57	55	42	47	74
57	Drexel University	8.40	$107.1	7.85	59	67	52	86	45
58	Washington State University	8.38	$195.9	4.27	62	56	49	85	70
59	University of Tennessee	8.16	$332.0	2.46	58	89	98	56	20
60	Oregon State University	8.10	$246.7	3.28	64	41	70	69	69
61	Louisiana State University System	8.07	$353.4	2.28	61	68	72	80	25
62	Texas Tech University System	7.87	$217.2	3.63	60	133	47	96	24
63	Virginia Tech	7.73	$508.8	1.52	63	78	61	81	40
64	Boston University/Boston Medical Center	7.38	$415.8	1.77	65	104	79	46	30
65	University of Miami	7.01	$327.1	2.14	67	91	44	84	81
66	Emory University	7.00	$498.4	1.41	68	60	68	41	82
67	Washington University of St. Louis	6.92	$600.0	1.15	69	75	56	49	77
68	Colorado State University	6.88	$321.7	2.14	71	73	67	63	65
69	University of Kansas	6.82	$241.8	2.82	72	66	92	65	55
70	University of Kentucky	6.69	$260.6	2.57	74	93	69	72	49
71	Sloan Kettering Institute	6.60	$580.2	1.14	66	17	118	54	170
72	Oregon Health & Science University	6.58	$333.7	1.97	80	47	75	89	108
73	University of Houston	6.53	$150.6	4.34	70	77	86	91	47
74	University of Connecticut	6.50	$180.1	3.61	76	88	77	82	51
75	Temple University	6.49	$175.4	3.70	73	115	95	66	34
76	Virginia Commonwealth University	6.47	$215.7	3.00	75	111	78	101	41
77	University of Rochester	6.30	$355.4	1.77	77	54	87	61	92
78	Mount Sinai School of Medicine of NYU	6.13	$420.1	1.46	79	38	57	151	152
79	Florida State University	6.01	$194.1	3.10	81	82	71	79	75
80	University of Oklahoma	5.96	$201.6	2.95	78	118	102	67	42

FULL RANKING FOR INNOVATION IMPACT (cont.)

		Innovation Impact Score (PCA)	Total Research Spending ($m)	Innovation Impact Productivity Score	Innovation Impact Rankings (simple weighted average method)				
					Overall Rank	Comm. Rank	Entrep. Rank	Res. Rank	Teaching Rank
81	University of Alabama at Birmingham	5.85	$497.50	1.18	83	82	105	108	54
82	Baylor College of Medicine	5.84	$392.70	1.49	85	72	54	45	155
83	University of Louisville	5.81	$181.90	3.19	84	95	58	104	83
84	University of Cincinnati	5.76	$218.10	2.64	82	109	115	75	43
85	Tufts University	5.51	$174.80	3.15	86	87	104	88	63
86	Medical University of South Carolina	5.34	$241.60	2.21	88	120	55	128	86
87	University of South Carolina	5.31	$207.70	2.56	87	100	126	62	58
88	University of New Hampshire	4.97	$108.70	4.57	93	40	163	119	125
89	Rice University	4.97	$120.50	4.12	92	78	73	64	135
90	University of Toledo	4.84	$56.70	8.54	90	110	108	115	67
91	Wayne State University	4.83	$221.10	2.18	89	121	129	77	57
92	Auburn University	4.68	$153.70	3.05	91	125	139	105	62
93	Cleveland Clinic	4.67	$258.00	1.81	96	49	101	68	171
94	Albert Einstein Coll. of Med./Yeshiva Univ.	4.32	$175.10	2.47	101	104	76	94	112
95	Thomas Jefferson University	4.31	$76.30	5.65	94	131	85	117	84
96	North Dakota State University	4.31	$153.60	2.80	102	61	150	135	116
97	University of Oregon	4.22	$77.20	5.47	99	71	90	93	146
98	Children's Hospital Boston	4.17	$315.20	1.32	111	62	84	113	172
99	University of Delaware	4.14	$139.90	2.96	95	135	81	98	93
100	Clemson University	4.11	$77.60	5.30	97	122	100	99	87
101	Tulane University	4.08	$137.90	2.96	98	130	74	125	99
102	University of Akron	3.92	$59.60	6.59	106	116	83	103	121
103	Dana-Farber Cancer Institute	3.90	$263.20	1.48	103	63	103	45	173
104	Kansas State University	3.89	$167.70	2.32	100	108	122	83	90
105	Montana State University	3.87	$111.90	3.46	110	86	88	130	141
106	University of Notre Dame	3.82	$192.70	1.98	107	112	89	74	129
107	Oklahoma State University	3.74	$139.80	2.68	105	129	127	118	79
108	Ohio University	3.66	$60.40	6.06	104	127	171	100	61
109	Stevens Institute of Technology	3.62	$29.00	12.49	112	148	64	168	127
110	University of Arkansas at Fayetteville	3.62	$137.60	2.63	119	84	132	150	110
111	Temple University System	3.58	$163.90	2.19	121	117	51	195	174
112	Georgetown University	3.54	$142.40	2.49	114	103	138	70	96
113	West Virginia University	3.54	$113.90	3.11	108	161	156	102	68
114	University of North Carolina at Charlotte	3.52	$34.80	10.09	116	128	93	114	111
115	University of Hawaii	3.49	$290.70	1.20	113	144	136	58	89
116	University of Vermont	3.46	$108.90	3.17	117	140	99	122	100
117	Rockefeller University	3.43	$160.00	2.14	123	58	121	97	175
118	University of Mississippi	3.42	$68.10	5.02	115	154	128	121	80
119	Brown University	3.36	$155.70	2.16	118	124	130	59	101
120	University of Alabama	3.33	$58.50	5.68	120	141	106	155	94

FULL RANKING FOR INNOVATION IMPACT (cont.)

		Innovation Impact Score (PCA)	Total Research Spending ($m)	Innovation Impact Productivity Score	Innovative Impact Rankings (simple weighted average method)				
					Overall Rank	Comm. Rank	Entrep. Rank	Res. Rank	Teaching Rank
121	Dartmouth College	3.30	$190.1	1.74	124	102	120	90	131
122	Utah State University	3.25	$169.8	1.92	126	104	113	106	132
123	Moffitt Cancer Center	3.19	$135.3	2.36	127	99	63	162	176
124	Jackson Laboratory	3.12	$70.6	4.41	109	69	168	23	177
125	Johns Hopkins University Applied Physics Lab.	3.09	$1,245.2	0.25	140	80	96	185	178
126	Southern Illinois University	3.06	$124.3	2.46	122	158	114	73	97
127	University of Arkansas for Medical Sciences	3.03	$79.5	3.81	129	132	116	169	104
128	University of Wisconsin - WiSys	3.03	$14.9	20.30	125	146	162	191	72
129	Mississippi State University	3.02	$224.6	1.35	128	143	119	124	102
130	Portland State University	2.90	$60.4	4.80	133	97	145	133	128
131	Whitehead Institute for Biomedical Research	2.89	$47.5	6.08	132	98	80	141	179
132	New Jersey Institute of Technology	2.86	$119.4	2.40	134	114	146	164	109
133	Creighton University	2.86	$19.9	14.39	130	178	172	166	76
134	Beth Israel Deaconess Medical Center	2.83	$222.2	1.28	141	94	94	107	180
135	East Carolina University	2.78	$29.4	9.45	131	162	140	145	91
136	Michigan Technological University	2.71	$70.6	3.83	136	134	109	159	134
137	University of Wisconsin at Milwaukee	2.66	$57.9	4.60	135	152	123	116	119
138	University of Nevada at Las Vegas	2.64	$64.6	4.09	138	155	112	144	123
139	University of South Alabama	2.57	$54.3	4.72	139	163	134	176	95
140	University of North Texas Health Science Center	2.56	$41.7	6.15	137	174	173	188	78
141	South Dakota State University	2.56	$60.9	4.20	142	140	124	167	122
142	Duquesne University	2.48	$16.0	15.43	143	164	141	152	103
143	Cedars-Sinai Medical Center	2.46	$128.6	1.91	144	85	107	109	181
144	University of Nevada at Reno	2.38	$106.5	2.23	146	145	155	127	113
145	San Diego State University	2.37	$56.8	4.17	145	147	152	134	107
146	Georgia Health Sciences University	2.33	$70.1	3.33	149	138	133	179	126
147	Colorado School of Mines	2.33	$59.3	3.93	148	126	153	112	133
148	New Mexico State University	2.30	$109.1	2.10	147	175	111	146	137
149	Fred Hutchinson Cancer Research Center	2.29	$359.4	0.64	150	90	117	110	182
150	Salk Institute for Biological Studies	2.27	$98.6	2.30	153	91	125	95	183
151	Nationwide Children's Hospital	2.26	$145.0	1.56	152	101	97	183	184
152	Boise State University	2.25	$30.1	7.48	155	107	148	163	153
153	University of Rhode Island	2.15	$48.0	4.48	154	151	181	137	98
154	Rochester Institute of Technology	2.14	$42.0	5.10	151	153	164	136	105
155	Wichita State University	1.99	$67.0	2.97	156	159	135	170	136
156	Medical College of Wisconsin	1.97	$185.1	1.06	158	149	150	147	139
157	Northern Arizona University	1.87	$36.6	5.10	157	179	160	156	118
158	Cleveland State University	1.85	$80.7	2.29	160	160	143	165	140
159	The Wistar Institute	1.85	$61.4	3.02	159	76	154	182	185
160	Wright State University	1.80	$53.8	3.35	161	177	167	161	115

FULL RANKING FOR INNOVATION IMPACT (cont.)

		Innovation Impact Score (PCA)	Total Research Spending ($m)	Innovation Impact Productivity Score	Innovative Impact Rankings (simple weighted average method) Overall Rank	Comm. Rank	Entrep. Rank	Res. Rank	Teaching Rank
161	Marquette University	1.71	$28.0	6.10	162	172	179	143	117
162	University of Alabama at Huntsville	1.67	$84.5	1.98	163	169	137	173	147
163	University of North Carolina at Greensboro	1.65	$31.9	5.17	164	166	147	149	151
164	Northern Illinois University	1.58	$9.9	15.83	166	171	183	129	120
165	Loyola University of Chicago	1.55	$46.7	3.33	165	182	184	131	114
166	University of Idaho	1.53	$100.2	1.52	168	150	171	126	148
167	University of North Dakota	1.51	$84.8	1.78	167	170	176	158	130
168	Brandeis University	1.48	$62.0	2.39	170	139	157	120	160
169	Lehigh University	1.45	$41.8	3.46	169	168	169	123	145
170	Louisiana Tech University	1.44	$23.5	6.12	170	156	144	184	158
171	Children's Hospital of Philadelphia	1.30	$220.6	0.59	173	123	158	111	186
172	Hospital for Special Surgery	1.25	$38.3	3.27	172	137	131	171	187
173	University of Dayton Research Institution	1.25	$104.4	1.20	171	167	175	157	149
174	Children's Hospital Cincinnati	1.20	$402.2	0.30	178	113	177	154	188
175	Southern Methodist University	1.17	$22.0	5.31	174	173	174	142	156
176	National Jewish Health	1.16	$51.0	2.28	179	136	142	186	189
177	St. Jude Children's Research Hospital	1.08	$340.9	0.32	180	96	185	178	190
178	Illinois State University	1.05	$18.5	5.66	175	190	182	160	142
179	University of Memphis	1.04	$19.3	5.41	176	176	186	153	150
180	Miami University	0.98	$15.4	6.39	177	193	187	140	144
181	University of Alaska at Anchorage	0.98	$14.0	6.98	181	183	151	172	164
182	Tufts Medical Center	0.91	$74.4	1.22	184	157	159	138	191
183	University of South Dakota	0.87	$19.3	4.53	183	187	180	177	154
184	University of North Florida	0.84	$8.5	9.91	182	192	188	181	143
185	University of Northern Iowa	0.81	$39.5	2.05	186	181	165	175	163
186	Woods Hole Oceanographic Institution	0.79	$192.1	0.41	187	165	161	148	192
187	Bowling Green State University	0.78	$14.4	5.40	185	188	189	139	157
188	Ball State University	0.77	$6.1	12.56	192	189	191	192	167
189	Catholic University of America	0.70	$21.1	3.30	188	184	178	132	165
190	University of West Florida	0.49	$32.4	1.52	189	191	190	187	159
191	Embry-Riddle Aeronautical University	0.47	$17.6	2.68	190	186	192	180	161
192	Children's National Health System	0.39	$75.0	0.52	191	185	166	193	193
193	Boyce Thompson Institution	0.14	$10.4	1.31	193	180	192	189	194
194	Hackensack University Medical Center	0.02	$8.7	0.20	194	194	194	190	195
195	Salish Kootenai College	0.00	$3.3	0.00	195	195	195	194	166

Appendix 3

FULL RANKINGS FOR INNOVATION IMPACT PRODUCTIVITY

Large comprehensive research universities

		Innovation Impact Productivity Score	Rank Based on Weighted Avg.
1	University of Florida	4.97	1
2	University of Utah	4.25	2
3	California Institute of Technology	3.93	7
4	University of Chicago	3.80	3
5	North Carolina State University	3.69	6
6	Columbia University	3.61	4
7	Northwestern University	3.35	5
8	New York University (NYU)	3.31	8
9	Purdue University	3.13	11
10	University of Georgia	3.01	12
11	Arizona State University	2.98	13
12	Indiana University	2.97	10
13	University of South Florida	2.90	15
14	Iowa State University	2.80	9
15	University of Minnesota	2.72	14
16	Stanford University	2.59	16
17	University of Pennsylvania	2.56	17
18	University of Washington	2.47	19
19	University of Pittsburgh	2.43	22
20	University of Virginia	2.42	20
21	University of Iowa	2.42	18
22	University of Southern California	2.34	21
23	Louisiana State University System	2.28	23
24	University of Arizona	2.23	24
25	University of Nebraska	2.21	25
26	Cornell University	2.16	26
27	University of Michigan	2.11	29
28	University of Colorado	2.07	30
29	University of Illinois at Urbana-Champaign	2.07	32
30	Harvard University	2.06	28
31	University of Texas System	2.06	27
32	Rutgers/The State University of New Jersey	2.02	35
33	University of California System	2.00	31
34	University System of Maryland	1.99	33
35	Oregon Health & Science University	1.97	41
36	University of Massachusetts System	1.96	34
37	University of North Carolina at Chapel Hill	1.91	36
38	Massachusetts Institute of Technology (MIT)	1.91	38
39	Duke University	1.87	37
40	Ohio State University	1.82	40

FULL RANKINGS FOR INNOVATION IMPACT PRODUCTIVITY (cont.)

Large comprehensive research universities (cont.)

		Innovation Impact Productivity Score	Rank Based on Weighted Avg.
41	Boston University/Boston Medical Center	1.77	39
42	University of Rochester	1.77	42
43	Michigan State University	1.75	43
44	University of Wisconsin at Madison	1.72	47
45	State University of New York	1.72	44
46	Texas A&M University System	1.71	45
47	Penn State University	1.65	46
48	Georgia Institute of Technology	1.64	48
49	Vanderbilt University	1.60	50
50	Virginia Tech	1.52	49
51	Emory University	1.41	52
52	Johns Hopkins University	1.40	51
53	University of Alabama at Birmingham	1.18	53
54	Washington University of St. Louis	1.15	54

FULL RANKINGS FOR INNOVATION IMPACT PRODUCTIVITY (cont.)

Mid-sized comprehensive research universities

		Innovation Impact Productivity Score	Rank Based on Weighted Avg.
1	Drexel University	7.85	1
2	University of New Mexico	6.77	2
3	Princeton University	5.68	3
4	Carnegie Mellon University	5.42	4
5	University of Central Florida	4.78	5
6	University of New Hampshire	4.57	8
7	University of Houston	4.34	6
8	Washington State University	4.27	7
9	Rice University	4.12	9
10	Temple University	3.70	10
11	Texas Tech University System	3.63	11
12	University of Connecticut	3.61	12
13	Montana State University	3.46	14
14	University of Missouri System	3.44	13
15	Oregon State University	3.28	20
16	University of Louisville	3.19	17
17	University of Vermont	3.17	16
18	Tufts University	3.15	18
19	West Virginia University	3.11	15
20	Florida State University	3.10	23
21	Auburn University	3.05	21
22	Virginia Commonwealth University	3.00	20
23	Tulane University	2.96	25
24	University of Delaware	2.96	24
25	University of Oklahoma System	2.95	22
26	Case Western Reserve University	2.85	27
27	University of Kansas	2.82	26
28	North Dakota State University	2.80	32
29	Oklahoma State University	2.68	28
30	University of Cincinnati	2.64	29
31	University of Arkansas at Fayetteville	2.63	37
32	University of Kentucky	2.57	31
33	University of South Carolina	2.56	33
34	Georgetown University	2.49	34
35	Albert Einstein College of Medicine/Yeshiva University	2.47	35
36	Southern Illinois University	2.46	30
37	University of Tennessee	2.46	36
38	New Jersey Institute of Technology	2.40	39
39	Kansas State University	2.32	38
40	University of Nevada at Reno	2.23	40

FULL RANKINGS FOR INNOVATION IMPACT PRODUCTIVITY (cont.)

Mid-sized comprehensive research universities (cont.)

		Innovation Impact Productivity Score	Rank Based on Weighted Avg.
41	Temple University System	2.19	46
42	Wayne State University	2.18	42
43	Brown University	2.16	41
44	Rockefeller University	2.14	47
45	University of Miami	2.14	44
46	Colorado State University	2.14	45
47	New Mexico State University	2.10	43
48	University of Notre Dame	1.98	48
49	Utah State University	1.92	49
50	Dartmouth College	1.74	50
51	University of Idaho	1.52	51
52	Mississippi State University	1.35	52
53	University of Hawaii	1.20	53
54	University of Dayton	1.20	54

FULL RANKINGS FOR INNOVATION IMPACT PRODUCTIVITY (cont.)

Smaller comprehensive research universities

		Innovation Impact Productivity Score	Rank Based on Weighted Avg.
1	Brigham Young University	30.21	1
2	University of Wisconsin - WiSys	20.30	2
3	Northern Illinois University	15.83	3
4	Duquesne University	15.43	4
5	Creighton University	14.39	5
6	Ball State University	12.56	6
7	Stevens Institute of Technology	12.49	7
8	University of North Carolina at Charlotte	10.09	9
9	University of North Florida	9.91	8
10	East Carolina University	9.45	10
11	University of Toledo	8.54	11
12	Boise State University	7.48	13
13	University of Alaska at Anchorage	6.98	12
14	University of Akron	6.59	16
15	Miami University	6.39	14
16	Louisiana Tech University	6.12	19
17	Marquette University	6.10	17
18	Ohio University	6.06	15
19	University of Alabama	5.68	21
20	Illinois State University	5.66	18
21	Thomas Jefferson University	5.65	22
22	University of Oregon	5.47	28
23	University of Memphis	5.41	23
24	Bowling Green State University	5.40	20
25	Southern Methodist University	5.31	33
26	Clemson University	5.30	24
27	University of North Carolina at Greensboro	5.17	27
28	Northern Arizona University	5.10	25
29	Rochester Institute of Technology	5.10	26
30	University of Mississippi	5.02	29
31	Portland State University	4.80	34
32	University of South Alabama	4.72	30
33	University of Wisconsin – Milwaukee	4.60	32
34	University of South Dakota	4.53	31
35	University of Rhode Island	4.48	35
36	South Dakota State University	4.20	37
37	San Diego State University	4.17	36
38	University of Nevada at Las Vegas	4.09	38
39	Colorado School of Mines	3.93	39
40	Michigan Technological University	3.83	40

FULL RANKINGS FOR INNOVATION IMPACT PRODUCTIVITY (cont.)

Smaller comprehensive research universities (cont.)

		Innovation Impact Productivity Score	Rank Based on Weighted Avg.
41	University of Arkansas for Medical Sciences	3.81	41
42	Lehigh University	3.46	43
43	Wright State University	3.35	44
44	Loyola University of Chicago	3.33	42
45	Catholic University of America	3.30	45
46	Wichita State University	2.97	46
47	Embry-Riddle Aeronautical University	2.68	47
48	Brandeis University	2.39	48
49	Cleveland State University	2.29	49
50	University of Northern Iowa	2.05	50
51	University of Alabama - Huntsville	1.98	51
52	University of North Dakota	1.78	52
53	University of West Florida	1.52	53
54	Salish Kootenai College	0.00	54

FULL RANKINGS FOR INNOVATION IMPACT PRODUCTIVITY (cont.)

Pure medical institutions

		Innovation Impact Productivity Score	Rank Based on Weighted Avg.
1	University of North Texas Health Science Center	6.15	1
2	Georgia Health Sciences University	3.33	2
3	Medical University of South Carolina	2.21	3
4	Mayo Foundation for Medical Education and Research	1.55	4
5	Baylor College of Medicine	1.49	5
6	Mount Sinai School of Medicine of NYU	1.46	6
7	Medical College of Wisconsin	1.06	7

FULL RANKINGS FOR INNOVATION IMPACT PRODUCTIVITY (cont.)

Pure research/health care institutions

		Innovation Impact Productivity Score	Rank Based on Weighted Avg.
1	Cold Spring Harbor Laboratory	10.87	1
2	Whitehead Institute for Biomedical Research	6.08	2
3	Jackson Laboratory	4.41	3
4	Hospital for Special Surgery	3.27	4
5	The Wistar Institute	3.02	6
6	City of Hope National Medical Center	2.58	5
7	Moffitt Cancer Center	2.36	7
8	Salk Institute for Biological Studies	2.30	8
9	National Jewish Health	2.28	9
10	Cedars-Sinai Medical Center	1.91	10
11	Cleveland Clinic	1.81	11
12	Nationwide Children’s Hospital	1.56	12
13	Dana-Farber Cancer Institute	1.48	13
14	Children’s Hospital Boston	1.32	16
15	Boyce Thompson Institute	1.31	18
16	Beth Israel Deaconess Medical Center	1.28	15
17	Tufts Medical Center	1.22	17
18	Sloan Kettering Institute	1.14	14
19	Fred Hutchinson Cancer Research Center	0.64	19
20	Children’s Hospital of Philadelphia	0.59	20
21	Children’s National Health System	0.52	21
22	Woods Hole Oceanographic Institution	0.41	22
23	St. Jude Children’s Research Hospital	0.32	23
24	Children’s Hospital Cincinnati	0.30	24
25	Johns Hopkins University Applied Physics Laboratory	0.25	25
26	Hackensack University Medical Center	0.20	26

Appendix 4

FULL RESULTS FOR DATA ENVELOPMEMNT ANALYSIS

1	Arizona State University	1.00
2	Ball State University	1.00
3	Brandeis University	1.00
4	Brigham Young University	1.00
5	California Institute of Technology	1.00
6	Carnegie Mellon University	1.00
7	Cedars-Sinai Medical Center	1.00
8	Children's Hospital Boston	1.00
9	Children's Hospital of Philadelphia	1.00
10	City of Hope National Medical Center	1.00
11	Cleveland Clinic	1.00
12	Colorado State University	1.00
13	Columbia University	1.00
14	Creighton University	1.00
15	Dana-Farber Cancer Institute	1.00
16	Drexel University	1.00
17	Duquesne University	1.00
18	East Carolina University	1.00
19	Georgia Health Sciences University	1.00
20	Moffitt Cancer Center	1.00
21	Hackensack University Medical Center	1.00
22	Hospital for Special Surgery	1.00
23	Illinois State University	1.00
24	Indiana University	1.00
25	Iowa State University	1.00
26	Johns Hopkins University	1.00
27	Johns Hopkins Applied Physics Lab.	1.00
28	Kansas State University	1.00
29	Louisiana State University System	1.00
30	Louisiana Tech University	1.00
31	MIT	1.00
32	Mayo Foundation for Med. Educ. & Res.	1.00
33	Medical University of South Carolina	1.00
34	Michigan Tech University	1.00
35	Montana State University	1.00
36	Mount Sinai School of Medicine	1.00
37	National Jewish Health	1.00
38	New Jersey Institute of Technology	1.00
39	New York University	1.00
40	North Carolina State University	1.00
41	North Dakota State University	1.00
42	Northern Illinois University	1.00
43	Northwestern University	1.00
44	Ohio State University	1.00
45	Ohio University	1.00

46	Oregon State University	1.00
47	Penn State University	1.00
48	Portland State University	1.00
49	Princeton University	1.00
50	Purdue University	1.00
51	State University of New York	1.00
52	San Diego State University	1.00
53	Sloan Kettering Institute	1.00
54	South Dakota State University	1.00
55	Southern Illinois University	1.00
56	Stanford University	1.00
57	Stevens Institute of Technology	1.00
58	Temple University	1.00
59	Jackson Laboratory	1.00
60	The Salk Institute for Bio. Studies	1.00
61	University of Alabama at Birmingham	1.00
62	Thomas Jefferson University	1.00
63	Tufts Medical Center	1.00
64	University of Akron	1.00
65	University of Alabama	1.00
66	University of Alabama in Huntsville	1.00
67	University of Alaska Anchorage	1.00
68	University of Arkansas for Medical Science	1.00
69	University of California System	1.00
70	University of Central Florida	1.00
71	University of Chicago	1.00
72	University of Cincinnati	1.00
73	University of Florida	1.00
74	University of Georgia	1.00
75	University of Houston	1.00
76	University of Illinois at Urbana-Champaign	1.00
77	University of Kentucky	1.00
78	University of Louisville	1.00
79	University of Michigan	1.00
80	University of Minnesota	1.00
81	University of Mississippi	1.00
82	University of Missouri System	1.00
83	University of Nebraska	1.00
84	University of New Hampshire	1.00
85	University of New Mexico	1.00
86	University of North Carolina at Charlotte	1.00
87	University of North Florida	1.00
88	University of North Texas Health Sci. Ctr.	1.00
89	University of Oklahoma System	1.00
90	University of Oregon	1.00

FULL RESULTS FOR DATA ENVELOPMEMNT ANALYSIS (cont.)

91	University of Pittsburgh	1.00	**136**	University of Colorado	1.27
92	University of Rhode Island	1.00	**137**	Georgetown University	1.27
93	University of South Carolina	1.00	**138**	Mississippi State University	1.27
94	University of South Florida	1.00	**139**	Rutgers/The State University of New Jersey	1.28
95	University of Texas System	1.00	**140**	Rochester Institute of Technology	1.29
96	University of Toledo	1.00	**141**	University of Rochester	1.29
97	University of Utah	1.00	**142**	Rice University	1.31
98	University of Washington	1.00	**143**	Oregon Health & Science University	1.32
99	University of Wisconsin - Madison	1.00	**144**	University of Kansas	1.34
100	University of Wisconsin - Milwaukee	1.00	**145**	Michigan State University	1.44
101	University System of Maryland	1.00	**146**	Virginia Tech	1.45
102	Utah State University	1.00	**147**	Children's Hospital Cincinnati	1.46
103	Virginia Commonwealth University	1.00	**148**	Florida State University	1.46
104	Wayne State University	1.00	**149**	Medical College of Wisconsin	1.47
105	Whitehead Institute for Biomedical Research	1.00	**150**	University of Miami	1.47
106	The Wistar Institute	1.00	**151**	New Mexico State University	1.51
107	University of Iowa	1.01	**152**	University of Delaware	1.51
108	Texas A&M University System	1.02	**153**	Fred Hutchinson Cancer Research Center	1.52
109	University of Tennessee	1.03	**154**	Tulane University	1.52
110	University of Pennsylvania	1.03	**155**	University of Southern California	1.53
111	University of Massachusetts System	1.04	**156**	Case Western Reserve University	1.57
112	University of Notre Dame	1.05	**157**	Boston University	1.61
113	Northern Arizona University	1.06	**158**	University of Vermont	1.62
114	Miami University	1.07	**159**	University of Dayton	1.64
115	Duke University	1.07	**160**	University of Nevada at Reno	1.64
116	Georgia Institute of Technology	1.08	**161**	University of Arkansas at Fayetteville	1.66
117	Beth Israel Deaconess Medical Center	1.09	**162**	University of Northern Iowa	1.66
118	Clemson University	1.10	**163**	Oklahoma State University	1.71
119	University of Idaho	1.11	**164**	Baylor College of Medicine	1.72
120	University of Arizona	1.13	**165**	Albert Einstein College of Medicine	1.73
121	University of North Carolina at Greensboro	1.13	**166**	University of South Dakota	1.74
122	Loyola University of Chicago	1.13	**167**	University of Virginia	1.75
123	University of South Alabama	1.14	**168**	Emory University	1.81
124	University of Connecticut	1.16	**169**	Lehigh University	1.92
125	Auburn University	1.18	**170**	Vanderbilt University	1.92
126	University of Hawaii	1.19	**171**	University of West Florida	1.94
127	Harvard University	1.19	**172**	Dartmouth College	2.08
128	Tufts University	1.19	**173**	Brown University	2.24
129	West Virginia University	1.20	**174**	St. Jude Children's Research Hospital	2.61
130	University of Memphis	1.21	**175**	Washington University of St. Louis	2.75
131	University of North Carolina at Chapel Hill	1.23			
132	Cornell University	1.23			
133	Washington State University	1.24			
134	Colorado School of Mines	1.25			
135	Wright State University	1.25			

Appendix 5

MULTIVARIATE REGRESSION RESULTS

	1	2	3	4	5	6
Research ($100m)	2.30***	2.21***	1.74***	0.77*		1.97***
	(0.22)	(0.23)	(0.11)	(0.35)		(0.28)
Research^2 ($100m)	(0.046)*	(0.064)***	0.004	(0.044)*		(0.054)**
	(0.018)	(0.018)	(0.003)	(0.019)		(0.019)
Endowment ($bn)		(0.21)			0.05	
		(0.11)			(0.11)	
Total budget ($bn)					0.38*	
					(0.18)	
MSA population (m)	0.018	0.090			0.032	
	(0.082)	(0.079)			(0.090)	
MSA % with BA or more	(4.29)	2.11				3.84
	(6.17)	(5.83)				(7.11)
MSA med. HH inc ($000)				(0.024)		
				(0.030)		
MSA median age						(0.14)
						(0.08)
MSA housing price index				0.03		(0.10)
				(0.29)		(0.31)
MSA % foreign-born	5.57	0.21		10.98*	5.96	9.57
	(5.32)	(5.31)		(5.04)	(5.58)	(5.24)
Univ. invention disclosures				0.043***	0.053***	
				(0.006)	(0.005)	
Public (vs. pvt.)				0.56		
				(0.71)		
Compreh. univ. w/ med sch		0.42		0.98		0.40
		(0.62)		(0.69)		(0.68)
Pure med. institution		(2.79)*		(0.79)		(3.35)
		(1.29)		(2.24)		(2.00)
Pure research institute		(4.29)***		(3.36)		(4.23)*
		(0.87)		(2.18)		(1.89)
Univ. has business sch.				1.78		2.45
				(1.46)		(1.51)
Univ. has engineer sch.				(0.06)		
				(1.14)		
Univ. has entrep. pgm.				0.50	1.08	(0.74)
				(1.00)	(0.70)	(0.91)
# of members Nat'l Acads.		0.061***		(0.012)	(0.029)	0.020*
		(0.017)		(0.011)	(0.016)	(0.010)
Univ. is AAU member				0.31		
				(0.83)		
Univ. is on CMUP list				(0.60)		
				(0.87)		
TTO staff size						0.099***
						(0.028)
TTO head: engineer			1.71*	1.14	1.91*	
			(0.84)	(0.78)	(0.72)	

TTO head: startup exper.						(0.30)
						(0.70)
Patent applics.					(0.005)	
					(0.006)	
Univ. has seed fund				0.76	(0.46)	(0.11)
				(0.60)	(0.60)	(0.63)
Univ. has accelerator					0.40	0.07
					(0.61)	(0.55)
% of res. funded by ind.					(9.41)*	
					(4.62)	
Constant	1.21	1.14	1.46**	(1.23)	0.68	3.41
	(1.15)	(1.11)	(0.51)	(2.67)	(0.93)	(3.59)
No. of observations	184	168	162	118	122	135
Adj R^2	0.73	0.80	0.88	0.85	0.84	0.81

Notes:

"$Research^2$" is the square of research spending, measured in USD hundreds of millions. "MSA % with BA or more" is the population share (25 years and older) with a bachelor's degree or a higher level of educational attainment. "MSA med. HH income" is median household income.

The top number in each cell is the regression coefficient. Parentheses around coefficients signify negative values. The value below each coefficient in parentheses is the associated standard error.

(***) indicates statistical significance at the 0.001 level. (**) indicates significance at the 0.01 level, while (*) indicates significance at the 0.05 level.

MULTIVARIATE REGRESSION RESULTS (cont.)

	7	8	9	10	11	12
ln Research	4.07***	3.39***	5.90***	1.07		3.21***
	(0.28)	(0.30)	(0.52)	(0.56)		(0.37)
Endowment ($bn)		(0.30)*				
		(0.13)				
ln endowment ($bn)					0.50	
					(0.28)	
ln total budget ($m)					0.45	
					(0.30)	
MSA population (m)	(0.029)	0.152			0.067	
	(0.103)	(0.093)			(0.085)	
MSA % with BA or more	(0.87)	3.33				9.80
	(7.80)	(6.86)				(7.91)
MSA med. HH inc ($000)				(0.026)		
				(0.029)		
MSA median age						(0.18)*
						(0.09)
MSA housing price index				0.06		(0.15)
				(0.29)		(0.35)
MSA % foreign born	7.78	(5.34)		11.80*	6.20	7.14
	(6.74)	(6.17)		(5.01)	(5.29)	(5.80)
Univ. invention disclosures				0.041***	0.054***	
				(0.005)	(0.004)	
Public (vs. pvt)				0.66		
				(0.70)		
Compreh univ. w/ med. sch		0.54		1.03		0.42
		(0.74)		(0.69)		(0.76)
Pure med. institution		(3.19)*		(1.21)		(3.07)
		(1.52)		(4.06)		(2.24)
Pure research institute		(4.50)***		(4.06)		(3.80)
		(1.04)		(2.27)		(2.13)
Univ. has business sch.				1.85		3.36*
				(1.46)		(1.69)
Univ. has engineer sch.				(0.20)		
				(1.13)		
Univ. has entrep pgm.				0.55	0.71	(0.50)
				(0.99)	(0.72)	(1.02)
# of members Nat'l Acads.		0.098***		(0.013)	(0.025)*	0.037***
		(0.017)		(0.011)	(0.010)	(0.011)
Univ. is AAU member				0.63		
				(0.78)		
Univ. is on CMUP list				(1.26)		
				(1.02)		
TTO staff size						0.123***
						(0.030)
TTO head: engineer			3.52*	1.25	1.61*	
			(1.72)	(0.78)	(0.71)	
TTO head: startup exper.						(0.23)
						(0.79)

Patent applics.					(0.006)	
					(0.006)	
Univ. has seed fund			2.54*	(0.58)	(0.36)	
			(1.22)	(0.60)	(0.61)	
Univ. has accelerator				0.35	0.40	
				(0.61)	(0.55)	
% of res. funded by ind.					(4.69)	
					(4.58)	
Constant	(70.5)***	(57.6)***	(105.8)***	(19.5)	(14.5)*	(53.2)***
	(5.1)	(5.3)	(10.0)	(9.9)	(6.3)	(8.2)
No. of observations	184	168	162	118	118	135
Adj. R^2	0.57	0.72	0.47	0.85	0.85	0.75

Appendix 6

DEA LOGISTIC REGRESSION RESULTS

	1	2
MSA population (m)	0.078 (0.041)	
MSA % foreign-born		1.77 (2.08)
TTO staff size	0.0062 (0.0140)	0.0076 (0.0137)
TTO head: engineer	0.023 (0.482)	0.099 (0.471)
Univ. has seed fund	0.151 (0.366)	0.224 (0.363)
Univ. has accelerator	-0.176 (0.365)	-0.185 (0.364)
% of research funded by industry	0.839 (2.862)	0.764 (2.848)
Constant	-0.090 (0.365)	-0.108 (0.416)
No. of observations	155	155

BUSHCENTER.ORG

OPUS-FAVEO.COM