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Federal Technology Transfer Evaluation: An Overview of Measures and Metrics, Common Challenges, and Approaches to Improve Evidence-Building Capacity

Vanessa Peña
Brendan R. Novak

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1701 Pennsylvania Ave., Suite 500
Washington, DC 20006-5825

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For More Information

Vanessa Peña, Project Leader
vpena@ida.org, 202-419-5496

Kristen M. Kulinowski, Director, Science and Technology Policy Institute
kkulinow@ida.org, 202-419-5491

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Executive Summary

The process of technology transfer, whereby research discoveries, in the form of knowledge, capabilities, and technologies are transferred to other parties, is critical to the Federal Government ensuring that funding to support research and development (R&D) ecosystems provides benefits to taxpayers and leads to societal impacts. To assist in measuring the effectiveness of Federal technology transfer activities, the Office of Science and Technology Policy (OSTP) requested that the Science and Technology Policy Institute (STPI), in coordination with the National Science and Technology Council's Lab-to-Market (L2M) Subcommittee's Strategy Team Five interagency working group, develop this paper.

The paper consists of three sections: an overview of reporting mandates and Federal technology transfer metrics provided in annual reports, a description of common challenges in assessing the value of Federal technology transfer activities, and suggested approaches to address these challenges. Appendices provide additional information and resources to support continued exploration and implementation of the approaches described in this paper, including an annotated bibliography of 177 published articles and reports related to assessing the value of R&D and technology transfer intended to serve as an informational resource for Federal technology transfer practitioners.

To address the challenges related to evaluating Federal technology transfer activities, Federal agencies may wish to consider the following: (1) strengthen capacity for building evidence; (2) adopt or adapt innovative metrics; and (3) improve cross-sector engagement to leverage expertise to build evidence. These overarching approaches are cross-cutting in that each approach may be designed and operationalized by agencies to address one or more of the challenges described in the paper. They may also be applied across intramural and extramural R&D and technology transfer activities. These approaches reflect actionable suggestions that can be coordinated and led as interagency efforts by the L2M Subcommittee (or other relevant interagency coordination groups) or initiated by single Federal entities. Potential activities to pursue under both situations are described in the paper.

The L2M Subcommittee could further support these goals through concerted efforts to help guide and share information as agencies pursue these approaches, for instance, through the establishment of an interagency working group to help maintain updated information resources for the Federal community and help agencies identify exemplar practices, lessons learned, and coordination opportunities in pursuit of these approaches.

Contents

1. Introduction

U.S. leadership in innovation is founded upon its effective Federal research and development (R&D) ecosystem—including intramural and extramural R&D laboratories across public and private sectors. The process of technology transfer, whereby research discoveries, in the form of knowledge, capabilities, and technologies are transferred to other parties, is critical to the Federal Government ensuring that funding to support R&D ecosystems provides benefits to taxpayers and leads to societal impacts.

The U.S. Government strives to derive as much benefit as possible from Federal expenditures. To benefit the U.S. public and private sectors, the Nation's network of federally supported R&D laboratories and organizations need to be able to efficiently and effectively transfer technologies to parties that can transform these technologies into commercial products and other productive uses. This network comprises Federal and non-Federal researchers, entrepreneurs, businesses, investors, State and local governments, and intermediary organizations that provide vital resources and services across our Nation's innovation ecosystems.

To assist in measuring the effectiveness of Federal technology transfer activities, the Office of Science and Technology Policy (OSTP) requested that the Science and Technology Policy Institute (STPI), in coordination with the National Science and Technology Council's (NSTC) Lab-to-Market (L2M) Subcommittee's Strategy Team Five (ST5) interagency working group, develop this paper. Throughout this paper, "Federal technology transfer" refers to both federally supported intramural and extramural activities.

A. Purpose

The purpose of this paper is to provide an overview of the metrics used by Federal agencies to communicate the value and impact of their technology transfer activities, describe common challenges experienced by the Federal technology transfer community in measuring the performance of their activities, and provide suggested approaches that Federal agencies could implement to address these challenges.

The paper builds off ST5 interagency working group discussions occurring throughout 2018 and 2019 aimed at advancing the goals of the L2M Subcommittee. These discussions included a recognition that evaluating the performance of technology transfer activities broadly remains a challenge given the wide variety of activities and goals that these activities represent. The group sought to develop this paper to describe the common understanding across the Federal technology transfer community of the complexities in the interpretation and use of technology transfer metrics. They also intended for the paper to serve as a reference for the community and potential approaches that can advance efforts to measure and evaluate the impacts from Federal technology transfer activities. The paper compiles relevant metrics identified by the ST5 interagency working group that were integrated into updated Federal guidance (Appendix A) and literature on Federal technology transfer impacts (Appendix B).

B. Background

Concerns over generating adequate return on investment (ROI) from Federal funding, driven in part by the perception that technology transfer activities and impacts from Federal laboratories lagged behind those from the private sector, spurred legislation in the 1980s focused on bolstering technology transfer activities within the Federal Government (Appendix A). These seminal laws included the Stevenson-Wydler Technology Innovation Act of 1980 and the Bayh-Dole Act of 1980 focusing on governance for technology transfer activities of Federal and non-Federal organizations, respectively. Subsequent legislation, through the Federal Technology Transfer Act of 1986, built on the Stevenson-Wydler Technology Innovation Act of 1980 by improving access to Federal laboratories by non-Federal organizations and allowing inventors employed by the Federal Government to patent and receive royalties from patent licenses.

More broadly, over the last 30 years, the Federal Government has been promoting the use of evidence to ensure that taxpayers' dollars are maximized to meet agency missions.[1] Several efforts spanning multiple administrations have focused on strategic planning and strategic performance frameworks in the Federal Government—including in 1993 with the passage of the Government Performance and Results Act[2] and in 2002 with the Program Assessment Rating Tool (PART) developed by the Office of Management and Budget (OMB).[3] Throughout the last decade, OMB has issued further guidance to encourage agency performance evaluation and reporting.[4] OMB guidance in 2016 encouraged

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1 For a background on the evolution in the use of evidence and evaluation, *see* Vanessa Peña and Jonathan Behrens. 2019. *Evidence-Based Approaches for Improving Federal Programs and Informing Funding Decisions*. Washington, DC: IDA Science & Technology Policy Institute.

2 Pub.L. 103–62.

3 For further background on PART, *see* OMB, "Assessing Program Performance." https://georgewbush-whitehouse.archives.gov/omb/performance/index.html.

4 For further on related OMB guidance, *see* OMB. "Evaluating Programs for Efficacy and Cost-Efficiency." M-10-32, 2010, Executive Office of the President; and OMB. "Analytical Perspectives: Budget of the United States Government, Fiscal Year 2017." Office of Management and Budget, 2016.

agencies to develop learning agenda approaches to understand how Federal programs and activities could work more effectively.[5]

Federal technology transfer coordination activities have been enhanced through the 2011 Presidential Memorandum *Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses* as well as the continuation of technology transfer remaining a key aspect of the President's Management Agenda (PMA) released in 2018. Specifically, improving "the transfer of technology from federally funded R&D to the private sector to promote U.S. economic growth and national security" was one of 14 Cross-Agency Priority (CAP) Goals in the 2018 PMA.[6] The NSTC L2M Subcommittee—an interagency group led by OSTP, the Department of Energy (DOE), and the National Institute of Standards and Technology (NIST)—has been one of several coordinating groups focused on interagency strategies to improve Federal technology transfer activities.[7]

In July 2018, the L2M Subcommittee established five strategy teams made up of Federal technology transfer experts, each aimed at developing milestones to accomplish one of the five strategies defined under the CAP Goal. The ST5 interagency working group was established to identify ways to "improve understanding of global science and technology trends and benchmarks to measure progress and achieve results." ST5 members convened over the course of 6 months through March 2019 to discuss milestones for supporting this strategy. One of the milestones developed by ST5 was to write this paper. STPI, informed by ST5 discussions, further analyzed the relevant literature and identified common challenges and approaches for the L2M Subcommittee and agencies to consider to address the identified challenges.

C. Understanding ROI

As defined by the 2019 NIST ROI Initiative Green Paper, technology transfer encompasses "the broad range of mechanisms used to transfer technology, knowledge, and capabilities resulting from federally funded R&D to productive uses, and, where appropriate, commercialization" (NIST 2019). NIST's Green Paper states:

> ROI is not intended to be defined in classic economic terms. Instead, ROI as used here takes a broad approach that emphasizes the underlying social and public mission inherent in the development of Federal research into products and services benefiting American taxpayers**. The "return" is interpreted to encompass a wide variety of benefits of technology transfer, both tangible and intangible to the investor, namely American**

[5] For further on learning agendas, *see* Chapter 4 of this paper.

[6] The PMA is available at https://trumpwhitehouse.archives.gov/wp-content/uploads/2018/03/The-President%E2%80%99s-Management-Agenda.pdf.

[7] For more information on L2M, see https://www.nist.gov/tpo/lab-market.

> **citizens. It should not be viewed in the narrow context of revenue generation**, but rather as contributions to broader economic prosperity, national security, and societal impact. The "return" is to the American society as a whole in accordance with each agency's unique statutory mission. "Investment" refers to federally funded R&D both performed by the government (intramural) and by universities and the private sector (extramural) (emphasis added; NIST 2019).

This definition allows for an inclusive scope for technology transfer whereby commercialization can be for the benefit of public sectors, including the Federal Government, as well as the broader society. In this way, assessing value or ROI of Federal technology transfer activities may depend on the goals for conducting these activities, including improving the economy, achieving an agency's mission, and generating broader impacts to society and national security. This distinction has implications for the selection of measures for evaluating Federal technology transfer activities in that the outcomes may vary depending on the goals and end-consumers. In addition, ROI can be measured through quantitative as well as qualitative measures, as reviewed in this paper.

D. Structure of the Paper

The paper consists of three sections: an overview of reporting mandates and Federal technology transfer metrics provided in annual reports, a description of common challenges in assessing the value of Federal technology transfer activities, and suggested approaches to address these challenges. Appendices provide additional information and resources to support continued exploration and implementation of the approaches described in the paper. Appendix A provides an overview of Federal policies governing technology transfer activities. Appendix B provides an "a la carte" menu of metrics included in the recently updated Federal reporting guidance on technology transfer metrics. Appendix C provides an annotated bibliography of 177 published articles and reports related to assessing the value of R&D and technology transfer intended to serve as an informational resource for Federal technology transfer practitioners.

2. Federal Technology Transfer Metrics and Measures

This chapter provides an overview of the legislatively mandated technology transfer metrics collected and reported by Federal agencies. Federal agencies report these metrics for their intramural activities through their annual technology transfer reports and through other communication mechanisms, such as collections of case studies and press releases. Although no legislative mandate exists for reporting extramural technology transfer metrics, Federal agencies may also collect and disseminate information about technology transfer activities and outcomes related to their extramural R&D programs through various means, including studies, reports, and case studies.

A. Federal Policies Regarding Intramural Reporting of Metrics

Statutory reporting requirements for Federal intramural technology transfer activities are codified in 15 USC 3710 (f)(2)(B).[8] The statute requires agencies involved in scientific research to include in their technology transfer annual reports to Congress:

> *(B) information on technology transfer activities for the preceding fiscal year, including–*
>
> *(i) the number of patent applications filed;*
>
> *(ii) the number of patents received;*
>
> *(iii) the number of fully-executed licenses which received royalty income in the preceding fiscal year, categorized by whether they are exclusive, partially-exclusive, or non-exclusive, and the time elapsed from the date on which the license was requested by the licensee in writing to the date the license was executed;*
>
> *(iv) the total earned royalty income including such statistical information as the total earned royalty income, of the top 1 percent, 5 percent, and 20 percent of the licenses, the range of royalty income, and the median, except where disclosure of such information would reveal*

[8] For an overview of historical Federal technology transfer policies, see Appendix A.

the amount of royalty income associated with an individual license or licensee;

(v) what disposition was made of the income described in clause (iv);

(vi) the number of licenses terminated for cause; and

(vii) any other parameters or discussion that the agency deems relevant or unique to its practice of technology transfer.[9]

A Presidential Memorandum was issued in 2011. Titled "Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses," the memorandum directed Federal laboratories to "establish goals and measure performance, streamline administrative processes, and facilitate local and regional partnerships in order to accelerate technology transfer and support private sector commercialization" (The White House 2011). Six metrics are reported by every Federal agency in their annual technology reports, as recommended by the memorandum: invention disclosures, licenses issued on existing patents, collaborative research and development agreements (CRADAs), industry partnerships, new products, and successful self-sustaining spinoff companies. These common metrics allow for comparison across input and output metrics for Federal agencies. At the same time, however, the language from the memorandum encourages agencies to report measures based on their goals and mission—thus leaving room for variability.

In an effort to standardize reporting across agencies, in 2013, NIST issued "Guidance for Preparing Annual Agency Technology Transfer Reports Under the Technology Transfer Commercialization Act," which describes in more detail what should be reported in each of the required categories. The NIST guidance, which was updated in April 2020, included an "a la carte" menu developed in coordination with the ST5 interagency working group (Appendix B).

The Technology Partnerships Office at NIST coordinates the annual reporting to the President, Congress, and the U.S. Trade Representative on Federal agencies' technology transfer activities. It includes guidance on both qualitative and quantitative information categories. For example, with respect to qualitative information, NIST recommends descriptions of current technology transfer programs, plans for enhancing technology transfer activities, abstracts of economic impact studies completed during the fiscal year, and anecdotal evidence in the form of success stories that demonstrate downstream outcomes of technology transfer activities within the reporting fiscal year. For the last item, NIST provides tables on how to present and structure required data (e.g., number of patents and licensing income). Within the quantitative recommendations are several suggestions

9 Stevenson-Wydler Technology Innovation Act of 1980.

that could lead to variability in metrics used across agencies but allow for capturing a greater granularity for evaluating agency technology transfer activities. For example, agencies also report other authorities or mechanisms (besides CRADAs) used to support R&D collaborations.

Last, other performance measures determined as important by an agency may be included. NIST itself collects other relevant data including metrics on invention disclosures, patents, and licenses all by selected technology areas, in addition to scientific and engineering articles and their citations in other literature, including U.S. patents. The "a la carte" menu in the NIST Guidance provides an appendix with a variety of possible metrics and activities that can be reported by agencies, enabling agencies to capture a more granular and accurate snapshot of their technology transfer activities as related to their specific mission (Appendix A).

B. Intramural Metrics from Agency Technology Transfer Annual Reports

A review of Federal agency annual technology transfer reports reveals a relationship between agency mission and the metrics reported. These metrics can represent both formal and informal technology transfer mechanisms. Often, reported metrics are uniquely relevant to the mission and operating practices across the agency. At times, sub-agencies and offices within an agency may have distinctly different missions, which adds diversity to the technology transfer metrics reported across the agency.

Importantly, economic impact is not the only goal for technology transfer activities performed by agencies. Many agencies explicitly cite other goals—such as national security, safety, and environmental well-being—and include various internal agency-specific technology transfer needs that may not be shared outside the agency. The scope of these missions determines what technology transfer activities are pursued and dictates what metrics are used to evaluate their performance. Depending on their mission, agencies use a range of approaches for reporting successes.

For instance, in the case of the Department of Transportation (DOT), success stories emphasize improvements to safety outcomes, which are difficult to quantify with traditional technology transfer metrics. This is consistent with the DOT's strategic goal of distributing "innovative practices and technologies that improve the safety and performance of the Nation's transportation system." The U.S. Department of Agriculture (USDA) uses case studies to communicate how R&D outcomes have led to public benefits through collaborative research and the public release of information, tools, and other resources. The Department of Interior's (DOI) United States Geological Survey (USGS) states the delivery "of science information is a primary purpose of the bureau." Metrics reported by the USGS therefore include the number of publications authored by personnel. Other mission-driven agencies, such as the Department of Defense (DOD), focus on technology transfer metrics that represent their activities to support technology maturation and the transition of technologies for use in its own operations. These activities may be captured by many of the mandated reporting metrics, including licenses.

The review of NIST's Federal technology transfer report, as well as individual agency reports from several agencies, demonstrated that there is considerable variation in the intramural metrics Federal agencies and sub-agencies elect to include in their annual reports.[10] STPI categorized these metrics into 11 broad categories under 4 themes:[11]

Theme 1—Traditional Transfer

1. Research Productivity and Research Outputs
2. Licensing
3. Partnerships and Technology Transfer Agreements

Theme 2—Engagement and Outreach

4. Information Products and Services
5. Events and Outreach
6. Online Engagement

Theme 3—Workforce

7. Awards and Staff Achievements
8. Membership in Professional Bodies
9. Human Capital

Theme 4—Business and Economy

10. Results of Broader Impact Studies
11. Public and Market-Oriented Measures

Below is a short description of each category and representative examples of metrics collected by agencies that fall under each category. Some metrics are common across many agencies, while others are only reported by a select few. For example, the number of publications and publication downloads in a given fiscal year frequently appear as cited metrics across agencies in their annual technology transfer reports. The nature of these publications varies by agency (e.g., journal articles or technical manuals), but the use of this metric is consistent across a number of agencies. Other common metrics include conference participation and website traffic. Less frequently reported metrics include awards received and social media presence, which are cited by only a few sub-agencies.

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[10] STPI analyzed annual technology transfer reports for the Department of Commerce (DOC), Department of Energy, Department of Health and Human Services, DOI, DOT, Department of Veterans Affairs, Environmental Protection Agency, National Aeronautics and Space Administration, and USDA.

[11] These are loose categories and metrics across categories may overlap with one another, for example, a research dataset may be a direct research product and a tool and integrated in broader information products provided by the agency to support their technology transfer activities.

Theme 1—Traditional Transfer

1. Research Productivity and Research Outputs

This category describes metrics relating to direct outputs of research conducted at the agency or funded by the agency. Publications in scientific journals or trade journals were among the most cited metrics in technology transfer reports. Some agencies or sub-agencies track not only the number of publications but also occurrences of citations to their publications. Other examples of metrics related to research productivity and research outputs include technology reports, published datasets, and the use of medical tests and other tools developed.

2. Licensing

While all agencies are required to collect data on licenses based on existing patents, some agencies collect additional information to characterize the licensing process and licensees. These metrics include the average elapsed time to grant licenses, earned royalty income, and the number of licenses awarded to small businesses.

3. Partnerships and Technology Transfer Agreements

While agencies are mandated to collect data on CRADAs, many agencies also collect information about other collaborations and partnerships, including other informal and formal technology transfer mechanisms to transfer information, tools, and other resources. For example, some agencies track partnerships with academia, and many agencies also track non-CRADA agreements, such as material transfer agreements (MTAs), which can be used for transferring data and other research materials. Some agencies report on their use of other specialized agreements authorized by Congress or by their own agencies for their agency's sole use. In addition, some agencies report process measures related to establishing agreements, such as the average elapsed time for approving CRADAs.

Theme 2—Engagement and Outreach

4. Information Products and Services

This category includes metrics that agencies have collected relating to information products and services provided by the agency that might not directly be a result of their funded research. These metrics could include application programming interface (API) releases, which facilitate information and data sharing, newsletter distributions, briefings to senior policy officials, the development of toolkits and other guidance documents for researchers and broader technical communities, and assistance with agency accreditations.

5. Events and Outreach

Some agencies collect data on events they have hosted and attendance at these events. These events include conferences, workshops, webinars, and training sessions targeted to the R&D communities that the agency supports, as well as other stakeholders. Other outreach and engagement activities, such as prize competitions, are also reported.

6. Online Engagement

This category encompasses metrics related to user engagement with online services provided by an agency. Many agencies track website traffic or downloads. Agencies that provide public datasets and science and engineering publications online also track queries for, and downloads of, those resources. Agencies also track “new media” impressions, which include engagements on social media and YouTube (refer to Chapter 4.B.2. Altmetrics).

Theme 3—Workforce

7. Awards and Staff Achievements

Some agencies describe awards won by staff in their technology transfer reports, such as those awarded by the Federal Laboratory Consortium for Technology Transfer (FLC).[12] Some agencies also highlight staff achievements, such as media appearances, or cases of notable successful collaborations within their annual reports.

8. Membership in Professional Bodies

This category includes metrics relating to agency staff participation in committees or bodies external to their agency. For example, one agency tracks staff participation in relevant standards bodies, while another tracks staff participation in NSTC committees, subcommittees, and interagency working groups.

9. Human Capital

This category of metrics involves data relating to agency researchers and staff engaged in R&D and technology transfer activities. For example, one agency reports data on employed postdocs, post-doctoral placement, and guest researchers. Another agency reports data on its in-residence program, which brings guest technologists into the agency on a short-term basis. One agency collected a less common metric related to human capital—the number of staff-years supporting technology transfer activities.

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[12] The FLC Awards Program: https://federallabs.org/successes/awards

Theme 4—Business and Economy

10. Results from Broader Impact Studies

This category of metrics involves results from studies conducted by agencies to measure the broader impacts of R&D, including impacts on research fields or the economy. Agencies have conducted economic footprint studies to gauge the impact of their CRADAs, licenses, small business programs, and other technology transfer activities. Other studies identify how an agency's research has influenced scientific fields. For example, some agencies include in their reporting "downstream outcomes," which illustrate some success stories or notable transitions of Federal research. On occasion, agencies work with independent third parties to conduct specific impact studies based on commercialized products.

11. Public and Market-Oriented Measures

While the above categories encapsulate many of the metrics collected by agencies to represent their technology transfer activities, they are not exhaustive. Other metrics collected by agencies include customer satisfaction and complaints received, which can be used as indicators for the success of processes for technology transfer; however, these are not widely reported. Other measures include the types of scientific and technical services provided by laboratories and specific market outcomes related to their mission, such as the percentage of market needs addressed by an agency's service.

C. Extramural Metrics

Legislative mandates for reporting extramural R&D technology transfer metrics by Federal agencies do not exist. But Federal agencies do collect information about the inventions produced by Federal Government grantees and contractors from federally funded R&D through various invention data management systems (NIST 2019). Several agencies provide support to individuals or businesses to engage in research or product development. Many agencies keep track of the number of small businesses or startups supported in a given fiscal year. Participation in and grants for Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs are common metrics collected by agencies. Appendix C provides a list of studies related to the SBIR program.

On occasion, agencies work with independent third parties to conduct specific impact studies based on commercialized products or funding programs. These may include studies that trace back the impacts of Federal intramural or extramural R&D funding, for example, to researchers and organizations, and describe how this funding has led to specific outcomes, such as new technologies, advancement of scientific fields, and economic gains.[13]

[13] For example, see Vanessa Peña, Bhavya Lal, and Max Micali. "National Science Foundation's Role in Additive Manufacturing" (Alexandria, VA: Institute for Defense Analyses, 2015); and Appendix C for studies of technology transfer for intramural and extramural R&D funding programs.

3. Common Challenges in Assessing the Value of Federal Technology Transfer Activities

This chapter describes some common challenges in evaluating the value of Federal technology transfer activities. These common challenges apply to technology transfer activities for both intramural and extramural R&D programs. The challenges include the varied context for technology transfer given the specific missions and goals of agencies; the complexity of industry and discipline specific factors influencing outcomes; the limitations in the comparison of metrics and their interpretation; the limitations in evaluating economic impacts; issues with temporality; and distortion of incentives in the use of metrics.

The value of Federal technology transfer activities must be measured more broadly than through economic-based definitions of ROI. However, the evaluation and comparison of both economic and other impacts are difficult due to the variations in missions and goals across and within agencies, including sub-agencies, offices, and programmatic goals. In addition, the industry and disciplines targeted by Federal R&D and technology transfer activities influence the definitions, goals, and measurement of value. The complex nature of technology transfer means there are myriad pathways to diffuse and transfer knowledge. Given the numerous factors influencing outcomes and the variation of outcomes based on varied agency goals, count-based measures may be misleading and complicate the measurement and comparison of value. Selection of metrics may also have unintended consequences, distorting incentives that can shift behaviors towards activities that may not be the most effective routes for achieving technology transfer goals.

A. Varied Contexts for Technology Transfer Given Federal Missions and Goals

Beyond economic goals of technology transfer, assessing the value of these activities on achieving Federal missions can include assessing improvements to processes, such as the formal and informal knowledge exchanges that occur via collaborations and partnerships. Agencies' differing missions and goals affect the types of research, technology transfer, and impacts that Federal agencies pursue. This is an important consideration and is especially significant when attempting to interpret or standardize metrics across agencies.

Though standardized metrics may help simplify comparison across agencies, there is a danger of losing information if the metrics for comparison do not match with the missions of the agencies in question. For example, the USDA Fish and Wildlife Service conducts research on wildlife damage management strategies, with a biological and social responsibility mission in addition to an economic development mission. Its technology transfer activities “do not necessarily involve the transfer of intellectual property” (USDA 2017). Many of its metrics relate to cooperative agreements and institutional partnerships in both public and private sectors. As another example, the USDA U.S. Forest Service may develop a novel technology or piece of equipment, for example, to fight forest fires or for other uses in the forestry sector. This technology may not result in intellectual property that is transferred through patents and licenses; however, it may be broadly shared, such as through publications and demonstrations, with other agencies and forest management organizations to support mission critical needs. This exchange of information and tools may not be directly linked with the standardized metrics for Federal reporting.

A given agency’s mission could differentially impact performance as reflected in one metric relative to another, which might cloud determinations of its effectiveness in terms of technology transfer. For example, using licenses as a key metric might overrate the effectiveness of a laboratory that focuses on commercialization of relatively later-stage or applied R&D compared to one that supports foundational discoveries through basic research. Implicit in this challenge is the connection between research type and the mission of the institution. Laboratories engaged in applied research may perform better on certain metrics than others that may be engaged in basic research, and vice versa, independent of the efficiency with which they conduct their technology transfer activities.

The scope and nature of the R&D performed is not the only relevant determinant of a technology transfer office’s goals. There can still be variation in missions between laboratories supporting similar R&D portfolios, which in turn can have implications for the appropriate selection of evaluation metrics (Goldstein & Narayanamurti 2018). For example, a metric such as licensing revenue may be influenced by the organizational culture and the extent to which an agency seeks profits from its technologies.

The assessment of value should also consider that not all R&D outputs may be appropriate for broad technology transfer activities, in particular those focused on national and homeland security. Comparing Federal laboratories with disparate missions and goals for the purposes of evaluation might therefore require more holistic metrics or a broader variety and combination of metrics (Fini et al. 2018; Bozeman &Youtie 2017).

In addition, evaluations should consider that scientific and technical failures, such as failed experiments, can generate important information that advances knowledge in scientific fields. Failures—in the sense of not achieving an expected result—can also lead to serendipitous discoveries, such as new products, tools, and applications not initially thought of at the outset.

B. Complexity of Industry and Discipline-Specific Factors Influencing Outcomes

Impact in many disciplines may not be measurable for years or decades after a grant award or initial publication of scientific or technical findings. For instance, when charged with assessing the value of National Institutes of Health (NIH)-funded biomedical research, the Scientific Management Review Board (SMRB) found that "the breadth and complexity of the biomedical research enterprise [made] the task of assessing its value very challenging" (SMRB 2014). The SMRB cited issues such as lengthy timeframes, unpredictable paths from basic research to applied outcomes, and the multiple actors contributing to the process as making assessments more complex. Impacts from the transfer or use of R&D from Federal laboratories may have further-reaching effects on human health, national security, or scientific productivity than on how they affect the economy (Chatterjee & DeVol 2012; Malik 2018).

Additionally, some federally supported technologies have given rise to new industries or products spanning different industries.[14] The access to and the size of the industries and markets with which Federal agencies interface to successfully transfer their technologies are additional considerations that influence outcomes. For instance, some agencies have missions with R&D focused on a single or narrower set of industries than others with a multi-sectoral focus, such as the National Science Foundation (NSF), which funds R&D across a large number of disciplines. Outcomes can also occur across varied timelines. The speed with which technology transfer, maturation, and commercialization activities occur differs across disciplines and industries. The complex nature of these impacts is difficult to measure.

Other factors that can influence outcomes across agencies include the maturity of the technologies and their attractiveness to industry or other recipients of the transferred technology. Metrics—such as licensing revenues—collected at the agency level without additional context regarding the value of technology transfer outcomes relative to the disciplines, industries, and markets impacted may misrepresent performance. Some agencies, based on their missions, support non-revenue bearing technology transfer activities, such as accreditation, standards, databases and training. Comparing the metrics associated with these activities with those of revenue-bearing activities can be misleading.

C. Limitations in Making Comparisons and Interpretation

A number of different and sometimes unrelated factors conspire to make successful evaluation of Federal technology transfer a challenging endeavor. Chief among these

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[14] For example, global positioning system (GPS) was initially invented for military use and later available to the private sector, supporting the development of new applications, products, and services across a variety of industries, *see* Alan O'Connor et al., "Economic Benefits of the Global Positioning System (GPS)," *RTI International* (2019).

challenges is the issue of comparing and interpreting measures. Evaluating the effectiveness of technology transfer activities relies, in part, on the ability to compare any given output to a benchmark or a comparison group of peers. Technology transfer metrics based on a single, static point in time on their own are not useful for providing insights on value, such as sufficiency, efficiency, and effectiveness. It is only in context that these metrics provide useful information about the performance of a technology transfer activity or strategies as a whole. Simply comparing metrics across organizations is insufficient for a fair evaluation due to the variety of underlying factors that could affect the metrics. Federal reports and the academic literature raise concerns about the comparability of metrics, and discuss the different dimensions on which cross-comparison of raw metrics becomes complicated in practice (Choudhry & Ponzio 2019; Baglieri 2018).

Perhaps the most salient of these confounding factors is the substantial variation in the degree and scope of R&D and technology transfer activities conducted across laboratories—in particular among activities performed for basic, applied, testing, manufacturing, and operational needs. For any one given metric, an agency could perform very well and for another, it may perform much more poorly compared to its peers. Factors, such as size and operations cost of technology transfer office, R&D output, and potential commercial viability of those outputs, complicate metrics in a way that makes it difficult to draw conclusions about the effectiveness of a technology transfer activity compared with other activities (Balas & Elkin 2013; Heisey & Adelman 2011; Van Looy et al. 2011; Swamidass & Vulasa 2009). There is an acute need to normalize metrics in a way that meaningfully facilitates comparison across different disciplines, industries, and markets of relevance to the R&D outputs and technology transfer activities that are being studied.

The common foundation of federally mandated technology transfer metrics for intramural R&D from the 2011 Presidential Memorandum allows for easy, cursory comparison across input and output metrics for Federal agencies. However, Federal organizational complexities can present challenges in comparing and interpreting metrics across agencies. A notable variation within this otherwise consistent framework for reporting technology transfer performance is the degree to which different agencies disaggregate these metrics. For example, some agencies report the values for metrics for each sub-agency in addition to the aggregated value, whereas others report total values only for the agency as a whole. This situation complicates comparisons since sub-agencies within one agency may have differing missions and, hence, technology transfer goals or activities of interest.[15] Therefore, aggregating metrics at the agency level provides misleading results.

[15] For instance, USDA has eight Under Secretary offices focused on a variety of areas from farm production and conservation, food safety, and natural resources and the environment, to regulatory programs and research, education, and economics, *see* USDA, "Organization Chart,"

Furthermore, the focus on totals for quantitative measures can diminish the value of outliers. Outliers can represent high-impact outcomes relative to the remainder of the technology transfer activities or broader portfolio of activities. Metrics that represent total outputs of activities limit the ability of the government to assess the performance of technology transfer mechanisms. Providing these output measures with a corresponding proxy measure for impacts—for instance counts of licenses and revenues from licensing—can help identify the value of outliers, but does not provide the level of granularity necessary to understand the processes and other factors at play required to achieve such high impacts. This situation is especially important in the reporting of license revenues in which one or a few licenses are responsible for the majority of the revenues generated.

D. Limitations in Evaluating Economic Impacts

Economic impact studies investigate the economic effect of either one technology or an entire portfolio of technologies over a certain time period. Many economic impact studies have been conducted to analyze the impacts from research funded by the Federal Government and conducted by extramural researchers (e.g., academic or industry researchers). Fewer economic impact studies have been conducted that focus on Federal laboratory-developed technologies or technology portfolios (Makomva et al. 2008; DeVol 2012; Tripp & Grueber 2011; Wang 2014; Techlink 2019; Link 2019; Link et al. 2019). Impact metrics are typically derived from economic analyses of non-government markets and users over extended time periods, which are not well captured through agencies' annual reporting processes. The methodology relies on parameters set ahead of time by researchers, such as multipliers and discount rates, among others. The studies often report the results under different sets of assumptions. Commissioning such studies is typically expensive and contracted out to parties with specialized expertise separate from the programs they study. The complex methodology can be off-putting or unapproachable to non-technical audiences or stakeholders. In addition, from a theoretical standpoint there are questions about the value of such studies for technology transfer efforts given their pitfalls (further elaborated below).

We describe one example of an approach for conducting economic studies to demonstrate some of the complexities in this type of analysis. Economic impact studies used to analyze Federal laboratory-developed technologies or technology portfolios can employ an input-output (I-O) approach to estimate economic impact. The I-O approach is a mathematical, macroeconomic framework developed by Wassily Leontief—the 1973

https://www.usda.gov/sites/default/files/documents/usda-organization-chart.pdf. The Department of Energy has three Under Secretary offices, including those for Nuclear Security and the National Nuclear Security Administration and Science and Energy, which is further composed of a multitude of offices, including the Office of Science managing six interdisciplinary scientific program offices, *see* DOE, "Organization Chart," https://www.energy.gov/sites/default/files/2021/01/f82/OrgChart_20210124_0.pdf.

Nobel laureate in economics (Leontief 1987). Modern I-O analyses uses computable general equilibrium models to track the flow of money and resources through a regional economy. These models simulate the initial equilibrium state of the regional economy. Changes are then made to the model to simulate variations in specific technology transfer activities (e.g., licenses and CRADAs). The model estimates economic impact by re-computing the equilibrium state and comparing the new equilibrium with the former one. Measures of impact are derived from direct effects (e.g., changes in sales), indirect effects (e.g., changes in inter-industry purchases), and induced effects (e.g., changes in household expenditures). Under this approach, impact metrics typically include changes in regional or national output, employment, value added, labor income, and tax revenues (Roessner et al. 2013; Pressman et al. 2017). To be effective, this approach assumes the expected impact of technology transfer activities to be large enough to influence a broad section of an economy over a given period.

This approach has been applied in two ways to analyze the economic impacts of Federal technology transfer. One approach is to trace the direct economic impacts of licensed technologies by surveying the firms using them, and then to use computable general equilibrium I-O analysis to estimate the full downstream effect of those technologies on the economy. A TechLink study using this approach quantified how DOD license agreements contributed to new economic activity and job creation in the United States. Using the IMPLAN economic assessment software to estimate economic impacts, they found that license agreements spurred $48.8 billion in total economic output nationwide, created or retained 182,985 full time jobs, and stimulated $3.4 billion in sales of new products to the U.S. military (Techlink 2016).

An alternative method is to apply I-O analysis to revenue data from licenses. This strategy uses licensing payments as a proxy for sales revenue, and then applies the I-O model to the imputed direct economic impacts of the licensed technologies to estimate their full downstream effects. Such a technique is employed in a study by Pressman et al. (2018) called *A Preliminary Application of an I-O Economic Impact Model to US Federal Laboratory Inventions: 2008–2015* that was prepared for NIST in 2018. The study estimated that technologies licensed from national laboratories added between $10 and $40 billion to the U.S. Gross Domestic Product and supported between 70,000 and 265,000 jobs during that time frame. This model has the advantage of being simpler to execute, as only license data already collected and reported by the national laboratories are required. On the other hand, the approach requires more modeling assumptions than does the computable general equilibrium model, and cannot be used to estimate the economic value of licenses that do not generate revenue.

Additional caveats apply when attempting to use I-O methods to Federal technology transfer activities. I-O models have limited applicability when assessing an agency's economic impact because they require the assessment of a large number of technology transfer activities (e.g., licenses) that are similar in nature. These models assume that the activities can be aggregated to reveal an impact on a regional, national, or global economy (Pressman et al. 2018). Using an I-O model to analyze Federal technology transfer activities aggregated across different agencies may introduce oversimplifications that diminish confidence in the results. Additional considerations on the strengths and limitations of I-O based approaches drawn from ST5 interagency working group discussions are summarized in Table 1.

Table 1. Selected Strengths and Limitations of ROI-Based Approaches

Strengths	Limitations
Translates available data, such as license revenue and royalties associated with licensing into overall economic impact	Requires many assumptions, such as commonality in definitions and royalty rates, etc.
Can be used to enumerate a range of economic benefits from Federal technology transfer activities	Some agencies (and universities) lack large enough datasets to conduct meaningful trend analyses
Allows for the generation of a time series	The quality of data collected may vary across Federal agencies and laboratories and across universities
Allows for benchmarking among and across universities and Federal laboratories	While agency definitions of technology transfer and technology transfer activities vary, measures of ROI assume that the value of technology transfer consists of its economic impacts, which may not be appropriate for all Federal agencies

E. Issues with Temporality

> Technology transfer activities are not spontaneous events. Inventions typically require years, if not decades, of research before they are disclosed. A review of a patent application may take roughly three to five years before the patent is awarded. It may take several years to license a patent or form the collaborative commitments behind a CRADA (DOC 2019).

Temporality is a concern when evaluating technology transfer performance. A number of papers have referenced the long-time horizon of technology transfer, an issue that applies to technology transfer outputs as well as impacts (Kim et al. 2008). Furthermore, the economic impacts of the transfer can take years or even decades to materialize and circulate through the economy as discoveries are used as a touchpoint for further research, applied to productive processes, or adapted for commercial use. These delays complicate evaluation (Kim & Daim 2014).

The Federal reported metrics that describe a static point in time do not take into consideration that the metrics represent outputs and outcomes from varied points in time. Temporality is a limitation that applies to some metrics more than others. For instance, the number of active CRADAs or other collaborative partnerships reflect ongoing technology transfer activities at the time of reporting, which can be a connected to previously developed intellectual property or intellectual property under development through the collaboration. In addition, license revenues or royalties may reflect outcomes based on intellectual property that was patented or generated a decade or more ago.

F. Distortion of Incentives in the Use of Metrics

In his seminal paper, *Assessing the Impact of Planned Social Change*, Donald Campbell wrote: "The more any quantitative social indicator is used for social decision making, the more subject it will be to corruption pressures and the more apt it will be to distort and corrupt the social processes it is intended to monitor" (Campbell 1976). This statement, which has come to be known as Campbell's law, identifies an acute concern for evaluators when the subject of an evaluation is a human being. In the technology transfer context, Campbell's law has two major implications. The first of these concerns the efficacy of metrics; if evaluators attach rewards to meeting or increasing a given metric, technology transfer offices will focus on achieving goals that will be reflected in that metric. For example, if an evaluator decides that technology transfer funding will be tied to licensing activities, the metric will measure technology transfer activities that are best able to shift behavior towards generating licenses regardless of the long-term social or mission impacts of those licenses Rosli & Rossi 2016).

If the purpose of evaluating Federal technology transfer is to improve technology transfer efficiency, but the incentive framework is such that those conducting technology transfer activities are incentivized to alter their behavior (such as pursuing licenses) at the expense of efficiency (perhaps by de-emphasizing other methods of commercialization), the metric will have an adverse effect on the ecosystem it is supposed to monitor (Hallam et al. 2014). Emphasizing any one given evaluation metric opens the possibility of excluding relevant information from another transfer route measured by other metrics (Perkmann et al. 2015; von Kortfleisch et al. 2015; Bradley et al. 2013). This situation has implications for the interpretation of the metrics collected and reported. The use of metrics to which rewards are attached can bias evaluation when technology transfer offices pursue and emphasize different technology transfer routes. These are critical considerations for those tasked with constructing sustainable and effective evaluation frameworks.

4. Approaches to Address Challenges

This chapter describes three areas of suggested improvements for Federal agencies to address the challenges related to evaluating Federal technology transfer activities: (1) strengthen capacity for building evidence; (2) adopt or adapt innovative metrics; and (3) improve cross-sector engagement to leverage expertise to build evidence.

These overarching approaches are cross-cutting in that each approach may be designed and operationalized by agencies to address one or more of the challenges described in the prior chapter. They may also be applied across intramural and extramural R&D and technology transfer activities. These approaches reflect actionable suggestions that can be coordinated and led as interagency efforts by the L2M Subcommittee (or other relevant interagency coordination groups) or initiated by single Federal entities. Potential activities to pursue under both situations are described below.

A. Strengthen Capacity for Building Evidence

Two approaches are discussed to strengthen Federal agency capacity for building evidence to improve monitoring and measuring impacts: (1) the creation of a portfolio of metrics that captures the value generated from an array of technology transfer activities implemented across varied missions and goals, and (2) the development of learning agendas as evaluation frameworks.

1. Metrics Portfolio

Metrics portfolios may be used to strengthen Federal agency capacity for building evidence on their technology transfer activities. Identifying and using a combination of metrics to illustrate the successes and performance of technology transfer activities may help provide a more complete narrative of technology transfer sufficiency, efficiency, and effectiveness across an agency. The recent publication of the a la carte menu in NIST's updated guidance for intramural reporting provides an opportunity for agencies to reassess their use of measures and metrics beyond those mandated for annual reporting. Technology transfer staff across agencies could leverage this information to develop a portfolio of metrics that account for their agency's or laboratory's technology transfer goals, missions, and R&D activities. However, a similar a la carte menu or guidance for reporting on extramural technology transfer activities does not currently exist.

Specific Actions for Agencies in Developing Metrics Portfolios

Agencies may wish to develop a more holistic metrics portfolio that considers both intramural and extramural research, as well as metrics that appropriately capture the value to the mission. A holistic metrics portfolio should include metrics that measure activities beyond the narrow context of revenue generation and expand measures that capture contributions to broader economic prosperity, national security, and societal impact.

Agencies and researchers have long studied the outcomes stemming from extramural research and published their findings through numerous journal articles and reports (refer to Appendix C). Agencies could review this rich literature to identify and understand the measures and outcomes from studies related to their own agency's programs or the technical domains that are central to their missions. In this way, the development of a more holistic metrics portfolio could be informed by the state-of-the-art in evaluation methods, measures, and metrics that align with the specific mission and technology transfer goals of interest at the agency or laboratory. A holistic metrics portfolio could be developed in alignment with a learning agenda that explores the existing evidence and appropriate metrics to capture the flows of knowledge, technologies, and outcomes of interest to the agency (discussed in section 2 of this chapter).[16]

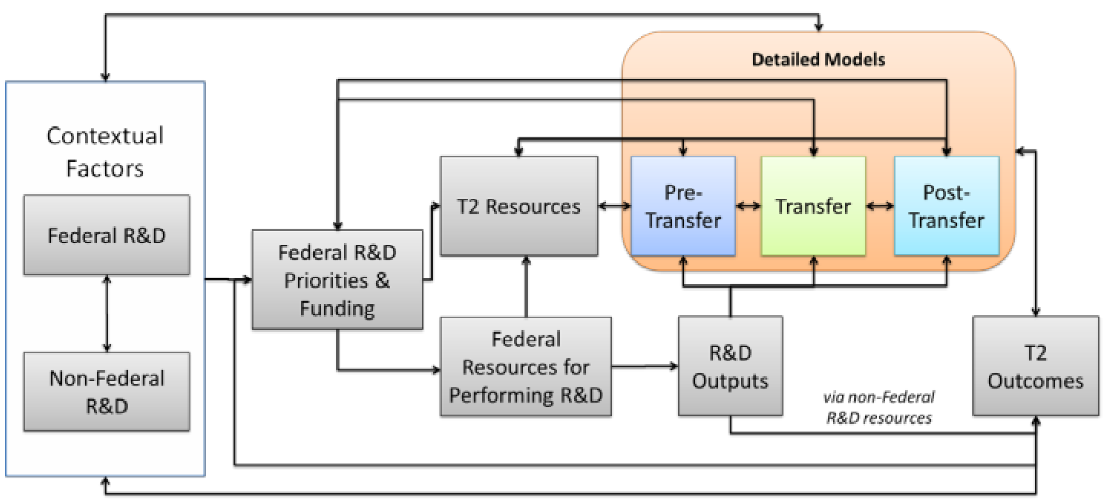
Specific Actions for the L2M Subcommittee in Coordinating Metrics Portfolios

Increasing the scope of evaluation via a metrics portfolio can result in a more inclusive understanding of technology transfer performance; however, it can also increase the difficulty to compare and interpret metrics across agencies. The L2M Subcommittee may wish to address how agency-level metrics portfolios can be coordinated at a cross-agency level to address issues of comparability. While the NIST guidance makes statutory reporting of metrics for intramural technology transfer consistent, there are continued gaps in capturing metrics for extramural, mission, and social impacts. This gap could be addressed by the L2M Subcommittee through the establishment of an interagency working group that can share progress on their development of agency-specific metrics portfolios and identify opportunities for how specific metrics for similar technology transfer goals, R&D, and the like can be aligned, as appropriate.

One way to address some of these issues could be through the development of a conceptual taxonomy of Federal technology transfer activities based on the level of

[16] *see* Appendix B for studies that can help guide the creation of metrics portfolios, such as Markus Perkmann, Andy Neely, and Kathryn Walsh, "How Should Firms Evaluate Success in University–Industry Alliances? A Performance Measurement System," *R&D Management* 41, no. 2 (2011), Philip L Gardner, Ann Y Fong, and Roshena L Huang, "Measuring the Impact of Knowledge Transfer from Public Research Organisations: A Comparison of Metrics Used around the World," *International Journal of Learning and Intellectual Capital* 7, no. 3-4 (2010), and Rubenstein, "Models and Metrics for the Technology Transfer Process from Federal Labs to Application and the Market," (2009).

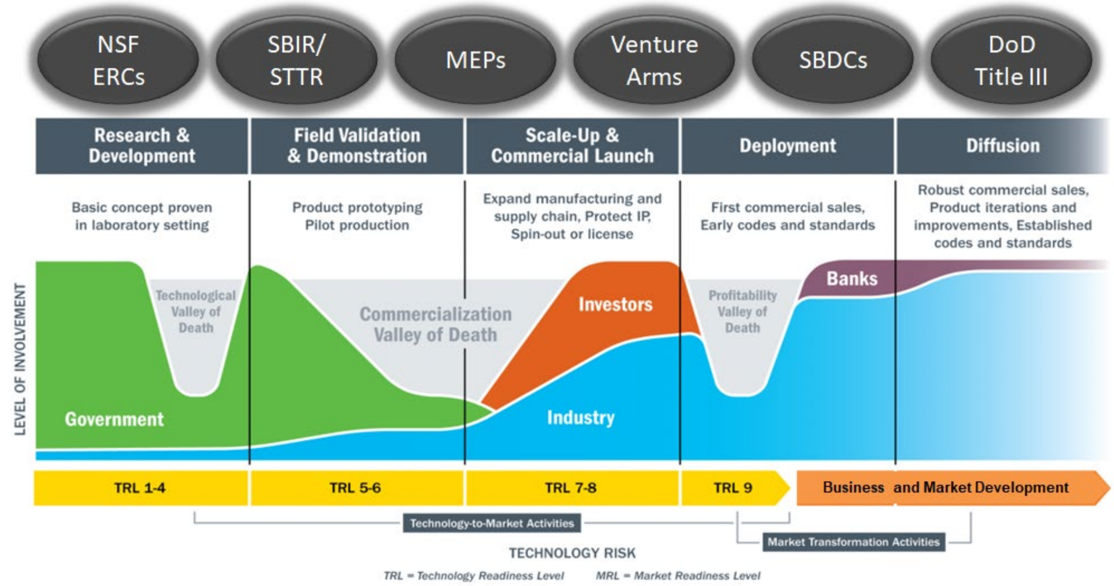
technological maturity of the R&D outputs, the mission context and industry, and disciplinary factors that characterize the nature of the activities pursued across agencies. In some cases, for activities in vastly differing disciplines or technology readiness, it may not make sense to compare technology transfer metrics. A taxonomy could categorize agencies' technology transfer activities by the technology transfer goals and outcomes to allow for improved comparisons and benchmarking across the Federal Government.[17] The L2M Subcommittee could develop this taxonomy in coordination with its members. It could also lean on the development of already established frameworks to analyze Federal technology transfer, for instance, a concept model developed by STPI (Figure 1) and technological readiness levels often used across Federal agencies to classify technology maturity (Figure 2). These frameworks could be used to better understand the landscape of Federal technology transfer activities, their expected outcomes, and the appropriateness of comparing these outcomes across agencies.



Notes: The "nodes" in the simple model represent results of activities that lead to or stem from Federal funding and technology transfer activities. The arrows connecting the nodes convey how one node influences another. The arrows are uni- or bidirectional depending on the relationship to the connecting nodes, as inputs that influence or outputs that are influenced by the other nodes. Detailed models for pre-transfer, transfer, and post-transfer are explained in Peña and Mandelbaum. 2020. *A Preliminary Concept for a Model of Federal Technology Transfer*. https://www.ida.org/-/media/feature/publications/a/ap/a-preliminary-concept-for-a-model-of-federal-technology-transfer/a-preliminary-concept-for-a-model-of-federal-technology-transfer

Figure 1. Simple Model of Federal Technology Transfer

[17] *see* Robert JW Tijssen, "Anatomy of Use-Inspired Researchers: From Pasteur's Quadrant to Pasteur's Cube Model," *Research Policy* 47, no. 9 (2018) and Peter W Moroz, Kevin Hindle, and Robert Anderson, "Formulating the Differences between Entrepreneurial Universities: A Performance Based Taxonomic Approach" (paper presented at the ICSB World Conference Proceedings, 2011) for further on taxonomic approaches for related technology transfer activities.



Notes: Conceptual placement of select Federal initiatives, variations in readiness are expected based on Federal agency missions and program goals; NSF (National Science Foundation), ERC (Engineering Research Center), SBIR (Small Business Innovation Research), STTR (Small Business Technology Transfer), MEP (Manufacturing Extension Partnership), SBDC (Small Business Development Center), Title III (Defense Production Act Title III), Technology Readiness Level (TRL) is commonly measured on a nine-point scale. Adapted from DOE, "Technology to Market." https://www.energy.gov/eere/buildings/technology-market-initiative

Figure 2. Technology to Market Readiness

2. Learning Agendas as Technology Transfer Evaluation Frameworks

The passage of the Foundations for Evidence-Based Policymaking Act of 2018 (Evidence Act) mandated the development of evidence plans that describe learning agendas, which allow Federal agencies to systematically identify and prioritize questions relating to their programs, policies, and regulations.[18] Per the Evidence Act, all agencies covered under the Chief Financial Officers Act of 1990 designated an Evaluation Officer who is responsible for coordinating an agency's enterprise-wide learning agenda.

OMB defines learning agendas as "a set of broad questions directly related to the work that an agency conducts that, when answered, enables the agency to work more effectively and efficiently, particularly pertaining to evaluation, evidence, and decision-making (OMB 2019)." OMB also states, "Learning agendas offer the opportunity to use data in service of addressing the key questions an agency wants to answer to improve its operational and programmatic outcomes and develop appropriate policies and regulations to support successful mission accomplishment (OMB 2019)."

[18] See U.S. Congress, "Foundations for Evidence-Based Policy Making Act of 2018" (paper presented at the 115 th Congress HR, 2018).

Efforts to establish and implement learning agendas, although not necessarily termed as such, follow long-standing Federal activities to evaluate the Federal Government's performance through rigorous analysis of evidence and credible documentation of their processes and impacts. The evolution of evidence-based approaches in the Federal Government dates back to a multitude of efforts—for example, the Government Performance and Results Act of 1993, which mandated Federal strategic planning and performance measurement activities, evolved into the Program Assessment Rating Tool in 2011, which institutionalized program reviews, and the Federal budgeting guidance established by OMB in 2010.[19]

A learning agenda specific to technology transfer activities could be developed by reviewing the state of evidence regarding evaluation and the gaps to inform decisions in this domain. Understanding gaps and collecting evidence on the performance and effectiveness of Federal technology transfer activities are foundational steps for establishing learning agendas. These actions can ultimately help agencies build their capacity in the use of evidence for policy and decision making for their technology transfer investments. Two recommendations below describe the development of Federal-wide and agency-level learning agendas. Appendix D provides further implementation details for agencies to facilitate establishing their learning agendas.

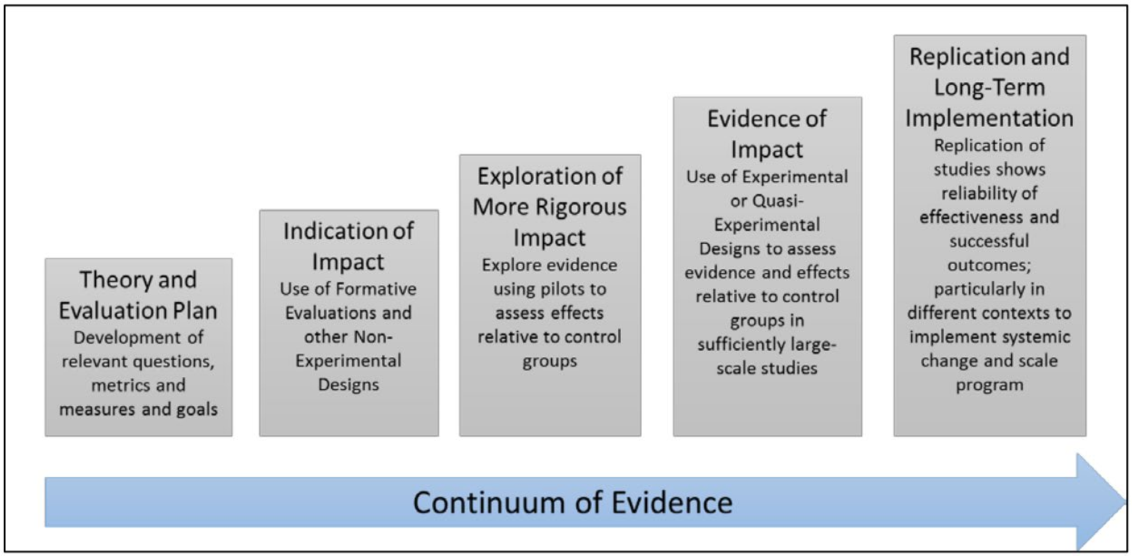
Specific Actions for Agency-Level Development of Learning Agendas

Learning agendas for an agency's technology transfer activities could be developed and integrated into broader learning agenda efforts at their agency and customized for their specific missions and needs. Offices within agencies that manage technology transfer programs, including across Federal laboratories, should coordinate with their agency's Evaluation Officer to explain how this state of evidence and gaps resonate specifically for their agency's technology transfer programs. To inform the learning agenda, Evaluation Officers may be interested in understanding the key learning questions, proposed activities and approaches needed to address these questions, available or needed data, and challenges that may arise when carrying out these efforts with proposed solutions.

Generally, the extent to which each agency implements learning agendas and evidence-building practices can exist on a continuum (Figure 3) (Peña & Behrens 2019). The ends of the continuum correspond to different stages of evidence collection and use of evidence for performance assessment. All agencies may find a place to start on any part of the continuum as they consider how to improve their evaluation of technology transfer activities. Evidence can be qualitative and quantitative in nature. As agencies strengthen their technology transfer evaluation capacity, evidence can progress from formative and non-experimental designs to experimental and rigorous, replicable studies that evaluate the

[19] For further on the evolution of Federal evidence-based practices, *see* Peña & Behrens. 2019. *Evidence-Based Approaches for Improving Federal Programs and Informing Funding Decisions*.

impacts of technology transfer activities. Agencies may also consider that the application of evidence along this spectrum may depend on the technology transfer activity being pursued and the extent of data collection on those activities.



Source: Peña and Behrens. 2019. Evidence-Based Approaches for Improving Federal Programs and Informing Funding Decisions.

Figure 3. Continuum of Evidence

There is no one size fits all for developing learning agendas. Learning agendas will vary across agencies, based on their technology transfer activities and where they fall in the continuum of evidence. Numerous factors will influence the development of a learning agenda, including overall mission, nature of the technology transfer activities (for instance whether focused on intramural and extramural R&D), staff capacity, cost, and measures of success. Agencies already perform continuous planning activities, which can involve evidence-based practices, including identifying and continually reviewing appropriate metrics and measures. Learning agendas focused on technology transfer goals, questions, and measures should be developed based on and aligned with these planning processes.

Specific Actions for the L2M Subcommittee in Developing a Federal-Wide Learning Agenda

To date, a Federal-wide learning agenda for technology transfer activities is not yet fully developed. While not all technology transfer activities may be appropriate for a Federal-wide learning agenda, as each activity has its own context; there may be some similarities across these activities that can be tracked and compared.

A learning agenda for Federal-wide technology transfer activities can take many forms and integrate manifold deliberation and decision processes.[20] OMB's guidance describes the following learning agenda components:

- Identification of strategic goals and objectives that the learning agenda will address;
- Identification of priority questions to be answered;
- Activities to address priority questions;
- Timing of learning agenda activities;
- Potential data, tools, methods and analytic approaches to be used to answer priority questions; and
- Anticipated challenges and proposed solutions to develop evidence to support the L2M Subcommittee's priorities (OMB 2019)

An example applying this framework to address the some of the challenges mentioned in this paper is provided in Appendix D.

In addition, the shift—from a single or a few metrics to evaluate technology transfer to strategic performance for specific mission-driven or common technology transfer outcomes—may help address the distortion of incentives and comparability issues that can occur when evaluating performance based on processes or activities. In a similar fashion, a learning agenda that provides a framework for the evaluation of Federal technology transfer activities can communicate the goals related to acquiring further evidence and how strengthening the capacity to collect and analyze this evidence supports the Federal Government's and L2M Subcommittee's strategic goals.

The L2M Subcommittee may wish to consider how the development of a Federal learning agenda can be coordinated across agencies to respond to the specific challenges in comparing metrics, evaluating economic impacts, and temporality issues. For example, economic impact studies and I-O models have acknowledged limitations, and a coordinated interagency effort could help address these limitations by developing a learning agenda to build evidence of the economic and societal impacts of Federal technology transfer. This effort could begin by identifying where Federal agencies may currently fit along the continuum of evidence, identifying common problem statements and questions, exploring

[20] As an example, the U.S. Department of Housing and Urban Development (HUD) developed a learning agenda modeled as a "Research Roadmap." The Roadmap is used to identify key research questions and is updated every 5 years through strategic dialogue with stakeholders relevant to HUD's mission, such as the academic community, practitioners, and Federal, State, and local policy makers. For further, see U.S. Department of Housing and Urban Development (HUD). 2017. "HUD Research Roadmap: 2017 Update," Washington, D.C.: HUD https://www.huduser.gov/portal/pdf/ResearchRoadmap2017Update.pdf; and Urban Institute. https://www.urban.org/sites/default/files/publication/97406/evidence_toolkit_learning_agendas_2.pdf

the body of evidence already identified across Federal agencies for both intramural and extramural R&D, collecting impact studies already conducted and their results, and analyzing their methods and outcomes.

The implementation of a Federal-wide learning agenda may include identifying and acquiring relevant comparable information on processes, outcomes, and contexts—such as the disciplines and industries as well as the policy context—in which the technology transfer activities occur. Answering learning agenda questions from a Federal-wide perspective may be appropriate only for a subset of agencies for any given technology transfer activity, given that there may be specific Federal authorities or agency policies that provide varied flexibilities to agencies to implement their activities.

As part of its L2M Subcommittee coordination efforts, agencies may also consider sharing best practices across Federal agencies in the development of their learning agendas, for instance through the development of an interagency working group focused on the topic. It may be useful for Federal technology transfer staff to share effective ways of interfacing with their agency's Evaluation Officers, who are responsible for implementing their agency's annual evaluation plans under the Evidence Act, and integrating their learning agenda specific to technology transfer with the agency's overall evaluation planning efforts. This forum could also provide a means to ensure agency-specific learning agendas are aligned with the L2M Subcommittee's broader strategic goals.

B. Adopt or Adapt Innovative Metrics

Three approaches are discussed in this section: (1) the normalization of metrics and development of indices to better benchmark and make comparisons across metrics, (2) the use of altmetrics to capture greater understanding of the impacts from knowledge diffusion, and (3) ways to link process, outputs, and outcome measures from technology transfer activities.

1. Normalization and Indices

The issue of temporality is partially mitigated by Federal agencies' reporting practices. Specifically, NIST has prepared guidance on technology transfer annual reports that includes a template for reporting quantitative metrics going back 5 fiscal years. Numerous agencies have adapted this framework and many report annual quantitative technology transfer metrics alongside those from preceding years. This simple approach contextualizes each metric for a more robust understanding of year-to-year trends and the complex relationship between input and output metrics.

However, robust comparisons require improvements to normalization that account for the nuanced complexities of industries, sectors, and other factors that influence outcomes. Some agencies have experimented with methodologies for introducing a temporal element to improve the benchmarking and interpretation of metrics in their annual reports. For example, NIST generates an index value for quantitative metrics by dividing each year's value by the benchmark value from fiscal year 2013 (NIST 2019a). This reformats each metric as a percentage change since 2013, rather than a raw value. These index values are then plotted on a chart with a line of best fit to visualize average trends over the relevant period. While providing a baseline within one organization, this type of normalization does not address the issues of comparison across organizations. However, an advantage of this particular strategy is that it addresses some issues with temporality in that it emphasizes relationships across a handful of years and limits the impact of any one year. Especially for annual reports, there is sometimes a temptation to implicitly weight the measure from the most recent year more heavily than data from previous years. This tendency can be misleading and even erroneous, especially when there are deviations from a persistent trend.

Another advantage of NIST's strategy for reporting these indices is the ease of comparison across metrics. By normalizing each value to a percentage change and plotting these percentages, an evaluator can understand the relationships between different metrics and compare trends across a given period of time within the organization. Similarly, the DOC's annual reports use indices to assess trends in key technology transfer metrics, such as invention disclosures, patents issued, invention licenses, and CRADAs (DOC 2019).

Normalization of a given metric may not address other limitations in their interpretation—specifically that existing metrics point to different time periods across interrelated technology transfer processes. For example, a patent may be based on an invention that was disclosed through published literature years prior to being issued. In addition, publications and patent applications may be submitted at the same time, in which case a patent would not indicate the publication as prior art. Normalization and indices should capture these process-level relationships, relating certain outputs, such as invention disclosures, to later-stage outputs, such as issued patents. In the academic literature, some have attempted to address these inconsistencies in benchmarking and proposed a way to normalize measures based on their relationships to other transfer outputs. For instance, researchers used a handful of normalization and benchmarking strategies to measure innovation performance in the biomedical sphere (Balas & Elkin 2013). They generated transfer ratios along intellectual property and knowledge diffusion pathways—disclosure to patents, patents to licenses, and licenses to royalties. They compared the ratios to different benchmarks across the entire set of data. This methodology allows for contextualization and evaluation of technology transfer activities across a number of different process measures. These approaches present alternatives to the output and outcome measures traditionally reported and identify opportunities for gaining insights into the efficiency of the processes for specific technology transfer mechanisms that agencies pursue.

Novel approaches evaluating technology transfer effectiveness through indices have also been applied in university technology transfer settings. One such approach employs a hierarchical decision model that quantitatively evaluates how various technology transfer mechanisms contribute to accomplishing an organization's mission to obtain a Knowledge and Technology Transfer Effectiveness Index (Tran 2016). With this index, universities can assess which areas of technology transfer are successful or need improvement as it relates to achieving their missions. Institutions that seek to measure financial return utilize different metrics than public service-oriented ones—the former relies mostly on counting startups and licensing, and the latter on a wider range of activities. Comparisons of technology transfer metrics are enabled between institutions to identify targets or performance. Other methods using indices have been developed by universities outside the United States that focus on quantifying different dimensions of effectiveness, such as entrepreneurship and technology transfer office productivity based on resources (e.g., staff) and outputs (e.g., spin-offs) (Fuller at al. 2019; Berbegal-Mirabent et al. 2019).

These approaches should be used with caution as indices using inappropriate metrics can lead to misinterpretations of an organization's own performance as well as when compared across organizations. Not all temporality issues can be addressed by existing methods. For instance, extant benchmarking, normalization, and indices do not capture that some industries are faster to commercialize than others. The broader context and complexity of industry and discipline-specific factors involved in technology transfer may influence the effectiveness and efficiency of processes and outcomes. Agencies may wish to consider how they use a combination of normalization methods and indices to measure processes within specific missions, industries, and disciplines rather than comparing across them.

2. Altmetrics

Altmetrics capture the impacts of knowledge diffusion and provide alternative ways to measure technology transfer impacts. Altmetrics are tools used to measure the impact of scholarly research outputs based on mentions online. The online platforms can include social media, news sites, social bookmarking sites, policy sites, and more. These metrics enable the user to measure the number of internet users that have viewed, shared, discussed, cited, or downloaded the output. Outputs may include journal articles, reports, data sets, presentations, videos, web pages, code repositories, and scientist biographical profiles, among others. An expanded definition is included below:

> Altmetrics are non-traditional metrics that cover not just citation counts but also downloads, social media shares, and other measures of impact of research outputs. The term is variously used to mean "alternative metrics" or "article level metrics," and it encompasses webometrics, or cybermetrics, which measure the features and relationships of online items, such as websites and log files. The rise of new social media has created an

> additional stream of work under the label altmetrics. These are indicators derived from [online social networks], such as Twitter, [and] Mendeley . . . with data gathered automatically by computer programs (Wilsdon 2016).

The advantages of altmetrics as compared to traditional citation counts include capturing online engagement and detailed composition of the impact (e.g., who is conducting the interaction and what are the commonalities?) (Priem et al. 2010; Costas 2015). Such online visibility could be used as a means to connect and communicate with stakeholders, such as universities and the wider public. As such, some scholars argue that altmetrics could partly determine the ROI of the output, since online engagement is evidence of societal impact. The use of altmetrics can address some of the issues with temporality, in particular addressing the latency in developing publications and patents related to new discoveries by capturing short-term impacts in the uptake of that knowledge through online pathways. Altmetrics can also be tracked over time, addressing potential issues with comparison—if standardized—and temporality, such as latency in the development and application of new knowledge and technologies.

However, altmetrics can be affected by aspects such as influential users within online social networks (e.g., increase speed and reach of sharing) or gaming (e.g., self-citations) to boost apparent impact (Fraumann 2018). In addition, consideration should be given to distinguish the nature of the metric, such as positive or negative sentiments or reviews. Although limitations of altmetrics to discern the quality of the online impact exist, researchers have posed solutions such as validating altmetrics with detailed qualitative analysis (Haustein et al. 2014; Robinson-Garcia 2018).

Agencies, in considering the use of altmetrics, may identify how altmetrics can apply in the contexts of their missions, such as what specific altmetrics can provide insight into the targeted industries and disciplines of their technology transfer activity. Agencies could consider how altmetrics can capture value that is currently not being captured through other existing measures and metrics. In this way, altmetrics could be used to measure alternative impacts of technology transfer activities—relating activities for knowledge diffusion to how they create broader impacts to missions.

3. Linking Metrics to Outcomes

Challenges identified in this paper included the limitation and the high level of effort necessary to link process and output metrics to the long-term outcomes of R&D investments and Federal technology transfer activities, in particular economic impacts. This is partly due to a general lack of systematic ways to track how Federal funds are used and to connect input and output metrics, like patents filed, to the downstream outcomes they enable, such as application of the patent to generate new technologies, new businesses, and economic measures, such as revenues and jobs. Relevant data and metrics associated with these downstream outcomes are also typically accessible from a variety of Federal and commercial data infrastructure and systems.

Studies have attempted to address these limitations by using a combination of qualitative and quantitative approaches to analyze and connect the relationships among processes, outputs, and outcomes. For instance, tracer studies are retrospective studies that trace the impacts of Federal funding to specific people, places, and organizations and track how those inputs contributed to the advancement of technologies, industries, and social benefits.[21] They often incorporate the evolution of a broader technology space or scientific field over time horizons of 20 to 30 or more years. These studies often rely on acquiring and connecting information and data from disparate sources and can be labor intensive endeavors. However, these methods can also provide an accurate representation of the specific roles of Federal investments relative to complementary activities from non-Federal investments, such as the private sector, foundations, educational institutions, and other nonprofits that support the Nation's R&D enterprise.

In particular, the case study approaches used in these studies, which are informed by data analysis, provide in-depth context for how innovations and technologies were developed to achieve specific outcomes. By tracing specific inputs, like funding, people, and organizations, and linking these over time, the methods can help address some of the common challenges related to understanding the varied contexts and missions in which technology transfer activities occur, limitations in evaluating economic impacts, and temporality.

C. Improve Cross-Sector Engagement to Leverage Expertise to Build Evidence

There are several opportunities for Federal agencies to improve engagement with experts across sectors to build evidence concerning the effectiveness of technology transfer activities. For instance, the NSF Science of Science and Innovation Policy program under its Directorate for Social, Behavioral and Economic Sciences funds academic researchers to study, among other topics, the impacts of federally funded R&D. NSF-funded research has led to innovative methods and metrics to analyze the impacts of Federal resources for R&D, in particular, and technology transfer, broadly.

[21] *see* Weber, C.L., Peña, V., Micali, M.K., Yglesias, E., Rood, S.A., Scott J.A., and Lal, B. 2013. The Role of the National Science Foundation in the Origin and Evolution of Additive Manufacturing in the United States. IDA Paper P-5091, and Viola, Jessica, Lal, Bhavya, and Grad, Oren. 2003. The Emergence of Tissue Engineering as a Research Field. Abt Associates.

Specific Actions for Agency-Level Improvement of Cross-Sector Engagement

Federal agencies could coordinate with NSF and the science of science research community more broadly to leverage the expertise, studies, data, and findings from prior research for the benefit of identifying lessons learned and improvements to policy and practice. In this way, Federal agencies could better leverage the numerous studies related to technology transfer impacts already analyzed by researchers (Appendix C).[22] Although outreach to this research community could be done independent of other efforts proposed in this paper, these efforts could inform the development and coordination of other suggested efforts: development of learning agendas, identification of appropriate metrics to create metrics portfolios, and the adoption or adaptation of innovative metrics.

Specific Actions for the L2M Subcommittee in Improving Cross-Sector Engagement

Other means of outreach to these research communities could include co-hosting cross-sector workshops or webinars with NSF and other funding agencies supporting these research communities, or inviting speakers to present their studies at interagency working group or L2M Subcommittee meetings. For example, developing a joint-solicitation with NSF and the L2M Subcommittee or specific agencies could be an opportunity to fund new studies that expand the state-of-the-art. Specifically, the L2M Subcommittee could support and help coordinate these initiatives, including the potential for agencies to pool efforts and resources for common evaluation needs. The L2M Subcommittee could also help identify ways to maintain an ongoing repository for historical and future references important to the research community. For instance, relevant needs could include the maintenance and storage of data, software, and research tools; the systems necessary to easily access this data; and implementation of policies needed to ensure these activities are maintained over the long term to support continuous learning as well as the robustness and replicability of future studies.

[22] For example, STPI identified 177 publications from a literature search conducted to support the ST5 interagency working group (see Appendix B).

5. Summary

Improvements in the evaluation of Federal technology transfer activities will support informed Federal decisions, including policy, practice, and interagency coordination activities in this area. Increasing the speed and quality of transfer activities ultimately bolsters commercialization outcomes—such as new products, processes, and services—that can result in increased societal welfare and be spun back into the public sector to meet the needs of the Federal Government. These improvements benefit many innovation ecosystem stakeholders and activities, including intramural and extramural researchers and R&D organizations across sectors and industries throughout the Nation.

In large part due to the laws regarding reporting of Federal intramural technology transfer activities, Federal agencies report many measures and metrics related to their technology transfer internal processes. Many of these intramural measures and metrics were further refined as a reference for the Federal technology transfer community in the updated NIST Guidance, which included an "a la carte" menu developed by the ST5 interagency working group (Appendix B). At the same time, there is a gap in the reporting of extramural measures and metrics across agencies. Based on the annual technology transfer reports and the literature search, we found many reports and studies related to both intramural and extramural R&D programs. While studies on intramural activities focus on outputs and process metrics, studies for extramural activities focus on longer term impacts or outcomes, such as on the economy, businesses, and employment. In particular, many economic impact studies have focused analysis on research funded by the Federal Government and conducted by extramural researchers rather than on Federal laboratory-developed technologies or technology portfolios (Appendix C).

This paper identified several common challenges in the evaluation of Federal technology transfer and considerations in the use and interpretation of metrics. It also identified several cross-cutting approaches to address these challenges (Table 2).

Table 2. Approaches to Address One or More Challenges

		Approaches to Address Challenges					
		Portfolio of Metrics	Learning Agenda	Normalization and Indices	Altmetrics	Linking Metrics to Outcomes	Cross-Sector Engagement
Challenges	Varied Contexts for Technology Transfer	X	X		X	X	X
	Complexity of Industry and Discipline-Specific Factors	X	X	X			X
	Limitations in the Comparison of Metrics and Their Interpretation		X	X			X
	Limitations in Evaluating Economic Impacts	X	X			X	X
	Issues with Temporality		X	X	X	X	X
	Distortion of Incentives		X				X

Notably, any single overarching approach presents actionable opportunities to address multiple challenges. However, these challenges are complex, and, as such, there is no one approach that fully addresses all the complexities an agency may experience. Federal agencies are encouraged to further analyze these challenges and determine what aspects are of highest priority to meet their needs. This analysis may require further assessment of an agency's own challenges in defining and measuring the value of their specific technology transfer activities of interest—including process, outputs, or outcomes—and the strategic contribution of these activities to support broader technology transfer goals and missions. Agencies could also further analyze how to apply state-of-the-art approaches given their goals (refer to Appendix C for further resources).

The L2M Subcommittee could further support these goals through concerted efforts to help guide and share information as agencies pursue these approaches. The L2M Subcommittee, or other relevant interagency bodies as appropriate,[23] should establish an ongoing and topical interagency working group specific to the implementation goals identified in this paper. This interagency working group could help maintain updated

[23] For example, the Interagency Working Group for Technology Transfer, the Interagency Working Group for Bayh-Dole, and the FLC. For further on these groups, *see* NIST, "Partnerships," https://www.nist.gov/tpo/lab-market.

information resources for the Federal community and help agencies identify exemplar practices, lessons learned, and coordination opportunities for strengthening their capacity to build evidence, using innovative measures, and improving cross-sector engagement to improve the evaluation of Federal technology transfer. In establishing an interagency working group, and to address the challenges related to comparability of technology transfer based on the disciplinary, market and S&T domains, it may be worthwhile to establish thematic grouping for some of these efforts (e.g., life sciences and biotechnology). Federal experts across the NSTC's topical Subcommittees could also be leveraged and integrated into these efforts, as needed, to ensure alignment with strategic planning and goals that already exist or are underway.

Appendix A. Overview of Two Seminal Federal Laws on Technology Transfer

Congress passed the Stevenson-Wydler Technology Innovation Act of 1980 in response to concerns about a slowdown in the rate of growth of national productivity. The Stevenson-Wydler Act focuses on Federal laboratories, noting the crucial importance of such technologies for economic progress. It states:

> Many new discoveries and advances in science occur in universities and Federal laboratories, while the application of this new knowledge to commercial and useful public purposes depends largely upon actions by business and labor. Cooperation among academia, Federal laboratories, labor, and industry, in such forms as technology transfer, personnel exchange, joint research projects, and others, should be renewed, expanded, and strengthened.[24]

The legislation required Federal laboratories to budget for and participate in technology transfer activities. In addition, each Federal laboratory was mandated to establish and maintain an Office of Research and Technology Applications (ORTA), more commonly known as a technology transfer office, staffed with technically proficient employees to perform technology transfer activities, such as engaging with industry organizations, licensing intellectual property, and establishing partnership agreements, among others. Passage of the Federal Technology Transfer Act of 1986 bolstered the Stevenson-Wydler Act by permitting Federal agencies to enter into cooperative R&D agreements (CRADAs) with other Federal agencies and the private sector.[25] This Act also permitted Federal agencies to negotiate licenses for patented inventions.

In conjunction with the aforementioned laws, the Bayh-Dole Act of 1980 contributed to strengthening technology transfer activities from non-Federal organizations. This Act enabled universities, small businesses, and nonprofits to commercialize inventions arising from federally funded research and retain principal ownership rights.[26] Federal agencies were authorized to grant exclusive licenses to federally owned inventions. Together, these

[24] *Stevenson-Wydler Technology Innovation Act of 1980*, 96-480.

[25] *Federal Technology Transfer Act of 1986*, 99-502.

[26] *The Bayh-Dole Act, 96-517.*

laws bolstered technology transfer across sectors through methods that disseminated knowledge and access to Federal laboratory technologies.

Appendix B.
ST5 A La Carte Menu

This appendix provides the a la carte metrics menu presented in NIST's guidance for reporting of agency technology transfer reports, updated in April 2020.[27]

[27] NIST. "Guidance for Preparing Annual Agency Technology Transfer Reports Under the Technology Transfer Commercialization Act." 2020.

Technology Transfer "A La Carte Metrics Menu"

The "à la carte Metrics Menu" was developed by Strategy Team 5 of the National Science and Technology Council (NSTC) Lab to Market Subcommittee and comprises a set of metrics that were collected by various agencies in excess of those that they are legally required to report under 15 USC 3710 (f)(2)(B).[18] The Strategy Team recognizes that each agency approaches technology transfer activities differently and in order to capture all that is reported across the agencies, ST5 has compiled a list of **optional** metrics in order to inform all agencies of additional possible metrics that they may want to consider. This list is intended to serve as a list of possibilities, rather than a strict prescription.

The metrics on this list were collected in March 2019 from Strategy Team member agencies--Centers for Disease and Control and Prevention (CDC), Departments of Agriculture, Commerce, Defense, Energy, Interior, Homeland Security, Transportation, Environmental Protection Agency (EPA), Food & Drug Administration (FDA), National Aeronautics and Space Administration (NASA), and National Institutes of Health (NIH).

The list is analogous to an "à la carte" menu where you may wish to choose none, a few, or all of the metrics as you see fit. The metrics are categorized under 5 categories: Research and Academic Dissemination; Scientific & Technology Transfer Training; Collaborations and Research Outputs; Economic Development Impacts; and Miscellaneous.

1. Research and Academic Dissemination
    - Number of publications by scientific or technology transfer staff
    - Number of citations to those publications
2. Scientific & Technology Transfer Training
    - Number of fellows, interns, or international staff trained, specifically regarding:
        - Amount and quality of management training at the project initiation and operations stage
        - Amount and quality of management and research staff training on invention disclosure, e.g., criteria for identifying, reporting, and protecting inventions and IP
        - Amount and quality of management training on the choice of transfer mechanism, e.g., criteria for selecting patents, publications, and for patenting itself
        - Amount and quality of training of technology transfer staff on transfer and marketing activities
        - Amount and quality of training research and technology transfer staff on acquiring and communicating feedback

18 The NSTC Lab to Market Subcommittee was established in FY2018-Q2 to support the President's Management Agenda (PMA). The Subcommittee's goal is to improve the transfer of federally funded research and development (R&D) to the private sector. The Subcommittee was divided into 5 "Strategy Teams," made up of Federal technology transfer experts, each aimed at developing milestones to accomplish one of 5 strategies outlined in the PMA.

- Number of talks, conference attendances, speeches, webinars (i.e. other forms of outreach) on Federal technology transfer
- Establishment of Personnel Exchange Programs
- Development of future scientists/number of scientists trained at the Federal Labs

3. Collaborations and Research Activities
    - Number of reimbursable agreements (with universities and non-profits)
    - Number of projects initiated under agency-specific agreements, e.g., Strategic Partnering Projects
    - Number of new alliances, e.g., Partnership Intermediary Agreements (PIA), Memorandum of Understanding (MOU)
    - Number and nature of alliances with local or state economic development organizations
    - Amount of non-federal partner funds and in-kind contributions from agreements or projects
    - Use of unique facilities by businesses e.g., user facilities, laboratory enhanced-use lease or out-lease transactions to private sector
    - Number of Federal sites involved in trials (clinical, field)
    - Number of and extent to which Biological Materials are transferred
    - Development of reference materials, standards
    - Development of new methods
    - Number of plant releases
    - Interagency collaborations, e.g., joint solicitations, joint funding for research equipment or infrastructure, joint research
    - Number of software licenses executed
    - Number of software products available for licensing
    - Number of copyright licenses executed
    - Number of demonstrations & Field days
    - Number of newsletters, briefs, or non-academic publications
    - Number of data sets open to the public
    - Number of SBIR-TT contracts and grants
4. Miscellaneous
    - Methods of leveraging Federal technologies
    - Number and types of evaluation processes implemented
    - Number of impact studies performed
    - New methods and mechanisms to transfer technologies

Appendix C.
Annotated Literature

This appendix presents the results of a literature search focused on studies that: (1) measure the value of technology transfer activities in particular sectors and industries; (2) assess Federal programs or technology transfer mechanisms; and (3) provide frameworks and models to evaluate technology transfer processes and outcomes, among other related topics. STPI conducted the literature search in March 2019 to support the deliberations of the ST5 interagency working group. STPI supplemented the results of the literature search with other studies identified by the ST5 interagency working group members. In total, STPI identified 177 publications, including studies published by academic researchers and Federal agencies. These publications are loosely categorized based on the focus of study, as follows:

A. Biomedical R&D

B. Agricultural R&D

C. Defense R&D

D. Energy R&D

E. Small Business Innovation Research (SBIR)

F. Collaborative Research Agreements

G. Other Publications

1. Input-Output Model
2. Studies Using Patents and Licenses
3. Entrepreneurship and Entrepreneurial R&D Training
4. Societal Impacts of R&D
5. Studies on Technology Transfer Offices
6. R&D Funding and Economic Productivity
7. Technology Transfer Evaluation Frameworks and Models
8. Research Parks
9. Research Data
10. International Technology Transfer

A. Biomedical R&D

1. Aldridge, Taylor, and David B. Audretsch. 2010. "Does policy influence the commercialization route? Evidence from National Institutes of Health funded scientists." *Research Policy* 39, no. 5: 583-588.

The purpose of this paper is to provide an empirical test of the commercialization route chosen by university scientists funded by the National Cancer Institute (NCI) at the NIH and how their chosen commercialization path is influenced by whether or not the university technology transfer office is involved. In particular, the paper identifies two routes for scientific commercialization. Scientists who select the TTO route by commercializing their research through assigning all patents to their university TTO account for 70% of NCI patenting scientists. Scientists who choose the backdoor route to commercialize their research, in that they do not assign patents to their university TTO, comprise 30% of patenting NCI scientists. The findings show a clear link between the commercialization mode and the commercialization route. Scientists choosing the backdoor route for commercialization, by not assigning patents to their university to commercialize research, tend to rely on the commercialization mode of starting a new firm. By contrast, scientists who select the TTO route by assigning their patents to the university tend to rely on the commercialization mode of licensing.

2. Azoulay, Pierre, Joshua S. Graff Zivin, Danielle Li, and Bhaven N. Sampat. 2019. "Public R&D Investments and Private-sector Patenting: Evidence from NIH Funding Rules." *Review of Economic Studies* 86: 117–152. https://doi.org/10.1093/restud/rdy034

We quantify the impact of scientific grant funding at the National Institutes of Health (NIH) on patenting by pharmaceutical and biotechnology firms. Our article makes two contributions. First, we use newly constructed bibliometric data to develop a method for flexibly linking specific grant expenditures to private-sector innovations. Second, we take advantage of idiosyncratic rigidities in the rules governing NIH peer review to generate exogenous variation in funding across research areas. Our results show that NIH funding spurs the development of private-sector patents: a $10 million boost in NIH funding leads to a net increase of 2.7 patents. Though valuing patents is difficult, we report a range of estimates for the private value of these patents using different approaches.

3. Balas, E. A., and P. L. Elkin. 2013. "Technology Transfer From Biomedical Research to Clinical Practice: Measuring Innovation Performance." *Evaluation & the Health Professions* no. 36 (4):505-517. doi: 10.1177/0163278713508135.

Studies documented 17 years of transfer time from clinical trials to practice of care. Launched in 2002, the National Institutes of Health (NIH) translational research initiative needs to develop metrics for impact assessment. A recent White House report highlighted that research and development productivity is declining as a result of increased research spending while the new drugs output is flat. The goal of this study was to develop an expanded model of research-based innovation and performance thresholds of transfer from research to practice. Models for transfer of research to practice have been collected and reviewed. Subsequently, innovation pathways have been specified based on common characteristics. An integrated, intellectual property transfer model is described. The central but often disregarded role of research innovation disclosure is highlighted. Measures of research transfer and milestones of progress have been identified based on the Association of University Technology Managers 2012 performance reports. Numeric milestones of technology transfer are recommended at threshold (top 50%), target (top 25%), and stretch goal (top 10%) performance levels. Transfer measures and corresponding target levels include research spending to disclosure (<$1.88 million), disclosure to patents (>0.81), patents to start-up (>0.1), patents to licenses (>2.25), and average per license income (>$48,000). Several limitations of measurement are described. Academic institutions should take strategic steps to bring innovation to the center of scholarly discussions. Research on research, particularly on pathways to disclosures, is needed to improve R&D productivity. Researchers should be informed about the technology transfer performance of their institution and regulations should better support innovators.

4. Bisias, Dimitrios, Andrew W. Lo, and James F. Watkins. 2012. "Estimating the NIH Frontier." *PLoS ONE* 7, no. 5 (May). https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0034569.

   Using data from 1965 to 2007, we provide estimates of the NIH "efficient frontier", the set of funding allocations across 7 groups of disease-oriented NIH institutes that yield the greatest expected return on investment for a given level of risk, where return on investment is measured by subsequent impact on U.S. years of life lost (YLL). Our analysis is intended to serve as a proof-of-concept and starting point for applying quantitative methods to allocating biomedical research funding that are objective, systematic, transparent, repeatable, and expressly designed to reduce the burden of disease. By approaching funding decisions in a more analytical fashion, it may be possible to improve their ultimate outcomes while reducing unintended consequences.

5. Blume-Kohout, Meg. 2012. "Does Targeted, Disease-Specific Public Research Funding Influence Pharmaceutical Innovation?" *JPAM* 31, no. 3: 641-660. https://www.ncbi.nlm.nih.gov/pubmed/22764378.

   Public funding for biomedical research is often justified as a means to encourage development of more (and better) treatments for disease. However, few studies have investigated the relationship between these expenditures and downstream pharmaceutical innovation. In particular, although recent analyses have shown a clear contribution of federally funded research to drug development, there exists little evidence to suggest that increasing targeted public research funding for any specific disease will result in increased development of drugs to treat that disease.

This paper evaluates the impact of changes in the allocation of U. S. National Institutes of Health (NIH) extramural research grant funding across diseases on the number of drugs entering clinical testing to treat those diseases, using new longitudinal data on NIH extramural research grants awarded by disease for years 1975 through 2006. Results from a variety of distributed lag models indicate that a sustained 10 percent increase in targeted, disease-specific NIH funding yields approximately a 4. 5 percent increase in the number of related drugs entering clinical testing (phase I trials) after a lag of up to 12 years, reflecting the continuing influence of NIH funding on discovery and testing of new molecular entities. In contrast, we do not see evidence that increases in NIH extramural grant funding for research focused on specific diseases will increase the number of related treatments investigated in the more expensive, late-stage (phase III) trials.

6. Chakravarthy, Ranjana, Kristina Cotter, Joseph DiMasi, Christopher- Paul Milne, and Nils Wendel. 2016. "Public and Private- Sector Contributions to the Research and Development of the Most Transformational Drugs in the Past 25 years: From Theory to Therapy." *Therapeutic Innovation & Regulatory Science* 50, no. 6 (November): 759-768. https://doi.org/10.1177/2168479016648730.

   We address the respective roles of the private and public sectors in drug development by examining a diverse array of evidentiary materials on the history of 19 individual drugs, 6 drug classes, and 1 drug combination identified as the most transformative drugs in health care over the past 25 years by a survey of over 200 physicians.

7. Chatterjee, Sabarni K. and Mark L. Rohrbaugh. 2014. "NIH Inventions Translate into Drugs and Biologics with High Public Health Impact." *Nature Biotechnology*, 32: 52-58.

   The contribution of inventions from public sector research institutions (PSRIs) to the development of drug and biologic products has long been recognized1–3. Until now, however, no study has carried out an in-depth comparison of the specific contributions of the US National Institutes of Health (NIH) Intramural Research Program (IRP) and other US PSRIs to the development of drugs and biologics approved by the US Food and Drug Administration (FDA). In the following article, we analyze the number of products resulting from inventions from these sources (Fig. 1), assess their public health impact, categorize the type of licenses made and the licensee organizations that made them and estimate the funding invested that resulted in drug and biologic products. We show that NIH-IRP inventions have had a disproportionately greater impact in three respects: first, the overall number of products, particularly vaccines, cancer therapeutics and in vivo diagnostics; second, the number of drugs granted orphan status; and third, the number of drugs developed under New Drug Applications (NDAs) granted priority review by the FDA because they offer major advances in

treatment. Gross annual commercial sales of these products serve as a limited but direct measure of their economic impact, which for the drugs and biologics that utilize NIH-IRP inventions is double the government's total annual investment in the NIH-IRP.

8. Chatterjee, Anusuya and Ross C. DeVol. 2012. "Estimating Long-Term Economic Returns of NIH Funding on Output in the Biosciences." Milken Institute (August). https://www.milkeninstitute.org/publications/view/535.

   Advances in biomedical research have spurred dramatic improvements in both human and economic health. Between 1950 and 2009, life expectancy in the United States has increased 10 years, and since 1970, this increase in longevity has produced a net national gain of $61 trillion in "social value," defined as the value of a lifetime expected utility. All this can be traced back to innovations in research, discovery, diagnostics and therapies - and strong federal policy positions that have pushed the U.S. to the forefront of biomedical R&D. An estimated 40 percent of U.S. medical research is federally funded. The benefit from every dollar invested by National Institutes of Health (NIH) outweighs the cost by many times. When we consider the economic value realized as a result of decrease in mortality and morbidity of all other diseases, the direct and indirect effects (such as increases in work-related productivity) are phenomenal. NIH funding has also played a major role in boosting economic growth and contributing to the growth of bioscience clusters - geographic concentrations of related industries or firms. An initial round of NIH funding encourages the hiring of more scientists and engineers, which boosts the bioscience industry's output. As production increases, private companies absorb information and invest more in R&D, which further boosts the economy. This growth attracts supporting industries and their own allied industries. Eventually the effect translates into higher economic activity for the region. It may take years to realize the actual long-term effect of NIH funding on the economy. A work in progress, this paper establishes the long-term relationship between NIH funding and the size of the bioscience industry at the state level. The preliminary results show that $1.00 in NIH funding can generate at least $1.70 of output in the bioscience industry. The long-term effects may be as high as $3.20 for every $1.00 spent, depending on the model specification. Thus, every NIH dollar that goes into the bioscience not only benefits crucial research, but the broader economy as well.

9. Clairborne- Johnston, S., John D. Rootenberg, Shereen Katrack, Wade S. Smith, and Jacob S. Elkins. 2006. "Effect of a US National Institutes of Health Programme of Clinical Trials on Public Health and Costs." *Lancet* 367: 1319-1327. DOI:https://doi.org/10.1016/S0140-6736(06)68578-4

   Few attempts have been made to estimate the public return on investment in medical research. The total costs and benefits to society of a clinical trial, the final step in testing an intervention, can be estimated by evaluating the effect of trial results on medical care and health. All phase III randomised trials funded by the

US National Institute of Neurological Disorders and Stroke before Jan 1, 2000, were included. Pertinent publications on use, cost to society, and health effects for each studied intervention were identified by systematic review, supplemented with data from other public and proprietary sources. Regardless of whether a trial was positive or negative, information on use of tested therapies was integrated with published per-use data on costs and health effect (converted to 2004 US$) to generate 10-year projections for the US population. 28 trials with a total cost of $335 million were included. Six trials (21%) resulted in measurable improvements in health, and four (14%) resulted in cost savings to society. At 10 years, the programme of trials resulted in an estimated additional 470 000 quality-adjusted life years at a total cost of $3·6 billion (including costs of all trials and additional health-care and other expenditures). Valuing a quality-adjusted life year at per-head gross domestic product, the projected net benefit to society at 10-years was $15·2 billion. 95% CIs did not include a net loss at 10 years. For this institute, the public return on investment in clinical trials has been substantial. Although results led to increases in health-care expenditures, health gains were large and valuable.

10. Cutler, David M., Allison B. Rosen and Sandeep Vijan. 2006. "The Value of Medical Spending in the United States, 1960-2000." *New England Journal of Medicine* 355, no. 9 (August): 920-927. DOI: 10.1056/NEJMsa054744.

The increased use of medical therapies has led to increased medical costs. To provide insight into the value of this increased spending, we compared gains in life expectancy with the increased costs of care from 1960 through 2000. We estimated life expectancy in 1960, 1970, 1980, 1990, and 2000 for four age groups. To control for the influence of nonmedical factors on survival, we assumed in our base-case analysis that 50 percent of the gains were due to medical care. We compared the adjusted increases in life expectancy with the lifetime cost of medical care in the same years. From 1960 through 2000, the life expectancy for newborns increased by 6.97 years, lifetime medical spending adjusted for inflation increased by approximately $69,000, and the cost per year of life gained was $19,900. The cost increased from $7,400 per year of life gained in the 1970s to $36,300 in the 1990s. The average cost per year of life gained in 1960–2000 was approximately $31,600 at 15 years of age, $53,700 at 45 years of age, and $84,700 at 65 years of age. At 65 years of age, costs rose more rapidly than did life expectancy: the cost per year of life gained was $121,000 between 1980 and 1990 and $145,000 between 1990 and 2000. On average, the increases in medical spending since 1960 have provided reasonable value. However, the spending increases in medical care for the elderly since 1980 are associated with a high cost per year of life gained. The national focus on the rise in medical spending should be balanced by attention to the health benefits of this increased spending.

11. Dorsey, E. Ray, Joel P. Thompson, Melisa Carrassco, Jason de Roulet, Philip Vitticore, Sean Nicholson, S. Claiborne Johnston, Robert G. Holloway, and Hamilton Moses III. 2009. "Financing of U.S. Biomedical Research and New Drug Approvals across Therapeutic Areas." *PLoS ONE* 4, no. 9 (September). https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0007015.

We calculated funding from 1995 to 2005 and totaled Food and Drug Administration approvals in eight therapeutic areas (cardiovascular, endocrine, gastrointestinal, genitourinary, HIV/AIDS, infectious disease excluding HIV, oncology, and respiratory) primarily using public data. We then calculated correlations between funding, published estimates of disease burden, and drug approvals. Across therapeutic areas, biomedical research funding increased substantially, appears aligned with disease burden in high income countries, but is not linked to new drug approvals. The translational gap between funding and new therapies is affecting all of medicine, and remedies must include changes beyond additional financial investment.

12. Ehrlich, Everett. 2011. "An Economic Engine: NIH Research, Employment, and the Future of the Medical Innovation Sector." United for Medical Research Report (Spring). http://www.unitedformedicalresearch.com/wp-content/uploads/2012/07/UMR_Economic-Engine.pdf.

NIH investment in 2010: 1) Led to the creation of 484,939 quality jobs; 2) Produced $69.190 billion in new economic activity across the country; and 3) Allowed 15 states to experience job growth of 10,000 jobs or more.

13. Gleary, Ekaterina Galkina, Jennifer M. Beierlein, Navleen Surjit Khanuja, Laura M. McNamee, and Fred D. Ledley. 2018. "Contribution of NIH Funding to New Drug Approvals 2010-2016." *PNAS* 115, no. 10 (March): 2329-334. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5878010/.

This work examines the contribution of NIH funding to published research associated with 210 new molecular entities (NMEs) approved by the Food and Drug Administration from 2010-2016. The analysis, which captures basic research on biological targets as well as applied research on NMEs, suggests that the NIH contribution to research associated with new drug approvals is greater than previously appreciated and highlights the risk of reducing federal funding for basic biomedical research.

14. Hendrix, Dean. 2008. "An Analysis of Bibliometric Indicators, National Institutes of Health Funding, and Faculty Size at Association of American Medical Colleges Medical Schools, 1997-2007." *Journal of the Medical Library Association* 96, no. 4 (October): 324-334. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2568842/.
The objective of this study was to analyze bibliometric data from ISI, National

Institutes of Health (NIH)–funding data, and faculty size information for Association of American Medical Colleges (AAMC) member schools during 1997 to 2007 to assess research productivity and impact. This study gathered and synthesized 10 metrics for almost all AAMC medical schools (n=123): (1) total number of published articles per medical school, (2) total number of citations to published articles per medical school, (3) average number of citations per article, (4) institutional impact indices, (5) institutional percentages of articles with zero citations, (6) annual average number of faculty per medical school, (7) total amount of NIH funding per medical school, (8) average amount of NIH grant money awarded per faculty member, (9) average number of articles per faculty member, and (10) average number of citations per faculty member. Using principal components analysis, the author calculated the relationships between measures, if they existed. Principal components analysis revealed 3 major clusters of variables that accounted for 91% of the total variance: (1) institutional research productivity, (2) research influence or impact, and (3) individual faculty research productivity. Depending on the variables in each cluster, medical school research may be appropriately evaluated in a more nuanced way. Significant correlations exist between extracted factors, indicating an interrelatedness of all variables. Total NIH funding may relate more strongly to the quality of the research than the quantity of the research. The elimination of medical schools with outliers in 1 or more indicators (n=20) altered the analysis considerably. Though popular, ordinal rankings cannot adequately describe the multidimensional nature of a medical school's research productivity and impact. This study provides statistics that can be used in conjunction with other sound methodologies to provide a more authentic view of a medical school's research. The large variance of the collected data suggests that refining bibliometric data by discipline, peer groups, or journal information may provide a more precise assessment.

15. Jacob, Brian A. and Lars Lefgren. 2011. "The Impact of Research Grant Funding on Scientific Productivity." *Journal of Public Economics* 95, no. 9 (October): 1168-1177. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3156466/pdf/nihms295510.pdf

    In this paper, we estimate the impact of receiving an NIH grant on subsequent publications and citations. Our sample consists of all applications (unsuccessful as well as successful) to the NIH from 1980 to 2000 for standard research grants (R01s). Both OLS and IV estimates show that receipt of an NIH research grant (worth roughly $1.7 million) leads to only one additional publication over the next five years, which corresponds to a 7 percent increase. The limited impact of NIH grants is consistent with a model in which the market for research funding is competitive, so that the loss of an NIH grant simply causes researchers to shift to another source of funding.

16. Makomva, Kudzai and Dee Mahan. 2008. "In Your Own Backyard: How NIH Funding Helps Your State's Economy." Families USA Global Health Initiative Report (June). http://research.policyarchive.org/8274.pdf.

We analyzed NIH grants and contracts awarded to each state in fiscal year 2007 and the economic impact of these awards in each state. We also provided a framework for predicting the economic impact of potential increases in NIH funding in fiscal year 2008. On average, in fiscal year 2007, each dollar of NIH funding generated more than twice as much in state economic output. That is, an overall investment of $22.846 billion from NIH generated a total of $50.537 billion in new state business activity in the form of increased output of goods and services. In fiscal year 2007, NIH grants and contracts created and supported more than 350,000 jobs that generated wages in excess of $18 billion in the 50 states. The average wage associated with the jobs created was $52,000.

17. Stevens, Ashley J., Jonathan Jensen, Katrine Wyller, Patrick Kilgore, Sabarni Chatterjee, and Mark L. Rohrbaugh. 2011. "The Role of Public- Sector Research in the Discovery of Drugs and Vaccines." *The New England Journal of Medicine* 364 (February): 535-541. https://www.nejm.org/doi/pdf/10.1056/NEJMsa1008268.

We identified new drugs and vaccines approved by the Food and Drug Administration (FDA) that were discovered by public-sector research institutions (PSRIs) and classified them according to their therapeutic category and potential therapeutic effect. We found that during the past 40 years, 153 new FDA-approved drugs, vaccines, or new indications for existing drugs were discovered through research carried out in PSRIs. More than half of these drugs have been used in the treatment or prevention of cancer or infectious diseases. PSRI-discovered drugs are expected to have a disproportionately large therapeutic effect. As such, public-sector research has had a more immediate effect on improving public health than was previously realized.

18. Scientific Management Review Board. 2014. "Report on Approaches to Assess the Value of Biomedical Research Supported by NIH." National Institutes of Health (March). https://smrb.od.nih.gov/documents/reports/VOBR%20SMRB__Report_2014.pdf

The Scientific Management Review Board (SMRB) was established under the National Institutes of Health (NIH) Reform Act of 2006 to advise the NIH Director and other appropriate officials on the use of certain organizational authorities reaffirmed under the same act. In July 2012, the SMRB was charged by NIH Director Francis Collins with helping to identify appropriate parameters and approaches for assessing and communicating the value of biomedical research supported by NIH. NIH is the steward of public investments in biomedical research and strives to uphold high standards of accountability, manage resources effectively, and convey important findings to the public. Improved assessments of

the value of NIH-supported biomedical research will help NIH achieve these goals. In response to the charge, the SMRB assembled the Working Group on Approaches to Assess the Value of Biomedical Research Supported by NIH. The Working Group conducted extensive consultations, were briefed on existing and planned assessment tools and databases, and reported their findings and recommendations to the full SMRB. SMRB members found that the breadth and complexity of the biomedical research enterprise makes the task of assessing its value very challenging. Assessment efforts must contend with lengthy timeframes and unpredictable paths from basic discoveries to tangible outcomes, as well as the many individuals, institutions, industries, and agencies that contribute to these outcomes. These challenges are present when assessing the value of a single area of research and are significantly compounded when assessing the broad range of biomedical research supported by NIH. Therefore, assessing the value of biomedical research supported by NIH requires a systematic, comprehensive, dynamic, and strategic approach.

19. Toole, Andrew A. 2007. "Does Public Scientific Research Complement Private Investment in Research and Development in the Pharmaceutical Industry?" *Journal of Law and Economics* 50, no. 1 (February): 81-104. https://www.journals.uchicago.edu/doi/10.1086/508314

    This paper analyzes how pharmaceutical research and development (R&D) investment responds to publicly supported biomedical research performed mainly at universities and nonprofit institutions. New microlevel data on investment, by the U.S. National Institutes of Health, allow measures of public basic and clinical research in seven medical classes to be included in a distributed lag model explaining pharmaceutical R&D investment. Using a panel of medical classes observed over 18 years, the analysis found strong evidence that public basic and clinical research are complementary to pharmaceutical R&D investment and thereby stimulate private-industry investment. However, differences in the relevance and degree of scientific and market uncertainty between basic and clinical research lead to differences in the magnitude and timing of the pharmaceutical investment response.

20. Toole, Andrew A. 2012. "The Impact of Public Basic Research on Industrial Innovation: Evidence from the Pharmaceutical Industry." *Research Policy* 41 (February): 1-12. https://www.sciencedirect.com/science/article/pii/S004873331100117X

    While most economists believe that public scientific research fuels industry innovation and economic growth, systematic evidence supporting this relationship is surprisingly limited. In a recent study, Acemoglu and Linn (2004) identified market size as a significant driver of drug innovation in the pharmaceutical industry, but they did not find any evidence supporting science-driven innovation from publicly funded research. This paper uses new data on biomedical research investments by the U.S. National Institutes of Health (NIH) to examine the contribution of public research to pharmaceutical innovation. The empirical analysis finds that both market size and NIH funded basic research have economically and statistically significant effects on the entry of new drugs with the contribution of public basic research coming in the earliest stage of pharmaceutical drug discovery. The analysis also finds a positive return to public investment in basic biomedical research.

21. Tripp, Simon and Martin Grueber. 2011. "Economic Impact of the Human Genome Project." Battelle Report (May). https://www.battelle.org/docs/default-source/misc/battelle-2011-misc-economic-impact-human-genome-project.pdf

    This report aims to fill a gap in the literature regarding the Human Genome Project by assessing its economic and functional impacts. The HGP required the development of advanced equipment, technologies, data analysis tools, and specialized analysis techniques that has facilitated the growth of an expanding "genomics industry." Today this industry is empowering further scientific discovery, progress and commercial innovation on a broad range of fronts. From human healthcare to veterinary medicine, from industrial biotechnology to high productivity agriculture, the knowledge, tools and technologies supported through the sequencing of the human genome form a foundation of advanced economic and social progress for the United States and humankind. Between 1988 and 2010 the human genome sequencing projects and associated research and industry activity directly and indirectly generated: 1) $796 billion in U.S. economic output ; 2) $244 billion in personal income for Americans; and 3) 3.8 million job-years of employment.

B. Agriculture R&D

22. Alston, Julian M., Matthew A. Andersen, Jennifer S. James, Philip G. Pardey. 2011. "The Economic Returns to U.S. Public Agricultural Research." *American Journal of Agricultural Economics* 93, no. 5 (October): 1257-1277. https://doi.org/10.1093/ajae/aar044.
    We use newly constructed state-specific data to explore the implications of common modeling choices for measures of research returns. Our results indicate that state-to-state spillover effects are important, that the research and development lag is longer than many studies have allowed, and that misspecification can give rise to significant biases. Across states, the average of the own-state benefit cost rations is 21:1, or 32:1 when the spillover benefits to other states are included. These rations correspond to real internal rates of return of 9% or 10% per annum, much smaller than those typically reported in the literature, partly because we have corrected for a methodological flaw in computing rates of return.

23. Alston, Julian M., Philip G. Pardey, Jennifer S. James, and Matthew A. Andersen. 2009. "The Economics of Agricultural R&D." *Annual Review of Resource Economics* 1: 537-566. https://doi.org/10.1146/annurev.resource.050708.144137

> Agricultural research has transformed agriculture and in doing so contributed to the transformation of economies. Economic issues arise because agricultural research is subject to various market failures, because the resulting innovations and technological changes have important economic consequences for net income and its distribution, and because the consequences are difficult to discern and attribute. Economists have developed models and measures of the economic consequences of agricultural R&D and related policies in contributions that relate to a very broad literature ranging across production economics, development economics, industrial organization, economic history, welfare economics, political economy, econometrics, and so on. A key general finding is that the social rate of return to investments in agricultural R&D has been generally high.

24. Alston, Julian M., Joanna P. MacEwan, and Abigail M. Okrent. 2016. "Effects of U.S. Public Agricultural R&D on U.S. Obesity and its Social Costs." *Applied Economic Perspectives and Policy* 38, No. 3 (September): 492-520. https://doi.org/10.1093/aepp/ppw014

> In this paper we investigate the effects of public investment in agricultural R&D on food prices, per capita calorie consumption, adult body weight, obesity, public healthcare expenditures related to obesity, and consumer welfare. We find that a 10% increase in the stream of annual U.S. public investment in agricultural R&D in the latter half of the twentieth century would have caused a modest increase in the average daily calorie consumption of American adults, resulting in small increases in public healthcare expenditures related to obesity. On the other hand, such an increase in spending would have generated very substantial consumer benefits, and net national benefits, given the very large benefit-cost ratios for agricultural R&D. This implies that current policy objectives of revising agricultural R&D priorities to pursue obesity objectives are likely to be comparatively unproductive and socially wasteful.

25. Andersen, Matthew A. 2015. "Public Investment in U.S. Agricultural R&D and the Economic Benefits." *Food Policy* 51 (February): 38-43. https://doi.org/10.1016/j.foodpol.2014.12.005

> A better understanding of the relationship between public investments in agricultural R&D and the productivity enhancing benefits they produce is critical to informing the public funding of agricultural R&D and insuring future increases in agricultural productivity. This paper describes a method of estimating the relationship between research investments, productivity growth, and the resulting economic benefits generated. The data requirements include indexes of multi-factor productivity, investments in R&D, and the value of agricultural output. The

real rate of return to public investments in agricultural R&D in the United States is estimated to be 10.5% per annum; however, a reduction in the growth of spending on public agricultural R&D in recent decades raises concerns about productivity growth in coming decades, which is required to insure an adequate supply of food to meet increasing demand.

26. Baldos, Uris Lantz C., Frederi G. Viens, Thomas W. Hertel, and Keith O. Fuglie. 2018. "R&D Spending, Knowledge Capital, and Agricultural Productivity Growth: A Bayesian Approach." *American Journal of Agricultural Economics* (July).

    In this article, we employ Bayesian hierarchical modeling to better capture and communicate the uncertainties surrounding the transformation of U.S. public agricultural research and development (R&D) expenditures to knowledge capital stocks as well as its contribution to the historic growth of U.S. agricultural total factor productivity. Our results show a significant level of uncertainty on the R&D lag weight structure, indicating that published assumptions about the R&D lag structure can now be tested and validated against available data. Our results show that the best-fit linear model yields slightly higher mean returns to R&D spending relative to the log model results and have significantly less uncertainty. This suggests that marginal returns to U.S. public agricultural research spending might have remained relatively constant despite a century of growth in expenditure.

27. Fuglie, Keith O. and Paul W. Heisey. 2007. "Economic Returns to Public Agricultural Research." *United States Department of Agriculture Economic Research Service: Economic Brief* no.10 (September): 1-10. https://www.ers.usda.gov/webdocs/publications/42826/11496_eb10_1_.pdf?v=0

    Over the last several decades, the U.S. agricultural sector has sustained impressive productivity growth. The Nation's agricultural research system, including Federal-State public research as well as private-sector research, has been a key driver of this growth. Economic analysis finds strong and consistent evidence that investment in agricultural research has yielded high returns per dollar spent. These returns include benefits not only to the farm sector but also to the food industry and consumers in the form of more abundant commodities at lower prices. While studies using different methods and coverage give a range of estimates of returns to agricultural research, there is a consensus that the payoff from the government's investment in agricultural research has been high.

28. Fuglie, Keith, Matthew Clancy, Paul Heisey, and James MacDonald. 2017. "Research, Productivity, and Output Growth in U.S. Agriculture." *Journal of Agriculture and Applied Economics* 49, no. 4: 514-554. https://doi.org/10.1017/aae.2017.13

    This article reviews the current debate on whether U.S. agricultural productivity growth is slowing. It also assesses recent research on how productivity is related to long-term investment in research and development (R&D). It describes significant changes taking place in the U.S. agricultural research system, including the growing role of private agribusiness as a main developer of new agricultural technologies and what this implies for agricultural science policy. The conclusion has suggestions for future research on these issues.

29. Heisey, Paul W., and Keith O. Fuglie. 2018. "Agricultural Research Investment and Policy Reform in High- Income Countries." *United States Department of Agriculture Economic Research Service* Report No. ERR- 249 (May). https://www.ers.usda.gov/webdocs/publications/89114/err-249.pdf?v=43244

    Investment in research is a primary driver of productivity growth in agriculture. However, in high-income countries, as agriculture's contribution to national economies declines, many public agricultural research systems face stagnant or falling financial support while research costs continue to rise. Public spending on agricultural research and development in high-income member countries of the Organisation for Economic Co-operation and Development as a whole has fallen in real (inflation-adjusted) terms since at least 2009. At the same time, society's expectations of food and agricultural systems have evolved to include a broader set of issues. These forces have induced pressure to reform agricultural research policies. Lessons from research policy reforms include accommodating a larger role for private firms in conducting agricultural research, diversifying funding sources to broaden the public research agenda, and providing stronger incentives for producer-levy funding of research.

30. Hurley, Terrance M., Xudong Rao, and Philip G. Pardey. 2014. "Re-examining the Reported Rates of Return to Food and Agricultural Research and Development." *American Journal of Agricultural Economics* 96, no. 5 (October): 1492-1504. https://doi.org/10.1093/ajae/aau047

    Hurley, Rao and Pardey (2014) analytically and empirically evaluate the internal rate of return (IRR) vis a vis the modified internal rate of return (MIRR) for investments in agricultural research and development (R&D). They find that estimates of the IRR are 2.5 to 5 times larger than the MIRR for a wide range of assumptions, leading them to question the value of the IRR as a metric to represent the rate of return to agricultural R&D. Oehmke (2016) defends the IRR by arguing that it has important properties that the MIRR does not possess. In this article, we critically examine these properties demonstrating that some are not inherent to the MIRR. For other properties, we simply disagree with Oehmke's assessment of their desirability. Therefore, we are not compelled to change our original recommendation.

31. Jin, Yu and Wallace E. Huffman. 2015. "Measuring Public Agricultural Research and Extension and Estimating their Impacts on Agricultural Productivity: New Insights

from U.S. Evidence." *Agricultural Economics* 47, no.1 (December): 15-31. https://doi.org/10.1111/agec.12206

This article provides new estimates of the marginal product of public agricultural research and extension on state agricultural productivity for the U.S., using updated data and definitions, and forecasts of future agricultural productivity growth by state. The underlying rationale for a number of important decisions that underlie the data used in cost-return estimates for public agricultural research and extension are presented. The parameters of the state productivity model are estimated from a panel of contiguous U.S. 48 states from 1970 to 2004. Public research and extension are shown to be substitutes rather than complements. The econometric model of state agricultural *TFP* predicts growth rates of *TFP* for two-thirds of states that is less than the past trend rate. The results and data indicate a real social rate of return to public investments in agricultural research of 67% and to agricultural extension of 100+%.

32. Plastina, Alejandro and Sergio H. Lence. 2018. "A Parametric Estimation of Total Factor Productivity and Its Components in U.S. Agriculture." *American Journal of Economics* 100, no. 4 (July): 1091-1119. https://doi.org/10.1093/ajae/aay010

The present study aims at improving our understanding of the individual contribution of the components of total factor productivity (TFP) change to U.S. agricultural productivity. A novel sequential primal-dual estimation routine to calculate TFP change is proposed, using a multi-output input distance function in the first stage, followed by a cost minimization routine in the second stage. TFP change is estimated as the direct sum of the estimates of technical change, technical efficiency change, allocative efficiency change, input price effects, changes in output markup, and changes in returns to scale in each state. This is the first study to find a slowdown of technical progress in the U.S. farm sector in the 1990s and 2000s, and technical regress during the farm crisis of the 1980s. While technical efficiency shows a positive overall trend, allocative efficiency shows a negative overall trend, and their combined effect (i.e., the overall cost efficiency) slows down TFP growth.

33. Wang, Sun Ling, Alejandro Plastina, Lilyan E. Fulginiti, and Eldon Ball. 2017. "Benefits of Public R&D in US Agriculture: Spill-ins, Extensions, and Roads." *Theoretical Economic Letters* 7: 1873-1898. https://doi.org/10.4236/tel.2017.76128

This paper uses panel data for the 1980-2004 period to estimate the contributions of public research to US agricultural productivity growth. Local and social internal rates of return are estimated accounting for the effects of R & D spill-in, extension activities and road density. R & D spill-in proxies were constructed based on both geographic proximity and production profile to examine the sensitivity of the rates of return to these alternatives. We find that extension activities, road density, and R & D spill-ins, play an important role in enhancing the benefit of public R & D investments. We also find that the local internal rates

of return, although high, have declined through time along with investments in extension, while the social rates have not. Yet, the social rates of return are not robust to the choice of spill-in proxy.

34. Wang, Sun Ling, Paul Heisey, David Schimmelpfennig, and V. Eldon Ball. 2015. "Agricultural Productivity Growth in the United States: Measurement, Trends, and Drivers." *United States Department of Agriculture Economic Research Service* Paper No. ERR-189 (July). www.ers.usda. gov/publications/erreconomic-researchreport/err189

    U.S. agricultural output more than doubled between 1948 and 2011. With little growth in total measured use of agricultural inputs, the extraordinary performance of the U.S. farm sector was driven mainly by increases in total factor productivity (TFP). Over the last six decades, the mix of agricultural inputs used shifted significantly, with increased use of intermediate goods (e.g., fertilizer and pesticides) and less use of labor and land. The output mix changed as well, with crop production growing faster than livestock production. Based on econometric analysis of updated (1948-2011) TFP data, this study finds no statistical evidence that long run U.S. agricultural productivity has slowed over time. Model-based projections show that in the future, slow growth in research and development investments may have only minor effects on TFP growth over the next 10 years but will slow TFP growth much more over the long term.

35. Wang, Sun Ling. 2014. "Cooperative Extension System: Trends and Economic Impacts on U.S. Agriculture." *Choices* 29, No. 1: 1-8.

    The economic benefit and return on investments of extensions are not easy to measure nor to be distinguished from those of public research funding and other local resources. Yet extension's overall contribution to agricultural productivity growth has been well recognized. Nevertheless, there are challenges awaiting extension in its second century, including the changing roles between state specialists and county agents, budget constraints, and emerging issues—such as climate changes' impact on production, and greenhouse gas emissions, as well as its focus on agriculture versus a broader role addressing rural development, youth, and human health and nutrition.

36. Weißhuhn, Peter, Katharina Helming, and Johanna Ferretti. 2017. "Research impact assessment in agriculture—A review of approaches and impact areas." *Research Evaluation* no. 27 (1):36-42. doi: 10.1093/reseval/rvx034.

    Research has a role to play in society's endeavour for sustainable development. This is particularly true for agricultural research, since agriculture is at the nexus between numerous sustainable development goals. Yet, generally accepted methods for linking research outcomes to sustainability impacts are missing. We conducted a review of scientific literature to analyse how impacts of agricultural research were assessed and what types of impacts were covered. A total of 171

papers published between 2008 and 2016 were reviewed. Our analytical framework covered three categories: (1) the assessment level of research (policy, programme, organization, project, technology, or other); (2) the type of assessment method (conceptual, qualitative, or quantitative); and (3) the impact areas (economic, social, environmental, or sustainability). The analysis revealed that most papers (56%) addressed economic impacts, such as cost-effectiveness of research funding or macroeconomic effects. In total, 42% analysed social impacts, like food security or aspects of equity. Very few papers (2%) examined environmental impacts, such as climate effects or ecosystem change. Only one paper considered all three sustainability dimensions. We found a majority of papers assessing research impacts at the level of technologies, particularly for economic impacts. There was a tendency of preferring quantitative methods for economic impacts, and qualitative methods for social impacts. The most striking finding was the 'blind eye' towards environmental and sustainability implications in research impact assessments. Efforts have to be made to close this gap and to develop integrated research assessment approaches, such as those available for policy impact assessments.

C. Defense R&D

37. Franza, Richard M. and Rajesh Srivastava. 2009. "Evaluating the Return on Investment for Department of Defense to Private Sector Technology Transfer." *International Journal of Technology Transfer and Commercialisation*: Volume 8, Issue 2-3. https://www.inderscienceonline.com/doi/abs/10.1504/IJTTC.2009.02439

    The United States Government policy indicates maximising Return On Investment (ROI) on R&D as a fundamental reason for technology transfer. Under public laws, federal agencies, are required to spend 0.5/ of their overall budget on technology transfer. Since no models exist to evaluate transfer ROI, this paper presents a framework for such a model. Individual Cooperative Research and Development Agreements (CRDAs) between the Air Force Research Laboratory (AFRL) and private firms are analysed using the model proposed, using objective and subjective measures. Sensitivity analysis is used to identify the best CRDA choice over a range of parameter values.

38. Malik, Tariq H. 2018. "Defence Investment and the Transformation National Science and Technology: A Perspective on the Exploitation of High Technology." *Technological Forecasting and Social Change* Volume 127 (February): 199-208. https://www.sciencedirect.com/science/article/pii/S0040162517308223

    Whether and how defence investment in the industrialised economies contributes to high technology transfer by moderating national science and technology into high economic products is the exploratory question posed in this paper as part of a comparative analysis of OECD economies. Based on defence dollar investments, we perform two analyses. For the first analysis, we assess moderating effects of defence dollars dedicated to national science (articles) and technology (patents) on high technology exports. For the second analysis, we assess the moderating role of defence dollars on individual economies regarding their comparative advantages/disadvantages relative to the US as the leading economy of the OECD. A panel analysis covering 23 years (1993 to 2015) presents three sets of findings. First, defence dollars positively correlate with national science productivity in articles but are not correlated with national patents. Second, defence dollars positively moderate patent technologies but negatively moderate the application of scientific articles for the development of economic products. Third, in the moderation analysis of defence dollars, the US appears to be at a comparative disadvantage relative to the most developed OECD economies. This finding may imply that (a) there is a plurality of institutions in national innovation systems and that (b) not all economies are equally emulating American institutional development. We propose several avenues for future research and policy-making.

39. Moretti, Enrico, Claudia Steinwender, and John Van Reenen. 2016. "The Intellectual Spoils of War? Defense R&D, Productivity and Spillovers." *Econometrics Laboratory, University of California Berkeley* (July). https://eml.berkeley.edu/~moretti/military.pdf

    We examine the impact of government funding for R&D on privately performed R&D and its ultimate effect on productivity growth. Shocks to defense R&D are mainly driven by geopolitical factors that we argue are largely orthogonal to technology shocks. We uncover strong evidence of "crowding in" rather than "crowding out", as increases in government funded R&D result in significant increases in private sector R&D. Analysis of the wage and employment effects suggests that the increase in private R&D expenditures reflect actual increases in R&D employment, not just higher wages. In turn, increases in R&D in a country and industry pair result in sizeable productivity gains. At the international level, we find that increased R&D spending by foreign governments has two offsetting effects on domestic firms. On net, the effect of foreign R&D on domestic productivity is significantly positive (but small in magnitude), pointing to the global benefits of national R&D increases.

40. TechLink. 2016. "National Economic Impacts from DoD License Agreements with U.S. Industry: 2000–2014." TechLink: Bozeman, MT.

D. Energy R&D

41. Goldstein, Anna P., and Venkatesh Narayanamurti. 2018. "Simultaneous pursuit of discovery and invention in the US Department of Energy." *Research Policy* 47, no. 8: 1505-1512.

    There is a sharp boundary between basic and applied research in the organizational structure of the US Department of Energy (DOE). In this work, we consider a branch of DOE that was designed to operate across this boundary: the Advanced Research Projects Agency – Energy (ARPA-E). We hypothesize that much of energy research cannot be neatly categorized as basic or applied and is more productive outside of the confines of the basic/applied dichotomy; ARPA-E gives us an opportunity to test that hypothesis. We construct a novel dataset of nearly 4000 extramural financial awards given by DOE in fiscal years 2010 through 2015, primarily to businesses and universities. We collect the early knowledge outputs of these awards from Web of Science and the United States Patent and Trademark Office. Compared to similar awards from other parts of DOE, ARPA-E awards are significantly more likely to jointly produce both a publication and a patent. ARPA-E has been highly productive in creating new technology, while also contributing new scientific knowledge. This observation points to the productive overlap of science and technology in energy research and, more generally, for mission-oriented research funding organizations.

42. Popp, David. 2017. "From science to technology: The value of knowledge from different energy research institutions." *Research Policy* 46, no. 9: 1580-1594.

    Expansion of public energy R&D budgets continues to be a key component of climate policy. Using an original data set of both scientific articles and patents pertaining to three alternative energy technologies (biofuels, solar and wind energy), this paper provides new evidence on the flows of knowledge between university, private sector, and government research. Better understanding of the value of knowledge from these institutions can help decision makers target R&D funds where they are most likely to be successful. I use citation data from both scientific articles and patents to answer two questions. First, what information is most useful to the development of new technology? Does high quality science lead to applied technology development? I find that this is the case, as those articles most highly cited by other scientific articles are also more likely to be cited by future patents. Second, which institutions produce the most valuable research? Are there differences across technologies? Research performed at government institutions appears to play an important translational role linking basic and applied research, as government articles are more likely to be cited by patents than any other institution, including universities. Universities play a less important role in wind research than for solar and biofuels, suggesting that wind energy research is at a more applied stage where commercialization and final product development is more important than basic research.

E. Small Business Innovation Research (SBIR) Program

43. Andersen, Martin S., Jeremy W. Bray, and Albert N. Link. 2017. "On the Failure of Scientific Research: an Analysis of SBIR Projects Funded by the U.S. National Institutes of Health." *Scientometrics* 112, no. 1 (July): 431-442. https://link.springer.com/article/10.1007/s11192-017-2353-7

    The Small Business Innovation Research (SBIR) program is the primary source of public funding in the United States for research by small firms on new technologies, and the National Institutes of Health (NIH) is a major contributor to

that funding agenda. Although previous research has explored the determinants of research success for NIH SBIR projects, little is known about the determinants of project failure. This paper provides important, new evidence on the characteristics of NIH SBIR projects that fail. Specifically, we find that firms that have a founder with a business background are less likely to have their funded projects fail. We also find, after controlling for the endogenous nature of woman-owned firms, that such firms are also less likely to fail.

44. Audretsch, David B., Albert N. Link, and John T. Scott. 2002. "Public/Private Technology Partnerships: Evaluating SBIR-Supported Research." *Research Policy* 31, no. 1 (January): 145-158. https://doi.org/10.1016/S0048-7333(00)00158-X

    This paper evaluates public support of private-sector research and development (R&D) through the Department of Defense's (DOD's), Small Business Innovation Research (SBIR) Program. Based on alternative evaluation methods applicable to survey data and case studies, we conclude that there is ample evidence that the DOD's SBIR Program is stimulating R&D as well as efforts to commercialize that would not otherwise have taken place. Further, the evidence shows the SBIR R&D does lead to commercialization, and the net social benefits associated with the program's sponsored research are substantial.

45. DOD. 2018. *National Economic Impacts from the DOD SBIR/STTR Program 1995–2018*. https://www.sbir.gov/sites/default/files/DOD_SBIR%20Economic%20Impacts_1995-2018_03OCT19_releasedbyDOPSR_upload_SBIR_16OCT19.pdf

    The Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs are the U.S. government's primary mechanism for engaging small technology businesses in research and development (R&D) to benefit the nation. The Department of Defense (DoD) accounts for approximately 50 percent of all federal SBIR/STTR funds. This study quantifies the DoD SBIR/STTR Program's overall contribution to the nation's economy and defense mission. It examines the economic outcomes and impacts up to 2018 from DoD SBIR/STTR Phase II contracts initiated during the 1995 2012 fiscal year (FY) period, providing definitive answers to the question: What resulted from the DoD's investment of $14.4 billion in small business R&D funding provided to companies nationwide via 16,959 separate SBIR/STTR Phase II contracts?

46. Howell, Sabrina T. 2017. "Financing Innovation: Evidence from R&D Grants." *American Economic Review* 107, no.4 (April): 1136-1164. https://www.aeaweb.org/articles?id=10.1257/aer.20150808

    Governments regularly subsidize new ventures to spur innovation. This paper conducts the first large-sample, quasi-experimental evaluation of R&D subsidies. I use data on ranked applicants to the US Department of Energy's SBIR grant program. An early-stage award approximately doubles the probability that a firm receives subsequent venture capital and has large, positive impacts on patenting and revenue. These effects are stronger for more financially constrained firms. Certification, where the award contains information about firm quality, likely does not explain the grant effect. Instead, the grants are useful because they fund technology prototyping.

47. Joshi, Amol M., Todd M. Inouye, and Jeffrey A. Robinson. 2017. "How Does Agency Workforce Diversity Influence Federal R&D Funding of Minority and Women Technology Entrepreneurs? An analysis of the SBIR and STTR Programs, 2001–2011." *Small Business Economics* 50, no. 3 (June): 499-519. https://link.springer.com/article/10.1007/s11187-017-9882-6.

    U.S. Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs provide Federal research and development (R&D) grants to technology ventures. We explore how grantor demographic diversity explains why demographically diverse grantees experience different odds for successfully transitioning from initial to follow-on R&D grants. We find a positive association between agency workforce diversity and Phase II funding for Phase I grantees, but minority and women technology entrepreneurs are less likely to receive this funding than their non-minority and male counterparts. Agencies valuing workforce ethnic diversity or leveraging gender homophily positively influence the likelihood of women technology entrepreneurs obtaining Phase II funding. We discuss evidence-based implications for policy and practice.

48. Lanahan, Lauren. 2016. "Multilevel public funding for small business innovation: a review of US state SBIR match programs." *The Journal of Technology Transfer* 41, no. 2: 220-249.

    US State governments invest in early-stage innovative activity as an economic development strategy. Nevertheless, attention directed at the public sector's role in this capacity has been placed on federal policy actions overlooking the growing role of states. The primary aims of this paper are two-fold: (1) to articulate the motivations for multilevel public support for small business innovative activity, placing emphasis on state level incentives directed towards entrepreneurial activity; and (2) to empirically evaluate the State Match Phase I (SMP-I) program. The SMP-I program is a diffuse state level policy designed to complement the federal Small Business Innovation Research (SBIR) program by offering noncompetitive matching funds to the state's successful SBIR Phase I recipients. This offers an opportunity to examine the marginal impact of public R&D given the state intervention. This paper employs a state and year fixed effects model and considers two outcome variables—SBIR Phase II success rates and SBIR Phase I application activity. To account for industrial heterogeneity, the data are stratified by the federal mission agencies. Results from the empirical analysis indicate that the state match increases the Phase II success rates for firms participating in the National Science Foundation SBIR program.

49. Link, Albert N., and John T. Scott. 2010. "Government as Entrepreneur: Evaluating the Commercialization Success of SBIR Projects." *Research Policy* 39, no. 5 (June): 589-601. https://doi.org/10.1016/j.respol.2010.02.006

Thinking of government as entrepreneur is a unique lens through which to view a subset of government actions. We argue that the innovative action of government – the innovative use of public resources through the SBIR program to target and support research in small firms – does lessen innovation barriers that cause small firms to underinvest in R&D. We quantify the uncertainty that the government accepts in the context of innovation supported by the SBIR program; or stated alternatively, we quantify the probability that a project funded by the SBIR program will fail to commercialize its results. Our empirical results show that the entrepreneurial risk that characterizes the SBIR program is, on average, somewhat more than the probability of failing to get heads on the toss of a fair coin. Importantly, however, our evidence shows that there is a large range in the entrepreneurial risk that the government accepts.

50. Link, Albert N., and John T. Scott. 2018. "Toward an Assessment of the US Small Business Innovation Research Program at the National Institutes of Health." *Science and Public Policy* 45, no. 1 (February): 83-91. https://doi.org/10.1093/scipol/scx049

The Small Business Innovation Development Act of 1982, which established the Small Business Innovation Research (SBIR) program, is arguably the hallmark policy initiative in USA to support technology development and commercialization in small firms. While scholars have studied this program in detail, there has yet to be a systematic assessment of how well it is meeting its legislated goals of stimulating technological innovation and increasing private sector commercialization. We use a unique set of data on projects funded by the National Institutes of Health (NIH) SBIR program to assess the extent to which these program goals are being met. We find that, relative to a counterfactual control group, NIH can be characterized as supporting, on average, the development of high commercialization risk technologies, and we suggest that this finding aligns with the goals of the SBIR program and may in fact be for the common wealth.

51. Link, Albert N. and Christopher J. Ruhm. 2009. "Bringing Science to Market: Commercializing from NIH SBIR Awards." *Economics of Innovation and New Technology* 18, no. 4 (May): 381-402. https://doi.org/10.1080/10438590802208166.

We offer empirical information on the correlates of commercialization activity for research projects funded through the US National Institutes of Health's (NIH's) Small Business Innovation Research (SBIR) award program. Based on this analysis we suggest possible recommendations for improving this aspect of the performance of NIH's SBIR program. We find that additional developmental funding from non-SBIR federal sources and from own internal sources are important predictors of commercialization success, relatively more so than additional developmental funding from venture capitalists. We also find, among other things, that university involvement in the underlying research increases the probability of commercialization. Thus, these factors should be considered by NIH when making awards, if increased commercialization is an objective.

52. Link, Albert N., Christopher J. Ruhm, and Donald S. Siegel. 2013. "Private Equity and Innovation Strategies of Entrepreneurial Firms: Empirical Evidence from the Small Business Innovation Research Program." *Managerial and Decision Economics* 35, no. 2 (September). https://doi.org/10.1002/mde.2648.

    There is great interest in evaluating the impact of private equity investments on innovation and economic growth. However, there is no direct empirical evidence on the effects of such transactions on the innovation strategies of entrepreneurial firms. We fill this gap by examining a rich project-level data set consisting of entrepreneurial firms receiving Small Business Innovation Research (SBIR) program research awards. We find that SBIR firms attracting private equity investments are significantly more likely to license and sell their technology rights and engage in collaborative research and development agreements. Our results suggest that private equity investments accelerate the development and commercialization of research-based technologies, thus contributing to economic growth.

53. NASA. 2012. *SBIR/STTR Economic Impact Report*. NASA Small Business Innovation Research. https://www.sbir.gov/sites/default/files/NASA%20SBIR-STTR%20Economic%20Impact%20Study%202012.pdf

    The National Aeronautics and Space Administration's (NASA) Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs are highly competitive threephase award programs, which provide qualified small business concerns (SBCs) with opportunities to propose and develop innovative ideas that meet the specific research and development needs of the Federal Government. Specific technological research areas funded typically address the future mission needs of NASA's Mission Directorates – Science, Aeronautics Research, Human Exploration and Operations, and Space Technology. This study estimates the national economic and fiscal impact of NASA SBIR/STTR investments into the program's SBCs using the standard practice of input-output modeling. The time frame covered for this analysis was the fiscal year ending in September 2012. For purposes of this study, NASA's SBIR and STTR programs' economic impact derives from the annual research and development operations, which was undertaken by the programs' small business concerns during the fiscal year. In total, NASA SBIR and STTR small businesses received a total of $158,480,892.23 ($139,950,422.96 allocated to SBIR participating small businesses and $18,530,469.27 allocated to STTR participating small businesses) for the development of R&D technologies.

54. NASEM. 2008. *An Assessment of the SBIR Program at the Department of Energy*. The National Academies Press: Washington, DC. https://www.nap.edu/read/12052/chapter/1

The Small Business Innovation Research (SBIR) program is one of the largest examples of U.S. public-private partnerships. Founded in 1982, SBIR was designed to encourage small business to develop new processes and products and to provide quality research in support of the many missions of the U.S. government, including health, energy, the environment, and national defense. In response to a request from the U.S. Congress, the National Research Council assessed SBIR as administered by the five federal agencies that together make up 96 percent of program expenditures. This book, one of six in the series, reports on the SBIR program at the Department of Energy. It finds that, in spite of resource constraints, the DoE has made significant progress in meeting the legislative objectives of SBIR and that the program is effectively addressing the mission of the Department of Energy. The book documents the achievements and challenges of the program and recommends programmatic changes to make the SBIR program even more effective in achieving its legislative goals.

55. NASEM. 2009. *Venture Funding and the NIH SBIR Program*. The National Academies Press: Washington, DC. https://www.nap.edu/read/12543/chapter/1

The Small Business Administration issued a policy directive in 2002, the effect of which has been to exclude innovative small firms in which venture capital firms have a controlling interest from the SBIR program. This book seeks to illuminate the consequences of the SBA ruling excluding majority-owned venture capital firms from participation in SBIR projects.

56. NASEM. 2009. *Revisting the Department of Defense SBIR Fast Track Initiative*. The National Academies Press: Washington, DC. https://www.nap.edu/read/12600/chapter/1

In October 1995, the Department of Defense launched a Fast Track initiative to attract new firms and encourage commercialization of Small Business Innovation Research (SBIR) funded technologies throughout the department. The goal of the Fast Track initiative is to help close the funding gap that can occur between Phase I and II of the SBIR program. The Fast Track initiative seeks to address the gap by providing expedited review and essentially continuous funding from Phase I to Phase II, as long as applying firms can demonstrate that they have obtained third-party financing for their technology. Another program initiative, Phase II Enhancement, was launched in 1999 to concentrate SBIR funds on those R&D projects most likely to result in viable new products that the Department of Defense and others will buy.

57. NASEM. 2009. *An Assessment of the SBIR Program at NASA*. The National Academies Press: Washington, DC. https://www.nap.edu/read/12441/chapter/1

The Small Business Innovation Research (SBIR) program is one of the largest examples of U.S. public-private partnerships. Founded in 1982, SBIR was designed to encourage small business to develop new processes and products and to provide quality research in support of the many missions of the U.S. government, including health, energy, the environment, and national defense. In response to a request from the U.S. Congress, the National Research Council assessed SBIR as administered by the five federal agencies that together make up 96 percent of program expenditures. This book, one of six in the series, reports on the SBIR program at the National Aeronautics and Space Administration, and finds that the program is making significant progress in achieving the Congressional goals for the program. Keeping in mind NASA's unique mission and the recent significant changes to the program, the committee found the SBIR program to be sound in concept and effective in practice at NASA.. The book recommends programmatic changes that should make the SBIR program even more effective in achieving its legislative goals.

58. NASEM. 2009. *An Assessment of the SBIR Program at the Department of Defense*. The National Academies Press: Washington, DC. https://www.nap.edu/read/11963/chapter/1

    The SBIR program allocates 2.5 percent of 11 federal agencies' extramural R&D budgets to fund R&D projects by small businesses, providing approximately $2 billion annually in competitive awards. At the request of Congress, the National Academies conducted a comprehensive study of how the SBIR program has stimulated technological innovation and used small businesses to meet federal research and development needs. Drawing substantially on new data collection, this book examines the SBIR program at the Department of Defense and makes recommendations for improvements. Separate reports will assess the SBIR program at NSF, NIH, DOE, and NASA, respectively, along with a comprehensive report on the entire program.

59. NCI. 2019. *National Economic Impacts 1998–2018*. U.S. Department of Health and Human Services, National Institutes of Health. https://sbir.cancer.gov/sites/default/files/documents/NCI_SBIR_ImpactStudy_FullReport_2018.pdf

    The study examined the economic outcomes and impacts leading up to 2018 from all NCI SBIR/STTR Phase II awards initiated from FY 1998 to FY 2010. A total of 444 companies received Phase II funding for 690 separate projects over the period. Of the 690 awards, 368 (53%) resulted in sales and many of the newer awards have not yet resulted in sales. Total cumulative sales were $9.1 billion, which equates to average sales of approximately $24.8 million for each of the 368 awards.

60. U.S. Air Force. 2014. *2014 Economic Impact Study*. The Air Force SBIR/STTR Program. https://www.sbir.gov/sites/default/files/USAF%20SBIR-STTR%20Economic%20Impact%20Study%20FY2015.pdf

    This study was undertaken to quantify the Air Force SBIR/STTR Program's overall contribution to the national economy and nation's defense mission.1 The study examined the economic outcomes and impacts from all Air Force SBIR/STTR Phase II awards completed during the 2000-2013 period. It was intended to answer the following basic question: What resulted from the Air Force's SBIR/STTR research and development (R&D) investment of nearly $4 billion, provided to 1,750 companies in 4,524 separate SBIR/STTR contracts?

61. U.S. Navy. 2013. *National Economic Impacts from the Navy SBIR/STTR Program, 2000-2013*. https://www.sbir.gov/sites/default/files/NAVY%20SBIR-STTR%20National%20Economic%20Impacts%202000%20-%202013.pdf

The Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs are the U.S. government's primary way of encouraging and supporting research and development (R&D) in the nation's technology-focused small business community. The Navy accounts for approximately 12 percent of all federal SBIR/STTR funds. This study quantifies the Navy SBIR/STTR Program's overall contribution to the nation's economy and defense mission. It examines the economic outcomes and impacts from all Navy SBIR/STTR Phase II awards completed during the fiscal year (FY) 2000-2013 period, providing definitive answers to the question: What resulted from the Navy's SBIR/STTR investment of nearly $2.3 billion, provided to companies nationwide in 2,734 separate SBIR/STTR contracts?

F. Collaborative Research Agreements

62. Adams, James D., Eric P. Chiang, and Jeffrey L. Jensen. 2003. "The influence of federal laboratory R&D on industrial research." *Review of Economics and Statistics* 85, no. 4: 1003-1020.

This paper studies the influence of R&D in the U.S. federal laboratory system, the world's largest, on firm research. Our results are based on a sample of 220 industrial research laboratories that work with a variety of federal laboratories and agencies and are owned by 115 firms in the chemicals, machinery, electrical equipment, and motor vehicles industries. Using an indicator of their importance to R&D managers, we find that cooperative research and development agreements (CRADAs) dominate other channels of technology transfer from federal laboratories to firms. With a CRADA industry laboratories patent more, spend more on company-financed R&D, and devote more resources to their federal counterparts. Without this influence, patenting stays about the same, and only federally funded R&D increases, mostly because of government support. The Stevenson-Wydler Act and amendments during the 1980s introduced CRADAs, which legally bind federal laboratories and firms together in joint research. In theory the agreements could capitalize on complementarities between public and private research. Our results support this perspective and suggest that CRADAs may be more beneficial to firms than other interactions with federal laboratories, precisely because of the mutual effort that they demand from both parties.

63. Albats, E., I. Fiegenbaum, and J. A. Cunningham. 2018. “A micro level study of university industry collaborative lifecycle key performance indicators.” *Journal of Technology Transfer* no. 43 (2):389-431. doi: 10.1007/s10961-017-9555-2.

The assessment of university-industry collaborative projects has been complex and has become more prevalent in national research, educational and innovation system reviews. One criticism made about studies of university-industry collaboration (UIC) is they are too much orientated towards exclusively the outputs (Rossi and Rosli in Stud High Educ 40(10):1970-1991, 2015) and that there is a need to apply case specific metrics. To address this criticism we have taken Brown et al's Res Technol Manag 31(4):11-15, (1988) R&D lifecycle of inputs, in-process activities, outputs and impact at micro level to examine what are the common and context specific key performance indicators of UIC. Taking a qualitative approach and using university-industry collaborative projects set in Finland and Russia our study identified a common set of micro level KPIs across the UIC lifecycle at a micro level. Namely, the amount of resources allocated by partners to collaboration; efficiency of collaboration management and clearly defined roles; as well as a number of company innovations resulting from collaboration with a university and new strategic partnerships. Our study also found contextual micro level KPIs as number of young researchers involved, fit between collaboration and organizational strategy; number of joint publications; enterprise image improvements. Our research extends the existing knowledge on UIC KPIs in the following ways. First, we define those KPIs, which are applicable by all the three actors of the triple helix, but also identify those that are not used by some of these actors. Second, we analyse the relevance of certain KPIs proposed by governmental bodies and the literature in terms of their applicability in the analysed case studies. Finally, we define those metrics, which among other existing KPIs depend on the case context (region, research area, industrial sector and partners' goals) as well as identify additional KPIs, which have not received attention in UIC literature.

64. Carayannis, Elias, Manlio Del Giudice, and Maria Rosaria Della Peruta. 2014. "Managing the intellectual capital within government-university-industry R&D partnerships: A framework for the engineering research centers." *Journal of Intellectual Capital* 15, no. 4: 611-630.

Purpose – As the complexity and scope of technical and social challenges increase, solutions to those challenges must be addressed by collaborative research and intellectual capital sharing efforts involving multiple organizations. One prominent type of research collaborative is the government university-industry R&D partnership, an organizational form found in many countries. These collaboratives pose special management challenges, as they must combine the efforts of researchers coming from very different institutional and organizational cultures in order to capitalize their own intellectual capital. Many such partnerships have failed due to the inability to bridge these cultural gaps. The purpose of this paper is to propose a framework for establishing and managing these partnerships, using principles and constructs drawn from institutional theory, organizational learning, alliance theory, and innovation management. Design/methodology/approach – The examples of the NASA Laboratories, which are incubating several companies, are analyzed to show how this framework can highlight key attributes of successful research collaboratives. Findings – The recurring pattern from these diverse case studies shows that the presence of internal and external champions, appropriate technology, and patient risk capital make a difference in winning in a competitive environment. However, part of the same pattern perhaps is the lack of any identifiable recipes for success - critical factors appear to be situation specific. Originality/value – In light of the findings from the seven case studies the authors presented, they recommend using a hybrid portfolio approach in assessing the success of technology transfer and commercialization efforts.

65. Chen, ChuChu, Albert N. Link, and Zachary T. Oliver. 2018. "U.S. Federal Laboratories and their Research Partners: A Quantitative Case Study." *Scientometrics* 115, no. 1: 501-517. https://doi.org/10.1007/s11192-018-2665-2

    The Stevenson–Wydler Technology Innovation Act of 1980 made explicit the technology transfer responsibilities of U.S. Federal laboratories. The Federal Technology Transfer Act of 1986 and the National Competitiveness Technology Transfer Act of 1989 further enhanced the technology transfer activities of laboratories by permitting Cooperative Research and Development Agreements (CRADAs). However, very little is known about the characteristics of CRADA activity in Federal laboratories. Using a new, robust dataset of CRADA activity at the National Institute of Standards and Technology (NIST), we describe research partnerships over the years 1978 through 2014, and we explore several research questions. When did the Federal Technology Transfer Act have an impact on CRADA activity at NIST? Is CRADA activity at NIST a cyclical phenomenon? At what frequency do private sector establishments engage in CRADA activity with NIST? We find suggestive evidence that the Federal Technology Transfer Act began to influence NIST's CRADA activity within 2–3 years after its passage, and we find that CRADA activity moves with the business cycle. We also find that most establishments that were engaged in CRADA activity were engaged only once over this time period; it was only the larger establishments that continued to engage in CRADAs with NIST. We speculate about the implications of these findings, and we suggest a broader research agenda into CRADA activity in Federal laboratories.

66. Fernandes, Gabriela, Eduardo B. Pinto, Madalena Araújo, Pedro Magalhães, and Ricardo J. Machado. 2017. "A Method for Measuring the Success of Collaborative University-Industry R&D Funded Contracts." *Procedia Computer Science* no. 121:451-460. doi: https://doi.org/10.1016/j.procs.2017.11.061.

    This paper describes a method specially devoted to quantitatively measure the success of collaborative university-industry R&D funded contracts, which could

be managed as a singular project or a program of projects. The method aims to measure the success throughout the program/project lifecycle, combining both retrospective (lagging) and prospective (leading) performance indicators. The method uses tangible/specific outcomes as performance indicators, like patents or publications, as well as intangible/subjective performance indicators such as social relationships, organizational arrangements or motivations. The proposed method was conceived by conducting a thorough review of the published literature on this area, and by analyzing, as case studies, two consecutive R&D collaborative funded programs, between University of Minho and Bosch Car Mutimedia, amounting to an overall investment of over 70 million Euros, from 2012 to 2018.

67. Olmos-Peñuela, Julia, Jordi Molas-Gallart, and Elena Castro-Martínez. 2013. "Informal collaborations between social sciences and humanities researchers and non-academic partners." *Science and Public Policy* no. 41 (4):493-506. doi: 10.1093/scipol/sct075.

The analysis of how research contributes to society typically focuses on the study of those transactions that are mediated through formal legal instruments (research contracts, patent licensing and the creation of companies). Research has shown, however, that informal means of technology transfer are also important. This paper explores the importance of informal collaborations and provides evidence of the extent to which informal collaborations between researchers and non-academic partners take place informally in the social sciences and humanities (SSH). Data is obtained from two studies on knowledge exchange involving researchers working in the SSH area of the Spanish Council for Scientific Research. We show that informal collaborations not officially recorded by the organisation are much more common than formal agreements and that many collaborations remain informal over time. We explore the causes of such prevalence of informality and discuss its policy implications.

68. Perkmann, M., and K. Walsh. 2009. "The two faces of collaboration: impacts of university-industry relations on public research." *Industrial and Corporate Change* no. 18 (6):1033-1065. doi: 10.1093/icc/dtp015.

We analyze the impact of university-industry relationships on public research. Our inductive study of university-industry collaboration in engineering suggests that basic projects are more likely to yield academically valuable knowledge than applied projects. However, applied projects show higher degrees of partner interdependence and therefore enable exploratory learning by academics, leading to new ideas and projects. This result holds especially for research-oriented academics working in the "sciences of the artificial" and engaging in multiple relationships with industry. Our learning-centered interpretation qualifies the notion of entrepreneurial science as a driver of applied university-industry collaboration. We conclude with implications for science and technology policy.

69. Rossi, Federica, Ainurul Rosli, and Nick Yip. 2017. "Academic engagement as knowledge co-production and implications for impact: Evidence from Knowledge Transfer Partnerships." Journal of Business Research no. 80:1-9. doi: https://doi.org/10.1016/j.jbusres.2017.06.019.

Researchers have argued that management academics' engagement with non-academic stakeholders involves knowledge co-production rather than simple knowledge transfer from the former to the latter. This study suggests that the conceptual lens of knowledge co-production not only more fittingly describes academic engagement but also enables a clearer understanding of how academic engagement produces impact beyond academia. Building upon qualitative evidence on collaborations between management academics and businesses in the United Kingdom, the study supports the characterisation of academic engagement as knowledge co-production and argues that its impact (i) strongly depends on sustained knowledge co-producing interactions, (ii) 'ripples out' serendipitously, indirectly benefiting many stakeholders in ways that often cannot be anticipated, and (iii) unfolds and persists over a long period. These findings have implications for impact assessment and the development of the impact research agenda.

G. Other Publications

1. Input-Output Model

70. Pressman, Lori, Mark Planting, Robert Yuskavage, Jennifer Bond, and Carol Moylan. 2018. "A Preliminary Application of an I-O Economic Impact Model to US Federal Laboratory Inventions: 2008-2015." Prepared for the National Institute of Standards and Technology, July 2018. https://www.nist.gov/sites/default/files/documents/2018/09/20/prelimappioeconimpactmodelfedlabinventions2008-2015.pdf

An input-output "I-O" approach was used to estimate the economic impact of federal laboratory1 "FL" licensing under two different sets of assumptions. The assumptions are described and preliminary estimates provided. Under a first set of assumptions called Rev 1, and summing over 8 years of data from 2008-2015, the total contribution of these federal laboratory licensors to industry gross output ranges from $23.1 billion to $76.5 billion in 2009 U.S. dollars; contributions to gross domestic product (GDP) range from $10.6 billion to $34.6 billion in 2009 U.S. dollars. Estimates of the total number of person years of employment supported range from 73,000 to 215,000 over the eight-year period. Under a second set of assumptions called Rev 2, and summing over the same 8 years of data from 2008-2015, the total contribution of these federal laboratory licensors to industry gross output ranges from $25 billion to $83.6 billion in 2009 U.S. dollars; contributions to GDP range from $12.5 billion to $41.3 billion to in 2009 U.S. dollars. Estimates of the total number of person years of employment supported range from 86,000 to 265,000 over the eight-year period. Background on how the I-O approach to estimating the economic impact of nonprofit licensing

came to be developed is provided, along with an overview of how it has evolved since. Obtaining better information on i) the location of the production of the royalty generating licensed products, ii) the total sales of the licensed products to the federal government which may not generate earned royalties and thus are not visible using the approach described here and on iii) the industries that characterize the licensed products, should lead to more accurate estimates, particularly when they are disaggregated by federal laboratory. It will also be helpful to account for double counting, if any, and to have either systematic weighted average royalty rate information so earned royalty income can reliably be used to estimate sales, or preferably actual cumulative product sales information.

71. Pressman, Lori, Mark Planting, Robert Yuskavage, Sumiye Okubo, Carol Moylan, and Jennifer Bond. 2017. "The Economic Contribution of University/Nonprofit Inventions in the United States: 1996-2015." Prepared for the Biotechnology Innovation Organization and the Association of University Technology Managers, June 2017. https://www.bio.org/sites/default/files/June%202017%20Update%20of%20I-O%20%20Economic%20Impact%20Model.pdf

Using an input-output "I-O" approach to estimating the economic impact of academic licensing and summing that impact over 20 years of available data for academic U.S. Association of University Technology Managers (AUTM) Survey respondents, the total contribution of these academic licensors to industry gross output ranges from $320 billion to $1.33 trillion, in 2009 U.S. dollars; and contributions to gross domestic product (GDP) range from $148 billion to $591 billion, in 2009 U.S. dollars. Estimates of the total number of person years of employment supported by U.S. universities' and hospitals' and research institutes' licensed-product sales range from 1.268 million to over 4.272 million over the 20-year period. An explanation of the I-O approach is provided, and the assumptions used and the potential effects of the assumptions on the estimates are discussed. AUTM associated contributions to GDP, calculated using the I-O approach, are compared with U.S. GDP as a whole, and to selected industry, as defined by North American Industry Classification System (NAICS) codes, contributions to GDP. Factors affecting the AUTM contributions to GDP appear to differ from those affecting U.S. GDP as a whole, as well as from those affecting selected NAICS industry contributions to GDP.

2. Studies Using Patents and Licenses

72. Ahmadpoor, M., and B. F. Jones. 2017. "The dual frontier: Patented inventions and prior scientific advance." *Science* no. 357 (6351):583-587. doi: 10.1126/science.aam9527.

The extent to which scientific advances support marketplace inventions is largely unknown. We study 4.8 million U.S. patents and 32 million research articles to determine the minimum citation distance between patented inventions and prior scientific advances. We find that most cited research articles (80%) link forward to a future patent. Similarly, most patents (61%) link backward to a prior research article. Linked papers and patents typically stand 2 to 4 degrees distant from the other domain. Yet, advances directly along the patent-paper boundary are notably more impactful within their own domains. The distance metric further provides a typology of the fields, institutions, and individuals involved in science-to-technology linkages. Overall, the findings are consistent with theories that emphasize substantial and fruitful connections between patenting and prior scientific inquiry.

73. Anderson, G. W., and A. Breitzman. 2017. "Identifying NIST Impacts on Patenting: A Novel Data Set and Potential Uses." *Journal of Research of the National Institute of Standards and Technology* no. 122:1-16. doi: 10.6028/jres.122.013.
The National Institute of Standards and Technology's (NIST's) mission is to "promote U. S. innovation and industrial competitiveness." To meet this mission, NIST scientists produce a great variety of scientific and technical outputs. This paper presents results from a novel effort to measure usage and impact of a more complete set of outputs, including patents, publications, research data, software, reference materials, and a variety of additional formal and informal scientific outputs. This effort captures a significantly broader set of scientific outputs than traditional citation analysis which typically examines patent-to-patent citations or more recently patent-to-(peer-reviewed) paper citations. This may be of significant importance to NIST as NIST scientists produce a wide variety of scientific and technical outputs beyond patents and papers. Our results indicate that metrics that solely rely on patents issued to NIST inventors understate NIST's true impact on invention and do not capture usage of much of NIST's scientific output by other inventors. Thus, identifying the magnitude and varied usage of different types of NIST outputs represents a significant improvement in NIST impact metrics. The results clearly indicate that different companies, industries and technologies rely on different types of NIST outputs. Therefore, reliance on a limited set of technology transfer tools by either researchers or policy makers creates a risk that NIST knowledge and capabilities will not be transferred to and adopted by businesses and other organizations. Finally, the data developed here suggest a number of new technology transfer metrics that promote shared technology transfer responsibilities and may focus attention on activities that increase the impact of current research without fundamentally altering the infrastructural character of this research.

74. Belderbos, Rene, Bruno Cassiman, Dries Faems, Bart Leten, and Bart Van Looy. 2014. "Co-ownership of intellectual property: Exploring the value-appropriation and value-creation implications of co-patenting with different partners." *Research policy* 43, no. 5: 841-852.

Combining both interview data and empirical analyses at the patent and firm levels, we explore the value-appropriation and value-creation implications of R&D collaboration resulting in the co-ownership of intellectual property (i.e. co-patents). We make an explicit distinction between three different types of co-patenting partners: intra-industry partners, inter-industry partners, and universities. Our findings indicate that the value-appropriation challenges of IP sharing are clearly evident with intra-industry co-patenting, where partners are more likely to encounter overlapping exploitation domains. Co-patenting with universities is associated with higher market value, since appropriation challenges are unlikely to play a role and collaboration may signal novel technological opportunities. Although we find some evidence that co-patenting corresponds to higher (patent) value, patents co-owned with firms are significantly less likely to receive self-citations, indicating constraints on the future exploitation and development of co-owned technologies.

75. Chan, G. 2015. "The commercialization of publicly funded science: How licensing federal laboratory inventions affects knowledge spillovers." Essays on Energy Technology Innovation Policy. Doctoral Dissertation, Harvard University. http://nrs. harvard.edu/urn-3: HUL. InstRepos 17467190.

The U.S. federal government invests $126 billion per year in research and development (R&D), 40% of which is allocated to R&D centers it exclusively funds. For over thirty years national policy has required inventions discovered in federally funded R&D centers to be transferred to the private sector to diffuse knowledge and to promote private sector follow-on innovation, but there is limited empirical evidence for whether these policies have worked. I quantify the effect of technology transfer on innovation spillovers in the context of patent licensing at the U.S. National Laboratories using data on over 800 licensed patents since 2000. I demonstrate that licensing increases the annual citation rate to a patent by 20-37%, beginning two years after a license agreement is executed. I find that over 80% of follow-on innovation after a patent is licensed occurs outside of the licensing firm, indicating that knowledge from licensing diffuses broadly. These estimates rely on a novel matching algorithm based on statistical classification of the text of patent abstracts. I explore possible mechanisms for the effect of licensing on knowledge diffusion by examining the quality of patents that cite licensed patents and rule out the possibility of a strong strategic patenting effect. These results demonstrate that transactions over formal intellectual property enhance the benefits of publicly funded R&D in the “market for ideas.

76. Corredoira, Rafael A., Brent D. Goldfarb, and Yuan Shi. 2018. "Federal funding and the rate and direction of inventive activity." *Research Policy* 47, no. 9: 1777-1800.

Leveraging a new measure of patent citation trees (Corredoira and Banerjee, 2015), we demonstrate that research funded by the federal government is associated with more active and diverse technological trajectories. Our findings tie government funding to breakthrough inventions. The differences are especially

evident at the upper percentiles of the distribution of long term patent influence and stem primarily from research conducted outside the federal government and sponsored by the DOD, HHS and NSF. Government funded patents are inputs into a broader range of technologies. Additional analyses indicate that federal programs invest in some technological areas that private corporations eschew, and federally funded university patents are in different technological classes than non-federally funded university patents. In this sense, the government may play an irreplaceable role in the rate and direction of inventive activity.

77. Drivas, Kyriakos, Claire Economidou, Dimitris Karamanis, and Arleen Zank. 2016. "Academic patents and technology transfer." *Journal of engineering and technology management* 40: 45-63.

This paper exploits a particular facet of the US patent system, which thus far has been overlooked in the literature: The patent renewal fee scheme relating to switches from small to large entity status. Based on this observation, we are able to determine whether university patents are licensed over their enforceable lifecycle and at what point in time the licensing occurs. We find that while the funding source of patented inventions makes no difference to the propensity of an academic patent being licensed, federally sponsored patents are less likely to be licensed early compared to their non-federally funded counterparts.

78. Hall, Bronwyn H., & Ziedonis, Rosemarie. H. 2001. "The Patent Paradox Revisited: An Empirical Study of Patenting in the US Semiconductor Industry, 1979-1995," *RAND Journal of Economics*, 101-128.

We examine the patenting behavior of firms in an industry characterized by rapid technological change and cumulative innovation. Recent survey evidence suggests that semiconductor firms do not rely heavily on patents to appropriate returns to R&D. Yet the propensity of semiconductor firms to patent has risen dramatically since the mid- 1980s. We explore this apparent paradox by conducting interviews with industry rep- resentatives and analyzing the patenting behavior of 95 U.S. semiconductor firms during 1979-1995. The results suggest that the 1980s strengthening of U.S. patent rights spawned "patent portfolio races" among capital-intensive firms, but it also fa- cilitated entry by specialized design firms.

79. Heisey, P. W., and S. W. Adelman. 2011. "Research expenditures, technology transfer activity, and university licensing revenue." *Journal of Technology Transfer* no. 36 (1):38-60. doi: 10.1007/s10961-009-9129-z.

In this paper we relate university licensing revenues to both university research expenditures and characteristics of the university and the university technology transfer office. We apply the Hausman-Taylor estimator for panel data with timeinvariant explanatory variables and the Arellano-Bover dynamic panel model to unbalanced panels for the years 1991-2003 and balanced panels for the years 1995-2003. We find conflicting evidence regarding the short-term impacts of research expenditures on licensing revenues. On the other hand, both early initiation of technology transfer programs and staff size increase expected licensing revenues. Staff size and early entry appear to be substitutes, however. One-year lagged licensing revenue has strong predictive power for current licensing revenue. Further research is necessary to analyze changes in technology transfer office efficiency over time and the contribution of technology transfer to larger university missions.

80. Jaffe, Adam B., Michael S. Fogarty, and Bruce A. Banks. 1998. "Evidence from patents and patent citations on the impact of NASA and other federal labs on commercial innovation." *The Journal of Industrial Economics* 46, no. 2: 183-205.

Federal lab commercialization is explored: (1) by analyzing US government patents and (2) in a qualitative analysis of one NASA lab's patents. Tests apply to three distinct sets of patents, 1963–94: NASA, all other US government, and a random sample of all US inventors' patents. The federal patenting rate plummeted in the 1970s. Consistent with increasing commercialization, both NASA's and other federal agencies' rates recovered in the 1980s. The case study finds citations to be a valid but noisy measure of technology spillovers. Excluding 'spurious' cites, two-thirds of cites to patents of NASA-Lewis' Electro-Physics Branch were evaluated as involving spillovers.

81. Jaffe, Adam B., and Josh Lerner. 2001. "Reinventing public R&D: Patent policy and the commercialization of national laboratory technologies." *RAND Journal of Economics*: 167-198.

Despite their magnitude and potential impact, federal R&D expenditures outside of research universities have attracted little economic scrutiny. We examine the initiatives since 1980 to encourage patenting and technology transfer at the national laboratories. Both field and empirical research challenges the conventional picture of bleak failure. The policy changes had a substantial impact on the laboratories' patenting: they have gradually reached parity in patents per R&D dollar with research universities. Unlike universities, laboratory patent quality has remained constant or even increased despite this growth. Success is associated with avoiding technological diversification and with having a university as lab manager.

82. Jeong, Seongkyoon, and Sungki Lee. 2015. "Strategic timing of academic commercialism: evidence from technology transfer." *The Journal of Technology Transfer* 40, no. 6: 910-931.

While the markets for technology have received considerable attention because of the contribution to management and economy, universities and government research institutes have risen as important providers of technology. Their early licensing agreements may contribute to enhancing the licensor's productivity, the licensee's competency, and the efficiency of national innovation system. However, later licensing agreements enhance the licensor's bargaining power. Thus, the timing of licensing is not only a policy consideration at the national level but also a key strategic consideration at the R&D entity level. We first theoretically claim that the ability to "invent around" determines the impact of uncertainty attenuation on the timing of licensing on the condition of market friction. Based on this claim, the paper argues that technology transfers from public research organizations differ from inter-firm licensing transactions in regard to their timing patterns. Using the data of commercialization activity through national R&D programs in South Korea, we empirically find that resolving uncertainties rather delays the licensing time for technology transfers, as opposed to inter-firm transactions. In addition, our findings provide evidence of frictions related to search costs associated with the unique nature of R&D processes in public research organizations.

83. Kim, Jisun, and Tugrul U. Daim. 2014. "A new approach to measuring time-lags in technology licensing: study of US academic research institutions." *The Journal of Technology Transfer* 39, no. 5: 748-773.

This paper contributes to measurement of licensing performance of U.S. research institutions by suggesting an approach for identifying time-lags in the licensing process. Licensing is a multi-state process starting with a disclosure, and resulting in intermediate outcomes such as patents, licensing agreements, and licensing income. The time duration among these variables is critical in understanding which investment is responsible for which outcome. This study develops a statistic procedure estimating time-lag coefficients among licensing variables using an unstructured regression model (OLS). The procedure is applied to 46 U.S. academic research institutions using the licensing survey data from 1991 to 2007 by Association of University Technology Manager. The results present individual time-lag relationships between each pair of licensing variables.

84. Laplume, André O., Emanuel Xavier-Oliveira, Parshotam Dass, and Ramesh Thakur. 2015. "The organizational advantage in early inventing and patenting: Empirical evidence from interference proceedings." *Technovation* 43: 40-48.

Recent research suggests that individual inventors produce less valuable inventions than those operating within organizational boundaries. The current study demonstrates that organizations invent and file for patents earlier than individuals. Analyses of priority contests between competing agents reveal that public and private corporations invent faster than individual inventors, whereas public and private corporations, universities, and research institutes patent their inventions earlier than do individuals. We examine the outcomes of patent interference proceedings involving about 650 U.S. patents and patent applications occurring between 2005 and 2013. We theorize that individual inventors lack resources as well as functional and integrative capabilities needed to invent and patent as quickly as organizations. The paper offers policy-making insights and contributes quantitative-based grounds for further research into more efficient and effective intellectual property regimes.

85. Lee, Peter. 2012. “Transcending the tacit dimension: Patents, relationships, and organizational integration in technology transfer.” *Calif. L. Rev*. no. 100:1503.

As a key driver of innovation and economic growth, university-industry technology transfer has attracted significant attention. Formal technology transfer, which encompasses patenting and licensing university inventions, is often characterized as proceeding according to market principles. According to this dominant conception, patents help commodify academic inventions, which universities then advertise and transfer to private firms in licensing markets. This Article challenges and refines this market-oriented view of technology transfer. Drawing from empirical studies, it shows that effective technology transfer often involves long-term personal relationships rather than discrete market exchanges. In particular, it explores the significant role of tacit, uncodified knowledge in effectively exploiting patented academic inventions. Markets, patents, and licenses are ill-suited to transferring such tacit knowledge, leading licensees to seek direct relationships with academic inventors themselves. Drawing on the theory of the firm, this Article then explores the role of organizational integration in transferring patented technologies and associated tacit knowledge to private companies. Presenting a descriptive theory of university-industry technology transfer, it argues that the difficulties of conveying tacit knowledge encourage various forms of organizational integration by which licensees directly absorb academic human capital. From consulting arrangements to seats on boards of directors, licensees are bringing faculty inventors (and their tacit knowledge) “in house” to aid in commercialization. Turning from the descriptive to the normative, this Article provides prescriptions for enhancing tacit knowledge transmission and technology transfer. It concludes by exploring the implications of tacit knowledge for patent theory and the organization of technology commercialization efforts.

86. Link, Albert N., Donald S. Siegel, and David D. Van Fleet. 2011. "Public science and public innovation: Assessing the relationship between patenting at US National Laboratories and the Bayh-Dole Act." *Research Policy* 40, no. 8: 1094-1099.59.

Most studies of the effects of the Bayh-Dole Act have focused on universities. In contrast, we analyze patenting activity at two prominent national laboratories, Sandia National Laboratories and the National Institute of Standards and Technology before and after the enactment of this legislation and the Stevenson-Wydler Act. It appears as though the enactment of Bayh-Dole and the Stevenson-Wydler Act were not sufficient to induce an increase in patenting at these labs.

However, the establishment of financial incentive systems, embodied in passage of the Federal Technology Transfer Act, as well as the allocation of internal resources to support technology transfer, stimulated an increase in such activity.

87. Raiteri, E. 2018. A time to nourish? Evaluating the impact of public procurement on technological generality through patent data. *Research Policy*, 47(5), 936-952.

Innovative public procurement is increasingly considered as a form of public support for private innovation activities by both innovation scholars and policymakers. Economic historians have suggested an even more fundamental role of public procurement in setting the pace of technological change, reporting how defense-related procurement has had a major impact on the emergence and diffusion of many general purpose technologies developed in the United States in the 20th century. In this paper, I suggest that procurement might represent one of the most important elements in creating the right soil to 'cultivate' a technology that may have the potential to reach high levels of pervasiveness. To test this hypothesis, I make use of patent data and patent citations. I design a quasi-experiment to compare the changes in the level of generality level over time, between a group of treated and a group of control patents. A patent is assigned to the treatment group if it receives a citation from a patent related to public procurement. Results suggest a positive and significant impact of innovative public procurement on the generality of a patent.

88. Roach, M., and W. M. Cohen. 2013. "Lens or Prism? Patent Citations as a Measure of Knowledge Flows from Public Research." *Management Science* no. 59 (2):504-525. doi: 10.1287/mnsc.1120.1644.

This paper assesses the validity and accuracy of firms' backward patent citations as a measure of knowledge flows from public research by employing a newly constructed data set that matches patents to survey data at the level of the research and development lab. Using survey-based measures of the dimensions of knowledge flows, we identify sources of systematic measurement error associated with backward citations to both patent and nonpatent references. We find that patent citations reflect the codified knowledge flows from public research, but they appear to miss knowledge flows that are more private and contract based in nature, as well as those used in firm basic research. We also find that firms' patenting and citing strategies affect patent citations, making citations less indicative of knowledge flows. In addition, an illustrative analysis examining the magnitude and direction of measurement error bias suggests that measuring knowledge flows with patent citations can lead to substantial underestimation of the effect of public research on firms' innovative performance. Throughout our analyses we find that nonpatent references (e.g., journals, conferences, etc.), not the more commonly used patent references, are a better measure of knowledge originating from public research.

89. Roessner, David, Jennifer Bond, Sumiye Okubo, and Mark Planting. 2013. "The economic impact of licensed commercialized inventions originating in university research." *Research Policy* no. 42 (1):23-34. doi: https://doi.org/10.1016/j.respol.2012.04.015.

The purpose of this article is to estimate quantitatively the contribution that university licensing makes to the national U.S. economy. As regions and nations face increased economic problems, they seek ways to augment opportunities for economic growth and to identify areas where public funding can be cut. It is now well-recognized that the research university can be a significant engine of economic growth and job creation. University research and research-related activities contribute in many important ways to modern economies: notably through increased productivity of applied R&D in industry due to university-developed new knowledge and technical know-how; provision of highly valued human capital embodied in faculty and students; development of equipment and instrumentation used by industry in production and research; and creation of concepts and prototypes for new products and processes, which may have some unexpected and large social and economic impacts. Yet clear documentation of the proportional contributions these make to economic growth remains elusive. This article provides detailed estimates of the economic impact on the U.S. national economy of one core university activity – licensing of university inventions to industry. Our approach combines licensing data for U.S. universities with national input–output (I–O) model coefficients and provides more valid and complete estimates of the national economic impacts of university licensing of intellectual property than have previously been available. Our results estimate national economic impact expressed as annual increases in gross domestic product (GDP), in total industry output, and employment generated over a 15-year period. Summing over the entire 15 years for which we have data – 1996–2010, we estimate that assuming no product substitution effects and a 2–10% royalty fee, the total contribution of university licensing to gross industry output is at least \$162.1 billion and as much as \$686.9 billion (2005 dollars); estimates based on 5% royalty rates yields an estimated impact of \$293.3 billion (2005 dollars) over the period. Assuming 2% royalty fees and no product substitution effects, we estimate that over a 15-year period, university licensing agreements based on product sales contributed at least \$70.5 billion and as much as \$277.6 billion (2005 dollars) to the U.S. GDP; with a moderately conservative estimate based on 5% royalty rates, such agreements contributed more than \$122.2 billion (2005 dollars). The I–O model also calculates the number of jobs (person-years of employment) directly created or supported per million dollars of final purchases. Estimates of the total number of additional jobs created as a function of year due to university-licensed products (assuming no product substitution effects) ranged from about 7000 jobs in 1996 to 23,000 in 2010, or more than 277,000 person-years of employment over the entire 15-year period. Because of uncertainty, we also provide estimates of the economic impact of university licensing income based on a range of product substitution rates—5%, 10% and 50%. The magnitude of the estimated impact depends significantly on the assumptions made, for example the royalty fees and substitution rates, but even the most conservative yet reasonable assumptions yield estimates of very large impacts on GDP, industry output, and employment. Major discoveries emanating from academic and/or publicly-funded research have had enormous global economic and social impacts that are obvious but difficult to predict and quantify (e.g., Google, the World Wide Web, nanotechnologies, etc.). Although this article examines the economic impact of only a select technology transfer activity, it nevertheless offers quantitative evidence that the economic impact of university research and technology transfer activities is significant.

3. Entrepreneurship and Entrepreneurial R&D Training

90. Abreu, Maria, and Vadim Grinevich. 2017. "Gender patterns in academic entrepreneurship." *The Journal of Technology Transfer* no. 42 (4):763-794. doi: 10.1007/s10961-016-9543-y.

    Our study analyses the determinants of the gender gap in academic entrepreneurship among UK-based academics from across a wide range of academic disciplines. We focus on spinout activity as a measure of academic entrepreneurship, and explore the relevance of the different explanations for the gender gap. Our analysis is based on a unique survey of UK academics conducted in 2008/2009. The survey provides micro-data on over 22,000 academics in the sciences, social sciences, arts and humanities, across all higher education institutions in the UK. Our results show that female academics differ from the male academics in the sample in important ways. Female academics are more likely to be involved in applied research, to hold more junior positions, to work in the health sciences, social sciences, humanities and education, to have less prior experience of running a business, and to feel more ambivalent about research commercialisation. All of these characteristics are correlated with lower rates of spinout activity. Using a non-parametric decomposition analysis, we show that certain combinations of characteristics of male academics have few or no matches to female academics, and these characteristics explain a large proportion of the gender gap.

91. Aldridge, T. Taylor, and David Audretsch. 2011. "The Bayh-Dole act and scientist entrepreneurship." *Research Policy* 40, no. 8: 1058-1067.

    Much of the literature examining the impact of the Bayh-Dole Act has been based on the impact on patenting and licensing activities emanating from offices of technology transfer. Studies based on data generated by offices of technology transfer, suggest a paucity of entrepreneurial activity from university scientists in the form on new startups. There are, however, compelling reasons to suspect that the TTO generated data may not measure all, or even most of scientist entrepreneurship. Rather than relying on measures of scientist entrepreneurship reported by the TTO and compiled by AUTM, this study instead develops alternative measures based on the commercialization activities reported by scientists. In particular, the purpose of this paper is to provide a measure of scientist entrepreneurship and identify which factors are conducive to scientist entrepreneurship and which factors inhibit scientist entrepreneurship. This enables us to compare how scientist entrepreneurship differs from that which has been established in the literature for the more general population. We do this by developing a new database measuring the propensity of scientists funded by grants from the National Cancer Institute (NCI) to commercialize their research as well as the mode of commercialization. We then subject this new university scientist-based data set to empirical scrutiny to ascertain which factors influence both the propensity for scientists to become an entrepreneur. The results suggest that scientist entrepreneurship may be considerably more robust than has generally been indicated in studies based on TTO data.

92. Audretsch, David B. and Albert N. Link. 2018. "Entrepreneurship and Knowledge Spillovers from the Public Sector." *International Entrepreneurship and Management Journal*: 1-14. https://doi.org/10.1007/s11365-018-0538-z.

    A compelling body of research has found that investments in knowledge from other firms and universities spill over to enhance the performance of entrepreneurial firms. This literature has shown that firm performance is positively related to investments in new knowledge by other firms and research universities. This paper addresses a gap in the literature by positing that public sector knowledge is also conducive to enhancing performance by knowledge intensive entrepreneurial (KIE) firms. Our findings suggest that the public sector provides a fertile source of knowledge for enhancing KIE firm performance.

93. Boh, Wai Fong, Uzi De-Haan, and Robert Strom. 2016. "University technology transfer through entrepreneurship: faculty and students in spinoffs." *The Journal of Technology Transfer* no. 41 (4):661-669. doi: 10.1007/s10961-015-9399-6.

    This research informs our understanding of the technology commercialization process in university spinoffs, focusing in particular on student involvement in the early phases of the spinoff development process and on the impact of the larger university ecosystem. Detailed case studies indicate that graduate and post-doctoral students are important participants in university spinoffs. We offer a typology of spinoff development with four pathways, based on the varying roles of faculty, experienced entrepreneurs, PhD/post-doctoral students, and business students. The effects of the larger university ecosystem, beyond the university technology transfer office and the university's commercialization policies, are also considered, including an examination of programs and practices that may influence this process. We close with a discussion of guidelines for technology transfer and spinoff development at universities, based on the findings of this research.

94. Etzkowitz, Henry. 2016. "The Entrepreneurial University: Vision and Metrics." *Industry and Higher Education* no. 30 (2):83-97. doi: 10.5367/ihe.2016.0303.

Forged in different academic and national traditions, the university is arriving at a common entrepreneurial format that incorporates and transcends its traditional missions. The academic entrepreneurial transition arises from the confluence of the internal development of higher education institutions and external influences on academic structures associated with the emergence of ?knowledge-based? innovation. Policies, practices and organizational innovations designed to translate knowledge into economic activity as well as addressing problems from society have spread globally. The objective is to enable universities to play a creative role in economic and social development from an independent perspective while still being responsive to government and industry priorities. The entrepreneurial university model paradoxically includes both increased university autonomy and greater involvement of external stakeholders. However, to facilitate the successful development of the entrepreneurial university, the dominant metrics used to determine university rankings and academic performance need radical revision. This article concludes with a summary of the critical questions to be addressed by the recently launched Global Entrepreneurial University Metrics Initiative in its effort to develop a metrics system that will facilitate the evolution of the entrepreneurial university and emphasize the role of higher education in economic and social development.

95. Fuller, Daniel, Malcolm Beynon, and David Pickernell. 2019. “Indexing third stream activities in UK universities: exploring the entrepreneurial/enterprising university.” *Studies in Higher Education* no. 44 (1):86-110. doi: 10.1080/03075079.2017.1339029.

    Third Stream Activity (TSA) is increasingly important to UK universities and the wider economy, through innovation and entrepreneurship. Using data from the 2009/2010 UK Higher Education Business and Community Interaction Survey, this study investigates UK universities? TSA. Through considering the data in original and logged forms, two interpretations of TSA are investigated, in relation to entrepreneurial and enterprising university concepts. Using principle component analysis (PCA) on both data forms, four factors relating to universities? TSA are identified. A nascent indexing approach is employed to create sub-indexes using the identified factors, weight aggregated to produce final TSA indexes (one for each form of the data). Comparisons are then made between rankings of universities using the two versions of TSA index, and sub-indexes, illustrating differences utilising the entrepreneurial and enterprising university concepts. Important questions are raised for future government policy in terms of promoting interventions that drive towards different TSA types.

96. Geisler, Elie, and Giuseppe Turchetti. 2015. "Commercialization of Technological Innovations: The Effects of Internal Entrepreneurs and Managerial and Cultural Factors on Public–Private Inter-Organizational Cooperation." *International Journal of Innovation and Technology Management* 12, no. 02: 1550009.

Why do scientists and engineers in government laboratories and private companies cooperate and exchange and commercialize technology? What are the factors that impact the propensity to commercialize and the success of such collaborations? These research questions were explored in the extant literature, but the focus has mainly been on the impacts of incentives that employees of public technology laboratories received from their management. This paper reports the findings from a study of 43 government laboratories and 51 industrial companies in the United States. The study expanded the focus of previous research by considering the set of managerial, economic, cultural, and organizational factors as well as the impacts of internal entrepreneurship - in both the public laboratories and private industry. The study also contributed to the literature on internal entrepreneurship by expanding and empirically testing the integrative concept of intrapreneurship. The results show that internal entrepreneurship of the scientific and technical workforce in both types of organizations is the most powerful predictor of commercialization and technology transfer in the public-private cooperation. Other factors found to impact the success of the commercialization effort are senior management support and a culture that encourages cooperation across organizational boundaries. This paper contributes to the state of knowledge in that it establishes empirically that the incentives most likely to work to improve cooperation between public and private technology organizations are those that create a supportive environment for internal entrepreneurs within these organizations, rather than a basket of the usual incentives designed to foster a specific behavior. These findings also contribute to the making of technology policy in developed countries as well as in the emerging world, where the need to encourage cooperation between public and private technology enterprise is increasingly recognized as a powerful economic and technological foundation for growth and prosperity. © 2015 World Scientific Publishing Company.

97. Goel, Rajeev K., Devrim Göktepe-Hultén, and Rati Ram. 2015. "Academics' entrepreneurship propensities and gender differences." *The Journal of Technology Transfer* no. 40 (1):161-177. doi: 10.1007/s10961-014-9372-9.

Using survey data from a large public research organization, this study examines entrepreneurship propensities of academic researchers, focusing on gender differences. Although sample means of female and male propensities toward entrepreneurship are fairly similar, regression estimates show significant gender differences in the association of several factors with propensities to start businesses. In particular, prior record of researchers' patenting and institutional leadership promote tendencies towards entrepreneurship among male researchers, but not among female researchers. Also, unlike the male scientists, doctoral degrees and preference for open access of research results do not significantly influence the entrepreneurial attitudes of female researchers. The results for the full sample are similar to those for the male subsample, with a negative coefficient on the variable identifying females.

98. Grimaldi, Rosa, Martin Kenney, Donald S. Siegel, and Mike Wright. 2011. "30 years after Bayh–Dole: Reassessing academic entrepreneurship." *Research Policy* no. 40 (8):1045-1057. doi: https://doi.org/10.1016/j.respol.2011.04.005.

On the 30th anniversary of enactment of the Bayh–Dole Act in the U.S., we consider the rationale for academic entrepreneurship and describe the evolving role of universities in the commercialization of research. We also discuss and appraise the effects of legislative reform in several OECD countries relating to academic entrepreneurship. The article synthesizes papers from the special section and outlines an agenda for additional research on various aspects of academic entrepreneurship in terms of system, university and individual levels. We also consider measurement and methodological issues that must be addressed in additional research.

99. Guerrero, Maribel, James A. Cunningham, and David Urbano. 2015. "Economic impact of entrepreneurial universities' activities: An exploratory study of the United Kingdom." *Research Policy* no. 44 (3):748-764. doi: https://doi.org/10.1016/j.respol.2014.10.008.

Throughout economic history, institutions have established the rules that shape human interaction. In this sense, political, socio-cultural, and economic issues respond to particular forces: managed economy or entrepreneurial economy. In the entrepreneurial economy, the dominant production factor is knowledge capital that is the source of competitive advantage, which is complemented by entrepreneurship capital, representing the capacity to engage in and generate entrepreneurial activity. Thus, an entrepreneurial economy generates scenarios in which its members can explore and exploit economic opportunities and knowledge to promote new entrepreneurial phenomena that have not been previously visualized. In this context, the entrepreneurial university serves as a conduit of spillovers contributing to economic and social development through its multiple missions of teaching, research, and entrepreneurial activities. In particular, the outcomes of its missions are associated with the determinants of production functions (e.g. human capital, knowledge capital, social capital, and entrepreneurship capital). All these themes are still considerate potentially in the research agenda in academic entrepreneurship literature. This paper modestly tries to contribute to a better understanding of the economic impact of entrepreneurial universities' teaching, research, and entrepreneurial activities. Taking an endogenous growth perspective, the proposed conceptual model is tested using data collected from 2005 to 2007 for 147 universities located in 74 Nomenclature of Territorial Units for Statistics-3 (NUTS-3) regions of the United Kingdom. The results of this exploratory analysis show the positive and significant economic impact of teaching, research, and entrepreneurial activities. Interestingly, the higher economic impact of the United Kingdom's entrepreneurial universities (the Russell Group) is explained by entrepreneurial spin-offs. However, our control group composed by the rest of the country's universities, the highest economic impact is associated with knowledge transfer (knowledge capital).

100. Hayter, Christopher. 2011. "In search of the profit-maximizing actor: Motivations and definitions of success from nascent academic entrepreneurs." *The Journal of Technology Transfer* no. 36:340-352. doi: 10.1007/s10961-010-9196-1.

Scholars have traditionally assumed the establishment and management of university spinoffs are guided by growth and the pursuit of profit. However, few studies have examined the motivations and post-establishment success definitions of entrepreneurs themselves. This paper seeks to contribute to our understanding of the mediating factors of academic entrepreneurship through an in-depth interview-based study of 74 nascent academic entrepreneurs. The results show that academic entrepreneurs define success in a number of complex, interrelated ways including technology diffusion, technology development, financial gain, public service and peer motivations, among others. Furthermore, a large percentage of the respondents have little immediate interest in growth and have instead established their firms to pursue other sources of development funding.

101. Hayter, Christopher S. 2013. "Harnessing University Entrepreneurship for Economic Growth:Factors of Success Among University Spin-offs." *Economic Development Quarterly* no. 27 (1):18-28. doi: 10.1177/0891242412471845.

University spin-offs are an important vehicle for knowledge dissemination and have the potential to generate jobs and economic growth. Despite their importance, little research exists on spin-off performance or impact, especially from the perspective of academic entrepreneurs. Using logit regression, this article makes a scholarly contribution by testing the relationship between spin-off success—defined here as technology commercialization—and multiple factors derived from the extant literature. Several significant variables are found to enable commercialization success within the sample, including venture capital, multiple and external licenses, outside management, joint ventures with other companies, previous faculty consulting experience, and—surprisingly—a negative relationship to post-spin-off services provided by universities. The results have important implications for public policy and management, supporting an overall "open innovation" approach to spin-off success.

102. Hoye, Kate, and Fred Pries. 2009. "'Repeat commercializers,' the 'habitual entrepreneurs' of university–industry technology transfer." *Technovation* no. 29 (10):682-689. doi: https://doi.org/10.1016/j.technovation.2009.05.008.

Among academic faculty, is there a class of 'repeat commercializers' who account for a disproportionate share of commercialized technologies arising from university research? In a survey of 172 engineering, mathematics, and science faculty members from a major Canadian university, we found evidence that a class of repeat commercializers does exist. Further, we found that the 12% of the faculty who are repeat commercializers account for 80% of the commercialized innovations. Interviews with repeat commercializers in the same faculties at the same university suggest that repeat commercializers parallel habitual entrepreneurs in that they have the ability to commercialize (i.e. the ability to generate and identify commercializable inventions and the ability to acquire resources for the commercialization of their inventions) and the aspiration to do so (i.e. commercialization-friendly attitudes). Since repeat commercializers account for such a large percentage of commercialization activity, it is important that programs and policies associated with technology transfer address the needs of this subpopulation of the faculty.

103. Krabel, Stefan, and Pamela Mueller. 2009. "What drives scientists to start their own company?: An empirical investigation of Max Planck Society scientists." *Research Policy* 38, no. 6: 947-956.

Studies on academic spin-off companies have shown that the researchers' scientific potential, experience and established networks with other scientists or companies affect entrepreneurial activity. Most studies investigate official data such as patents and citations or qualitatively study a research group or spin-off formation. Only a few studies focus on the individual scientist. Our study fills this gap by analyzing survey interviews of 2604 scientists working for the Max Planck Society in Germany. Our empirical results indicate that the entrepreneurial activities of scientists heavily depend on patenting activity, entrepreneurial experience, and personal opinions about the benefits of commercializing research and close personal ties to industry.

104. Miranda, F Javier, Antonio Chamorro-Mera, Sergio Rubio, and Jesús Pérez-Mayo. 2017. "Academic entrepreneurial intention: the role of gender." *International Journal of Gender and Entrepreneurship* no. 9 (1):66-86.

The purpose of this study is firstly to analyze whether the determining factors of the entrepreneurial intention of academics are the same for men and women and test whether their degree of importance varies depending on gender, and secondly to test whether the lesser entrepreneurial intention of women detected in previous studies is because of the lesser presence of the determining factors of entrepreneurial intention among women or, on the contrary, is determined by the existence of implicit barriers that do not depend on these factors.

105. Moroz, Peter W., Kevin Hindle, and Robert Anderson. 2011. *Formulating The Differences Between Entrepreneurial Universities: A Performance Based Taxonomic Approach*. Washington: International Council for Small Business (ICSB).

This essay presents an exploration of entrepreneurial university typologies with the objective of developing an empirically justified, performance based taxonomical regime. Consideration is given to the need for providing a valid, reproducible and simple means for classifying entrepreneurial university types in order for comparison and contrast. This approach is able to accommodate growing

research interest in the tangencies between entrepreneurship and context and specifically provides a means for addressing gaps on what we know about the general differences between universities and the facilitation of entrepreneurial activities and associated outcomes associated with them. We find that international patterns in university commercialization data confirm the existence of skewed performance by a small cohort that is responsible for producing the majority of outcomes in each nation. This pattern is used to develop a taxonomic regime for classifying entrepreneurial universities into a top performing set and a set comprised of all other universities.

106. Wright, M. 2014. "Academic entrepreneurship, technology transfer and society: where next?" *Journal of Technology Transfer* no. 39 (3):322-334. doi: 10.1007/s10961-012-9286-3.

I outline a synthesis of micro and macro levels that attempts to provide a broader conceptualization of academic entrepreneurship and an appreciation of the contextual heterogeneity of academic entrepreneurship and the implications for how it occurs. The micro-level concerns how firms orchestrate their resources and capabilities, specifically knowing where resources come from and how to accumulate, bundle and configure them to generate sustainable returns. At the macro level, I analyse four different dimensions of context: temporal, institutional, social and spatial. Consequently, I argue that there is a need for a reconciliation of utilitarian and education-for-education's sake perspectives on the role of universities.

4. Societal Impacts of R&D

107. Fini, R., E. Rasmussen, D. Siegel, and J. Wiklund. 2018. "Rethinking The Commercialization Of Public Science: From Entrepreneurial Outcomes To Societal Impacts." *Academy of Management Perspectives* no. 32 (1):4-20. doi: 10.5465/amp.2017.0206.

Studies have demonstrated the importance of scientific research for innovation and economic performance at the firm and regional levels, and policymakers have extensively supported the commercialization of public science. However, we still lack theoretical and empirical evidence on the link between the commercialization of public science and broader societal impacts. Specifically, despite a large body of evidence on the determinants of science commercialization, mainly addressed in the literature on academic entrepreneurship, the consequences of such activities remain less explored. In this article, we seek to fill this void by viewing science commercialization as a means rather than as a final outcome. Instead of mapping the direct outcomes of the science commercialization process, mostly achieved through entrepreneurial activities, we see science commercialization as an enabler of broader societal impacts. This article outlines a research agenda on the societal impacts of science commercialization by extending current theories, data, and methods and exploring the need to consider ethical concerns and who is

benefiting from these impacts.

108. Link, A. N., and D. S. Siegel. 2009. “Evaluating The Social Returns To Innovation: An Application To University Technology Transfer.” *Measuring the Social Value of Innovation: A Link IN the University Technology Transfer and Entrepreneurship Equation*. Edited by G. D. Libecap, 171-187. Bingley: Emerald Group Publishing Ltd.

A fundamental problem in articulating the societal benefits of technology transfer is the lack of hard empirical evidence on the economic gains associated with this activity. To fill this gap, we apply the framework and methods developed by Griliches and Mans field et al. to assess the social returns to university-based inventions. This methodology can be used to derive explicit measures of key metrics, such as social rates of return and benefit-to-cost ratios characteristic of specific new technologies. A case study is used to illustrate the application of this method.

109. Roberts, Melanie R. 2009. "Realizing societal benefit from academic research: Analysis of the National Science Foundation’s broader impacts criterion." *Social Epistemology* 23, no. 3-4: 199-219.

The National Science Foundation (NSF) evaluates grant proposals based on two criteria: intellectual merit and broader impacts. NSF gives applicants wide latitude to choose among a number of broader impacts, which include both benefits for the scientific community and benefits for society. This paper considers whether including potential societal benefits in the Broader Impacts Criterion leads to enhanced benefits for society. One prerequisite for realizing societal benefit is to transfer research results to potential users in a meaningful format. To determine whether researchers who discuss broader impacts for society are more likely to engage in broad dissemination activities beyond the scientific publication, I analysed proposed broader impacts statements from recent award abstracts. Although 43% of researchers discussed potential benefits for society, those researchers were no more likely to propose dissemination of results to potential users than researchers who only discussed broader impacts for science. These findings suggest that considering potential societal benefit as a broader impact may not lead to more actual societal benefits and that many potentially useful results may not be disseminated beyond the scientific community. I conclude with policy recommendations that could increase the likelihood of realizing potential societal benefits from academic research.

110. Robinson-Garcia, Nicolas, Thed N van Leeuwen, and Ismael Ràfols. 2018. “Using altmetrics for contextualised mapping of societal impact: From hits to networks.” *Science and Public Policy* no. 45 (6):815-826. doi: 10.1093/scipol/scy024.

In this article, we develop a method that uses altmetric data to analyse researchers' interactions, as a way of mapping the contexts of potential societal impact. In the face of an increasing policy demand for quantitative methodologies to assess societal impact, social media data (altmetrics) have been presented as a potential method to capture broader forms of impact. However, current altmetric indicators were extrapolated from traditional citation approaches and are seen as problematic for assessing societal impact. In contrast, established qualitative methodologies for societal impact assessment are based on interaction approaches. These argue that assessment should focus on mapping the contexts in which engagement among researchers and stakeholders takes place, as a means to understand the pathways to societal impact. Following these approaches, we propose to shift the use of altmetric data towards network analysis of researchers and stakeholders. We carry out two case studies, analysing researchers' networks with Twitter data. The comparison illustrates the potential of Twitter networks to capture disparate degrees of policy engagement. We propose that this mapping method can be used as an input within broader methodologies in case studies of societal impact assessment.

111. Weißhuhn, Peter, Katharina Helming, and Johanna Ferretti. 2017. "Research impact assessment in agriculture—A review of approaches and impact areas." *Research Evaluation* no. 27 (1):36-42. doi: 10.1093/reseval/rvx034.

Interest in evaluating non-economic social outcomes of science and technology research has risen in policy circles in recent years. The interest in social impacts of research has not yet given rise to a great proliferation of useful, valid techniques for evaluating such impacts. This study presents detailed case studies of four US National Science Foundation (NSF) programs/initiatives to provide a framework for understanding diverse efforts at addressing social impacts, and to suggest some important gaps in our research approaches for assessing socio-economic impacts of research. The four cases studied − the Experimental Program to Stimulate Competitive Research (EPSCoR), the Innovation Corps (I-Corps), the Arizona State University Center for Nanotechnology in Society, and the NSF "Broader Impacts" criteria—were chosen for their diversity in intent and modality but operating within a single agency. The cases are compared based on criteria important for assessing socio-economic outcomes: the initiative's modality, enabling policy vehicle, benefit guarantor, distribution and appropriability of benefits, specificity of beneficiary, social-economic range, and timing of the benefit stream. The paper concludes with a discussion of the most pressing methodological and theoretical issues that need addressing for greater progress in assessing social impacts.

5. Studies on Technology Transfer Offices

112. Alexander, Allen T., and Dominique Philippe Martin. 2013. "Intermediaries for open innovation: A competence-based comparison of knowledge transfer offices

practices." *Technological Forecasting and Social Change* no. 80 (1):38-49. doi: https://doi.org/10.1016/j.techfore.2012.07.013.

Universities and Public Research Organisation rely on the capabilities and competences of their transfer offices to engage with commercial partners and to manage the exchange of knowledge and expertise. This paper promotes a model that can be used to analyze the capabilities and relative strategies of these transfer offices. Based on a 'core competences' approach the model enables the precise characterization of the different modes and methods of transfer and engagement. Findings, coming from a two-year, in-depth comparative study of two transfer offices located in France and in the UK, underline the office's relative positioning within their institutional environment and identify the relative priority given to their use of the channels of transfer. These results provide a guide for the strategic management of transfer offices that are now operating within an 'open innovation' paradigm.

113. Baglieri, D., F. Baldi, and C. L. Tucci. 2018. "University technology transfer office business models: One size does not fit all." *Technovation* no. 76-77:51-63. doi: 10.1016/j.technovation.2018.05.003.

Technology transfer processes enable universities to increase their positive impact on society by pursuing their entrepreneurial mission in several ways. By analyzing quantitative and qualitative data collected in a longitudinal dataset of 60 U.S. universities during the period 2002-2012, this article identifies four types of technology transfer business models that may generate economic and non-economic linkages that need to be evaluated. Findings reveal that business models that leverage high-quality research (i.e., catalyst) and startup creation (i.e., orchestrator of local buzz) are associated with higher economic performance. This study contributes to the emergent literature on university business models and provides suggestions to policymakers to incorporate a business model typology in university evaluation programs.

114. Castillo, Federico, J. Keith Gilless, Amir Heiman, and David Zilberman. 2018. "Time of adoption and intensity of technology transfer: an institutional analysis of offices of technology transfer in the United States." *The Journal of Technology Transfer* 43, no. 1: 120-138.

This paper considers the adoption of institutional innovations by not for profit organizations, an issue that can be considered in the context of the extensive literature on the adoption of technological innovation by firms. The specific institutional innovation considered is the offices of technology transfer (OTT)—the organization that assemble and disclose university innovations and negotiate and enforce licenses with users of these innovations. We propose a theoretical framework that depart from previous studies by focusing on the timing decision of institutions rather than on the percentage of institutions that adopt at each point in time. Our theoretical framework also incorporates organization theory via

imitation effects on the timing of adoption. We find that number of adopters has an S-shape function of time, which may indicate a strong element of imitation led universities to create OTTs. We also find that universities with higher research incomes and rankings were earlier adopters of the OTT model and that universities with medical schools were generally late adopters. Finally, we find that the number of universities who have already adopted the OTT model increases the speed by which other non-adopters make their OTT adoption decisions and that the number of invention disclosures, a primary indicator of output of OTTs, increases with the size of research budget, is smaller for those with medical schools, and larger for those that were earlier adopters of OTT. Section 1 of the paper discusses the recent trends in technology transfer while Section 2 reviews the advent of OTTs as facilitators of technology transfer activities. Section 3 reviews the relevant technology and institutional innovation literature. Section 4 develops a conceptual framework that links Sections 2 and 3 to analyze the advent and timing of the establishment of OTTs. Section 5 estimates the time of adoption of the OTT working model on the part of major research universities in the US, and analyzes the impact of time of adoption of the OTT model on the intensity of the technology transfer process. Section 6 presents empirical results while the conclusions and policy implications are discussed in Section 7.

115. De Beer, C., G. Secundo, G. Passiante, and C. S. L. Schutte. 2017. "A mechanism for sharing best practices between university technology transfer offices." *Knowledge Management Research & Practice* no. 15 (4):523-532. doi: 10.1057/s41275-017-0077-3.

Research has shown that university technology transfer offices (TTOs) learn through experimentation and failure, and by sharing these experiences with others. There are many barriers to successfully sharing the best practice between TTOs. The Maturity Model (MM) created by Secundo et al. (Meas Bus Excell, 20:42-54, 2016) provides a means by which the performance of a TTO can be better understood to allow for effective sharing of best practices. The aim of this study is to improve and validate the MM to formalize a mechanism through which best practices can be identified and shared between TTOs. This was accomplished by testing the MM in 54 TTOs across Europe and the United Kingdom. Findings regard several improvements of the intangible indicators and the maturity levels of the MM. This research improves the rigor of the MM and formalizes its application as a mechanism for sharing best practices through the Improved MM.

116. Hirt, Brian G. 2013. "Evaluating Impacts of the US Domestic Scan Program's Technology Transfer Model." *Transportation Research Record* 2328, no. 1: 47-53.

The U.S. Domestic Scan program creates opportunities for face-to-face information sharing and knowledge building between transportation agency professionals on selected timely topics. Its goals are broad information dissemination and accelerated implementation of new transportation technologies

and best practices. A companion to this program was a study to assess formally how well the program was meeting these goals. The study employed different collection instruments, including online surveys, telephone interviews, and webinars, to learn the extent of follow-up activities for six early scans conducted through the U.S. Domestic Scan program. Investigators communicated with a range of stakeholders: scan participants, the project oversight panel, and, notably, nonparticipants, those individuals who learned about the scan second-hand through formal or informal channels. Results confirmed that the scans were achieving their core missions: participants were making critical professional connections, sharing scan findings across a wide network of audiences, and making use of the findings at their home agencies. Nonparticipants were also found to use findings to support their own implementation efforts and to share the information with others and thus further propagate the ripple effect of information dissemination. Additional insights from the scan participants and oversight panel inform recommendations and best practices for technology transfer and accelerated implementation for any research program.

117. Horner, S., D. Jayawarna, B. Giordano, and O. Jones. 2019. "Strategic choice in universities: Managerial agency and effective technology transfer." *Research Policy* no. 48 (5):1297-1309. doi: 10.1016/j.respol.2019.01.015.

Current theorising about the contingencies underpinning the effectiveness of university technology transfer has emphasised the importance of organisational support, namely the scale of Technology Transfer Office (TTO) support and the provision of incentives. Empirical results pertaining to the effects of these organisational supports are mixed. More recently, academic research and policy reviews have highlighted the potential significance of the strategic choices made by university managers in contributing to the effectiveness of technology transfer activity. Our research attempts to reconcile these two streams of technology transfer research by drawing on Child's strategic choice theory as an integrating framework. Through operationalising a strategic choice framework and drawing upon data from 115 UK universities (collected through multiple waves of the HE-BCI Survey), this research shows that supporting organisational infrastructure is necessary but not sufficient to account for improved technology transfer effectiveness. Specifically, it highlights the key mediating role of strategic choice, suggesting that it is the alignment between strategic choices made by university managers and the supporting organisational infrastructure that accounts for variations in technology transfer effectiveness. Furthermore, we find the mediation relationship between strategic alignment and technology transfer effectiveness is moderated by the breadth of strategic planning efforts, with those universities that engage a wider number of faculty in strategic planning efforts benefiting most from the alignment between strategic choices and supporting organisational infrastructure.

118. Huyghe, Annelore, Mirjam Knockaert, Evila Piva, and Mike Wright. 2016. "Are researchers deliberately bypassing the technology transfer office? An analysis of TTO

awareness." *Small Business Economics* no. 47 (3):589-607. doi: 10.1007/s11187-016-9757-2.

Most universities committed to the commercialization of academic research have established technology transfer offices (TTOs). Nonetheless, many researchers bypass these TTOs and take their inventions directly to the marketplace. While TTO bypassing has typically been portrayed as deliberate and undesirable behavior, we argue that it could be unintentional as many researchers may simply be unaware of the TTO's existence. Taking an information-processing perspective and using data on 3250 researchers in 24 European universities, we examine researcher attributes associated with TTO awareness. Our evidence confirms that only a minority of researchers are aware of the existence of a TTO at their university. TTO awareness is greater among researchers who possess experience as entrepreneurs, closed many research and consulting contracts with industry partners, conduct research in medicine, engineering or life sciences, or occupy postdoctoral positions. Policy implications of these findings are discussed.

119. Lafuente, E., and J. Berbegal-Mirabent. 2019. "Assessing the productivity of technology transfer offices: an analysis of the relevance of aspiration performance and portfolio complexity." *Journal of Technology Transfer* no. 44 (3):778-801. doi: 10.1007/s10961-017-9604-x.

The paper investigates the productivity level of technology transfer offices (TTOs) affiliated to Spanish public universities. The proposed approach allows the development of a framework that matches universities' technology transfer concerns with the need to accurately analyze the role of the outcome configuration of TTOs. We analyze the productivity of Spanish TTOs during 2006-2011 by computing total factor productivity models rooted in non-parametric techniques, namely the Malmquist index. The results confirm that technology transfer productivity is affected by changes in the configuration of the TTO's outcome portfolio that result from benchmarking own and market peers' performance levels. While benchmarking own performance levels facilitates the exploitation of internal resources and yields superior productivity results, changes in TTO's portfolio based on comparisons with market peers might generate greater operational costs that negatively impact productivity.

120. Resende, David N., David Gibson, and James Jarrett. 2013. "BTP—Best Transfer Practices. A tool for qualitative analysis of tech-transfer offices: A cross cultural analysis." *Technovation* 33, no. 1: 2-12.

The objective of this article is to present a qualitative analysis tool which technology transfer offices (TTOs) can utilize to improve their efficiency and effectiveness. Such qualitative tool is one of the novelties presented. The other is information that advances understanding of the processes, procedures and structures required to transfer technology, as a set of best practices. From December 2008 to September 2010 a variety of methodologies (document analysis, participative observation, interviews and surveys) generated data which led to development of a theoretical framework. The theoretical framework, called Master Plan for Technology Transfer (TT), is a reference schema for best practices. The Master Plan contains 271 rules (good practices) referring to 43 facilitators distributed in seven groups. The facilitators and rules were selected from a coding process based on grounded theory, where facilitators are the categories and rules are their properties. Based on the methodologies and development of the Master Plan, we constructed a tool called Best Transfer Practices (BTP) which is a qualitative tool to assess and study TTOs and their host R&D institutions. The collection of rules and facilitators are the soul of our BTP. It is our contribution to the knowledge of actual practices in TT.

121. Swamidass, P. M., and V. Vulasa. 2009. "Why university inventions rarely produce income? Bottlenecks in university technology transfer." *Journal of Technology Transfer* no. 34 (4):343-363. doi: 10.1007/s10961-008-9097-8.

As intended, universities have gained ownership to an increased number of inventions from their labs after the enactment of Bayh-Dole act in 1980. But, how well are the universities taking advantage of the provisions of this Act? One aspect of this question is addressed empirically in this study. An analysis of the Association of University Technology Managers (AUTM) periodic Licensing Activity Surveys of 1995-2004 indicated that the annual income generated by licensing university inventions was 1.7% of total research expenditure in 1995 and 2.9% in 2004. Some consider this and the rate of commercialization of university inventions to be too low. A premise of this study is that the slow rate of commercialization of university inventions may be due to the lack of adequate trained staff and inventions processing capacity in University Offices of Technology Transfer (UOTT). This paper describes an empirical study of the non-legal, technical, and legal invention processing capacity of US UOTT and its implications. A survey questionnaire was sent to 99 randomly selected US research universities. Seventy-five percent of the respondents mentioned shortage of staff for non-legal and legal processing of inventions. More than a third of the respondents claimed that, in 2006, they failed to process more than 26% of the inventions due to insufficient processing capacity in the UOTT. The study includes multiple regression models to estimate the effect of staffing on performance variables (i.e., Provisional Applications Filed, Patent [non-provisional] Applications and Licenses Executed) and "Inventions Not Processed" by the UOTTs due to staff/budget shortages. It is argued that, when short of staff and budget, UOTTs will be reduced to devoting their resources to ensuring patent applications are filed and patents are issued at the expense of marketing of inventions. Further, high-tech inventions are difficult to market because, often, there are no ready markets for them, especially if the inventor had no pre-invention contacts with a potential licensee. High-tech inventions originating from university labs may need market space/niche identification, new market creation, and the translation of the lab result into an "investor friendly" business plan; most UOTTs may be significantly short on these skills. Recommendations of this study are: first, an in-depth study of universities that are prolific in licensing inventions (40 or more licenses a year) is necessary to understand the reasons for their success in the context of UOTTs capacity to process inventions. Further, all federal agencies sponsoring university research must earmark a small percentage of each grant exclusively for commercialization purposes at the university. The paper offers multiple options for the effective use of these funds. The paper also offers several avenues for future research.

122. Xu, Z. B., M. E. Parry, and M. Song. 2011. "The Impact of Technology Transfer Office Characteristics on University Invention Disclosure." *Ieee Transactions on Engineering Management* no. 58 (2):212-227. doi: 10.1109/tem.2010.2048915.

The authors examine faculty disclosure of inventions, which is an important precursor of university licensing. The authors hypothesize that invention disclosure (ID) is an increasing function of R&D expenditures, faculty size, faculty quality, royalty share, and technology transfer office (TTO) independence from university funding. The authors also argue that, because TTO size is a measure of TTO agent research expertise, large TTOs should be able to build stronger relationships with a broader range of faculty, which should attract more faculties to disclose inventions. In addition, the creation of such strong TTO-faculty relationships requires tacit knowledge of faculty skills, interests, and motivations, and the acquisition of this knowledge takes time. Thus, TTO age should also positively influence ID. Analysis of data from 123 TTOs indicates that the number of IDs is positively related with federal R&D expenditures and TTO size, and negatively related with TTO funding independence. In contrast, faculty size, royalty share to inventors, and TTO age are positively and significantly correlated with the number of IDs only among universities with small TTOs, while faculty quality is positively and significantly correlated with the number of IDs only among universities with large TTOs.

123. Yuan, C. H., Y. Li, C. O. Vlas, and M. W. Peng. 2018. "Dynamic capabilities, subnational environment, and university technology transfer." *Strategic Organization* no. 16 (1):35-60. doi: 10.1177/1476127016667969.

University technology transfer allows universities to extract benefits from their research. We examine how universities can create and capture value from their technology creation and technology commercialization efforts by embracing a dynamic capabilities perspective. Our longitudinal analysis involves 829 universities and 3908 university-year observations in 30 subnational regions (provinces) in China during a 6-year period. Our findings reveal (1) that universities create more ideas and capture more licensing value through dynamic management and active orchestration of assets, (2) that a developed factor market accelerates value creation and commercialization, and (3) that a developed institutional environment at the subnational level stimulates value creation but inhibits value capture. These interesting findings justify a dynamic capabilities perspective of the university technology transfer process while opening avenues for future research.

6. R&D Funding and Economic Productivity

124. Armstrong, Chanette, Jennifer Shieh, and Paul Zielinski. 2019. "Increasing the return on investment from federally-funded research and development." *Theoretical Issues in Ergonomics Science* 20, no. 1: 4-7.

> Each year, the United States invests approximately $495 billion in research and development (R&D)–about a quarter of the total global investment. While the private sector accounts for about 67% of U.S. investment, the Federal government plays a critical role in funding R&D, particularly in areas that address societal needs in which the private sector does not yet have sufficient clear or strong incentive to make the required investments. The Federal government invests approximately $150 billion each year in R&D conducted at Federal laboratories, universities and other research organizations. As Federal R&D investments wind down or are completed, additional work is often still needed to translate the knowledge accrued from that R&D into products and services that will improve lives and provide economic growth. Technology transfer is the process by which existing knowledge, facilities or capabilities developed through R&D are utilised to fulfill public and private need. The transfer of technology from federally-funded R&D to the private sector is crucial to realising the taxpayer's return on investment in the Federal R&D ecosystem. However, moving innovations from the lab to the market is more than inventing products for people to buy. Technology transfer is about creating jobs and growing the economy; ensuring a strong, secure, and resilient Nation; and improving Americans' health and environment, fostering the conditions for America to maintain leadership in global innovation.

125. Goldfarb, Brent. 2008. "The Effect of Government Contracting on Academic Research: Does the Source of Funding Affect Scientific Output." *Research Policy* 37, no. 1 (February): 41-58. http://dx.doi.org/10.1016/j.respol.2007.07.011.

> The growing share of university research funded by industry has sparked concerns that academics will sacrifice traditional scholarly activities to pursue commercial goals. To investigate this concern, I examine the influence of an applied sponsor and consider limitations of the grant funding mechanism. A novel dataset tracks the careers of academic engineers and their relationships with this sponsor. I find that (a) researchers who maintain a relationship with the directed sponsor experience a decrease in publications implying that academics' careers may be a function of the type of funding received, not only talent; (b) academic merit does not necessarily serve as a funding criterion for sponsors; and (c) citation and publication measures of academic output are often not useful proxies for short-term commercial or social value.

126. Kindlon, Audrey E. and John E. Jankowski. 2017. "Rates of Innovation among U.S. Businesses Stay Steady: Data from the 2014 Business R&D and Innovation Survey." National Science Foundation 17-321 (August). https://www.nsf.gov/statistics/2017/nsf17321/

Fifteen percent of an estimated 1.3 million for-profit companies introduced one or more product or process innovations in 2012–14. Nine percent of these companies introduced one or more product innovations, and 12% introduced one or more process innovations. Innovation rates are similar to those from 2009–11, when 14% of companies introduced one or more product or process innovations (9% product innovations, and 10% process innovations). Figures for product and process innovations cited in this report are not additive. Companies indicating product innovations may also have process innovations, and vice versa. Data are from the 2014 Business R&D and Innovation Survey (BRDIS), from the National Center for Science and Engineering Statistics within the National Science Foundation and the U.S. Census Bureau. These survey data provide an updated view of the incidence of innovation by businesses located in the United States and represent an estimated 1.3 million for-profit companies, publicly or privately held, with five or more employees, active in the United States in 2014 (see "Survey Information and Data Availability"). Approximately 104,000 of these companies (8%) were in manufacturing; most, 1.2 million companies (92%) were in nonmanufacturing (table 1). The innovation incidence data refer to product innovations (one or more new or significantly improved goods or services) or process innovations (one or more new or significantly improved methods for manufacturing or production; logistics, delivery, or distribution; or support activities). Distinctions must be made when discussing innovation incidence by industry because substantial differences exist between manufacturing and nonmanufacturing industries as well as between R&D-active companies and non-R&D-active companies. Although rates of innovation generally are higher for manufacturing and R&D-active companies than for nonmanufacturing and non-R&D-active companies, the absolute number of companies reporting innovation is larger in nonmanufacturing industries and in companies that are not R&D funders or performers.

127. Lane, J. I., J. Owen-Smith, R. F. Rosen, and B. A. Weinberg. 2015. “New linked data on research investments: Scientific workforce, productivity, and public value.” *Research Policy* no. 44 (9):1659-1671. doi: 10.1016/j.respol.2014.12.013.

Longitudinal micro-data derived from transaction level information about wage and vendor payments made by Federal grants on multiple US campuses are being developed in a partnership involving researchers, university administrators, representatives of Federal agencies, and others. This paper describes the UMETRICS data initiative that has been implemented under the auspices of the Committee on Institutional Cooperation. The resulting data set reflects an emerging conceptual framework for analyzing the process, products, and impact of research. It grows from and engages the work of a diverse and vibrant community. This paper situates the UMETRICS effort in the context of research evaluation and ongoing data infrastructure efforts in order to highlight its novel and valuable features. Refocusing data construction in this field around individuals, networks, and teams offers dramatic possibilities for data linkage, the evaluation of research investments, and the development of rigorous conceptual and empirical models. Two preliminary analyses of the scientific workforce and network approaches to characterizing scientific teams ground a discussion of future directions and a call for increased community engagement.

128. Peters, Michael, Malte Schneider, Tobias Griesshaber, and Volker H. Hoffmann. 2012. "The impact of technology-push and demand-pull policies on technical change–Does the locus of policies matter?" *Research Policy* 41, no. 8: 1296-1308.

How to foster technical change is a highly relevant and intricate question in the arena of policymaking. Various studies have shown that technology-push and demand-pull policies induce innovation. However, there is a lack of work that distinguishes between the loci of policy support when assessing the policy-innovation relationship. We address this gap by shedding light on the question how the innovation effects of domestic and foreign demand-pull and technology-push policies differ. Using solar photovoltaic modules as a research case we conduct a panel analysis on 15 OECD countries over the period 1978 through 2005 with patent data. Three key findings emerged: First, our analyses find no evidence that domestic technology-push policies foster innovative output outside of national borders. Second, both domestic and foreign demand-pull policies trigger innovative output in a country. Third, we detect no indication that market growth induced by domestic demand-pull policies leads to more national innovative output than market growth induced by foreign demand-pull policies. Consequently, demand-pull policies create significant country-level innovation spillovers, which could disincentivize national policymakers to engage in domestic market creation. Based on these findings we discuss the need to establish supranational demand-pull policy schemes in order to address the spillover issue.

129. Rowe, B. R., and D. S. Temple. 2011. “Superfilling technology: transferring knowledge to industry from the National Institute of Standards and Technology.” *Journal of Technology Transfer* no. 36 (1):1-13. doi: 10.1007/s10961-009-9141-3.

In the mid-1990s, the semiconductor industry manufactured devices with critical circuit dimensions of between 0.35 and 0.25 mu, and it used aluminum or an aluminum copper alloy to interconnect device components. However, the critical dimension needed to be reduced so that devices could become faster and more efficient. At circuits dimensions of 0.18 mu or less, aluminum no longer conducts electricity well enough to maintain the circuit's efficiency; thus, the industry determined that copper-a superior conducting material-would be needed to help the industry produce smaller and faster semiconductor devices. Still, technical barriers existed, preventing a seamless transition from aluminum to copper. Thus, in the 1990s, the National Institute of Standards and Technology (NIST) began focused research on superfilling aimed at assisting the semiconductor industry during this period. In this paper, we document the net economic benefits (private and social) accruing from NIST's core research investments in superfilling during the late 1990s and early 2000s. Using traditional evaluation methodology and

metrics, we calculated economic impact estimates, and the results suggest that NIST's public resources were, from a social perspective, used efficiently.

7. Technology Transfer Evaluation Frameworks and Models

130. Aguinis, Herman, Isabel Suárez-González, Gustavo Lannelongue, and Harry Joo. 2012. "Scholarly impact revisited." *Academy of Management Perspectives* no. 26 (2):105-132.

Scholarly impact is one of the strongest currencies in the Academy and has traditionally been equated with number of citations—be it for individuals, articles, departments, universities, journals, or entire fields. Adopting an alternative definition and measure, we use number of pages as indexed by Google to assess scholarly impact on stakeholders outside the Academy. Based on a sample including 384 of the 550 most highly cited management scholars in the past three decades, results show that scholarly impact is a multidimensional construct and that the impact of scholarly research on internal stakeholders (i.e., other members of the Academy) cannot be equated with impact on external stakeholders (i.e., those outside the Academy). We illustrate these results with tables showing important changes in the rank ordering of individuals based on whether we operationalize impact considering internal stakeholders (i.e., number of citations) or external stakeholders (i.e., number of non-.edu Web pages). Also, we provide tables listing the most influential scholars inside the Academy who also have an important impact outside the Academy. We discuss implications for empirical research, theory development, and practice regarding the meaning and measurement of scholarly impact.

131. Albors-Garrigos, José, José Luis Hervas-Oliver, and Antonio Hidalgo. 2009. "Analysing high technology adoption and impact within public supported high tech programs: An empirical case." *The Journal of High Technology Management Research* no. 20 (2):153-168. doi: https://doi.org/10.1016/j.hitech.2009.09.006.

The aim of this paper is to contribute to the body of knowledge in relation to the diffusion and adoption process of high technology. It intends to analyse those mechanisms that influence advanced technology transference and marketing, and those features that improve the impact of public programs supporting the adoption of high technology. The paper proposes a contingent construct that explains how advanced technology is transferred, diffused and adopted by users in a firm. In relation to the impact of technology transference this paper follows a novel approach: value mapping methodology adapted to the case of advanced technology. The article provides empirical evidence on the variables which contribute to the technology transference and commercialization process, and especially in the case of SMES. Key variables such as technology complexity, relationships between researchers, developers and final users, as well as market barriers appear to be critical for the transference process. Moreover, technology absorption by incumbent firms becomes a necessary requirement for its subsequent transfer. The paper has utilised the available experience from the GAME initiative, part of the European Commission IV Research Framework Programme, related to the promotion of microelectronics among Spanish firms. Using a representative sample and employing multivariable analysis methods, a model was developed in order to understand technology diffusion, absorption and transference knowledge flows. In addition, the model is useful for evaluating technology dissemination using the diffusion model to measure its social impact. The paper found that social impact can be explained by the creation of employment.

132. Amara, Nabil, and Réjean Landry. 2012. "Counting citations in the field of business and management: Why use Google Scholar rather than the Web of Science." *Scientometrics* no. 93 (3):553-581.

Research assessment carries important implications both at the individual and institutional levels. This paper examines the research outputs of scholars in business schools and shows how their performance assessment is significantly affected when using data extracted either from the Thomson ISI Web of Science (WoS) or from Google Scholar (GS). The statistical analyses of this paper are based on a large survey data of scholars of Canadian business schools, used jointly with data extracted from the WoS and GS databases. Firstly, the findings of this study reveal that the average performance of B scholars regarding the number of contributions, citations, and the h-index is much higher when performances are assessed using GS rather than WoS. Moreover, the results also show that the scholars who exhibit the highest performances when assessed in reference to articles published in ISI-listed journals also exhibit the highest performances in Google Scholar. Secondly, the absence of association between the strength of ties forged with companies, as well as between the customization of the knowledge transferred to companies and research performances of B scholars such as measured by indicators extracted from WoS and GS, provides some evidence suggesting that mode 1 and 2 knowledge productions might be compatible. Thirdly, the results also indicate that senior B scholars did not differ in a statistically significant manner from their junior colleagues with regard to the proportion of contributions compiled in WoS and GS. However, the results show that assistant professors have a higher proportion of citations in WoS than associate and full professors have. Fourthly, the results of this study suggest that B scholars in accounting tend to publish a smaller proportion of their work in GS than their colleagues in information management, finance and economics. Fifthly, the results of this study show that there is no significant difference between the contributions record of scholars located in English language and French language B schools when their performances are assessed with Google Scholar. However, scholars in English language B schools exhibit higher citation performances and higher h-indices both in WoS and GS. Overall, B scholars might not be confronted by having to choose between two incompatible knowledge production modes, but with the requirement of the evidence-based management approach. As a consequence, the various assessment exercises

undertaken by university administrators, government agencies and associations of business schools should complement the data provided in WoS with those provided in GS.

133. Bozeman, Barry, Heather Rimes, and Jan Youtie. 2015. "The evolving state-of-the-art in technology transfer research: Revisiting the contingent effectiveness model." *Research Policy* 44, no. 1: 34-49.

The purpose of our study is to review and synthesize the rapidly evolving literature on technology transfer effectiveness. Our paper provides a lens into relatively recent work, focusing particularly on empirical studies of US technology transfer conducted within the last 15 years. In doing so, we update and extend the Contingent Effectiveness Model of Technology Transfer developed by Bozeman (2000). Specifically, we include the growing interest in social and public value oriented technology transfer and, thus, the contingent effectiveness model is expanded to consider this literature. We categorize studies according their approaches to measuring effectiveness, draw conclusions regarding the current state of technology transfer evaluation, and offer recommendations for future studies.

134. Bozeman, Barry and Albert N. Link. 2015. "Toward an Assessment of Impacts from US Technology and Innovation Policies." *Science and Public Policy* 42, no. 3 (June): 369-376. https://doi.org/10.1093/scipol/scu058.

Five important policy initiatives were promulgated in response to the slowdown in US productivity in the early 1970s, and then again in the late 1970s and early 1980s. Scholars and policy-makers have long debated the direction and magnitude of impacts from these policies but empirical evidence remains modest, especially evidence of their aggregate effects. Our assessment of these policies is based on quantifying their collective impact on industrial investments in R&D in the post-productivity slowdown period. Our findings support the conclusion that the relative levels of industrial investments in R&D from 1980 onwards were significantly higher than before.

135. Bozeman, Barry. 2013. *Technology Transfer Research and Evaluation: Implications for Federal Laboratory Practice*. https://www.nist.gov/document/technology-transfer-research-and-evaluation-bozemandocx

On October 28, 2011, the White House released a Presidential Memorandum (White House, 2011) entitled "Accelerating Technology Transfer and Commercialization of Federal Research in Support of High Growth Businesses." The memorandum noted that one of the goals of the Administration's "Startup America" initiative is "to foster innovation by increasing the rate of technology transfer and the economic and societal impact from Federal research and development (R&D) investments." The Presidential Memorandum (hereafter President's memo) goes on to note that as part of this effort executive departments and agencies are mandated to improve their technology transfer and commercialization activities. In pursuit of these improvements, departments and agencies are required to "establish performance goals, metrics, and evaluation methods" and to track progress toward these goals. While the President's memo applies to all federal departments and agencies, it gives particular attention to federal agencies with federal laboratories, exhorting them to increase technology transfer activities "in partnership with non- federal entities, including private firms, research organizations, and nonprofit entities." The President's memo provides a special task for the Federal government's Interagency Workgroup on Technology Transfer to make recommendations about current programs and practices in Federal laboratory technology transfer; new or creative approaches that could serve as models; assessments of cooperative R&D; and, most pertinent to the present paper, "criteria to assess the effectiveness and impact on the Nation's economy of planned or future technology transfer efforts." The President's memo encourages a wide variety of activities, some of which could possibly benefit from extant research on technology transfer and commercialization. The current analysis provides a critical review of research, a review aimed at providing support for decisions and activities responding to the President's memo and seeking to improve U.S. Federal government technology transfer and commercialization policies, programs and activities. The study provides preliminary assessments of various approaches to developing and applying criteria and measures for technology transfer and commercialization and concludes with recommendations about strategies for developing measures and metrics. The study suggests no specific measures or metrics.

136. Bradley, R., Christopher Hayter, and A. N. Link. 2013. "Models and Methods of University Technology Transfer." *Foundations and Trends in Entrepreneurship* no. 9:571-650. doi: 10.1561/0300000048.

This monograph argues that a linear model of technology transfer is no longer sufficient, or perhaps even no longer relevant, to account for the nuances and complexities of the technology transfer process that characterizes the ongoing commercialization activities of universities. Shortcomings of the traditional linear model of technology transfer include inaccuracies - such as its strict linearity and oversimplification of the process, composition, a one-size-fits-all approach, and an overemphasis on patents - and inadequacies - such as failing to account for informal mechanisms of technology transfer, failing to acknowledge the impact of organizational culture, and failing to represent university reward systems within the model. As such, alternative views of technology transfer that better capture the progression of the university toward an entrepreneurial and dynamic institution are presented here, and that advance the body of knowledge about this important academic endeavor.

137. Cardozo, R., A. Ardichvili, and A. Strauss. 2011. "Effectiveness of university technology transfer: an organizational population ecology view of a maturing supplier

industry." *Journal of Technology Transfer* no. 36 (2):173-202. doi: 10.1007/s10961-010-9151-1.

In this article, we propose that universities engaged in technology transfer activities can be viewed as the University Technology Commercialization (UTC) industry. We use an organizational population ecology perspective to outline an economic model for the analysis of the UTC industry. We introduce cohort analysis and time-lagged comparisons of multiple stages in the commercialization process to examine the efficiency and productivity of the industry. Our main source of data is the Association of University Technology Managers licensing surveys from 1991 through 2004. Results indicate that industry growth is slowing, and that the technology transfer process is becoming less efficient; opportunities for individual and/or collective action are noted.

138. Choudhry, Vidita, and Todd A. Ponzio. 2019. "Modernizing federal technology transfer metrics." *The Journal of Technology Transfer*: 1-16.

Nearly 40 years ago Congress laid the foundation for federal agencies to engage in technology transfer activities with a primary goal to make federal laboratory research outcomes widely available. Since then, agencies generally rely on universal metrics such as licensing income and number of patents to measure the benefit of their technology transfer program. However, such metrics do not address the requirements set by the current and previous administrations, which require agencies to better gauge the effectiveness and return on investment of their technology programs. Here we evaluate two metrics, filing ratio and transfer rate, and empirically evaluate these metrics using data from Department of the Navy's most transactionally active laboratory, as well as recently released agency-reported data available from the FY 2015 annual technology transfer report (15 U.S.C. Section 3710). We additionally propose other federally-relevant metrics for which agency data are not currently available. Results presented here indicate that these modernized metrics may potentially fulfill the requirements set by executive guidance. The study findings also point out to other metrics that are relevant to practitioners, program managers, and policymakers in the evaluation of technology transfer.

139. Demircioglu, Mehmet Akif, and David B. Audretsch. 2018. "Conditions for complex innovations: evidence from public organizations." *The Journal of Technology Transfer*: 1-24.

Despite the growing interest in understanding innovative activities, an important limitation of the current literature on innovation—both public and private—is an assumption that innovative activity is a homogeneous phenomenon. However, most innovative activities are heterogeneous in nature. One way of characterizing innovation heterogeneity is the complexity of innovations. Using data from public organizations, this paper is one of the first studies to develop a framework for and provide an empirical test of the main influences on innovation complexity within the public sector context. The empirical evidence suggests that employees' innovative behavior and cooperation, along with collaborating with important external sources and the ability to work in a complex environment, are positively associated with complex innovations in the public sector, suggesting that the influences on complex innovations span the individual, work group, and external environment levels. However, an organization's leadership quality and innovation climate do not have any statistical effect on complex innovations.

140. Estep, Judith. 2015. "Development of a technology transfer score to inform the selection of a research proposal." IEEE, 2015 Portland International Conference on Management of Engineering and Technology (PICMET). pp. 1754-1768.

Against a backdrop of changing US energy strategies, which includes increased research investments in clean energy, the utility industry needs to respond to unprecedented technology challenges. These challenges include an aging infrastructure, a growing population, and aggressive energy efficiency targets. The utility industry is investing in research to identify solutions. However, it's not enough to just develop a technology that solves an energy related problem. In order for a solution to be effective and have an impact, the technology needs to be applied - without the technology transfer component, energy strategies cannot be realized. Therefore, there is a need to understand the difficulties associated with technology transfer. This research will focus the development of a technology transfer score (TTS) that can be used to inform the selection of a research proposal. The paper includes a comprehensive literature review, development of the TT score decision model, and implementation of the score through a pilot demonstration. This research will provide valuable information to the energy industry. Knowledge is power - by identifying those attributes which contribute to successful technology transfers, the industry could take a proactive approach by ensuring that those elements are implemented and effective in their organizations. While the focus of this research is on the utility industry, the model can easily be applied to any organization that solicits technology research proposals.

141. Feeney, Mary K., and Eric W. Welch. 2014. "Academic outcomes among principal investigators, co-principal investigators, and non-PI researchers." *The Journal of Technology Transfer* 39, no. 1: 111-133.

Faculty at research universities are evaluated on a number of productivity measures including their ability to conduct research, teach, and engage in service. Research outcomes include publishing research results and acquiring grants and contracts to conduct additional research. While it is assumed that researchers who are awarded grants are more likely to publish research results, there is little research investigating the ways in which grants affect outcomes or how principal investigators differ from researchers who do not hold research grants or those who are co-principal investigators. This research seeks to understand if principal investigators are more or less productive than co-principal investigators and those who do not have grants, and if so, what explains that variation in productivity. It also examines whether women PIs are more or less productive than men PIs. This research uses longitudinal data drawn from an NSF funded survey of academic scientists in Carnegie-designated Research I universities in six fields: biology, chemistry, computer science, earth and atmospheric sciences, electrical engineering, and physics. From this national random sample of men and women scientists and engineers we investigate whether there is variation in the production of outcomes (e.g. publications, teaching, and training graduate students) among PIs, co-PIs, and other researchers. Findings show that productivity and outcomes vary significantly for PIs, co-PIs and by sex.

142. Feller, I. 2013. "Performance measures as forms of evidence for science and technology policy decisions." *Journal of Technology Transfer* no. 38 (5):565-576. doi: 10.1007/s10961-012-9264-9.

Amidst current widespread calls for evidence based decision making on public investments in science and technological innovation, frequently interpreted to imply the employment of some bundle of output, outcome, productivity, or rate-of-return measures, the promises and limitations of performance measures, singly or collectively, varies greatly across contexts. The promises reflect belief in, scholarly research supportive of, and opportunistic provision of performance measures that respond or cater to executive and legislative branch expectations or hopes that such measures will facilitate evidence-based decision-making. The limitations reflect research on the dynamics of scientific discovery, technological innovation and the links between the two that even when well done and used by adepts, performance measures at best provide limited guidance for future expenditure decisions and at worst are rife with potential for incorrect, faddish, chimerical, and counterproductive decisions. As a decision-making enhancement, performance measurement techniques have problematic value when applied to the Big 3 questions of U.S. science policy: (1) what is the optimal size of the Federal government's investments in science and technology programs; (2) the allocation of these investments among missions/agencies/and programs (and thus fields of science); and (3) the selection of performers, funding mechanisms, and the criteria used to select projects and performers.

143. Gibson, Elizabeth, and Tugrul U. Daim. 2016. "A measurement system for science and engineering research center performance evaluation." IEEE, 2016 Portland International Conference on Management of Engineering and Technology (PICMET). pp. 2782-2792.

This research is focused on gaining deeper insights into US National Science Foundation (NSF) science and engineering research center challenges and motivated to develop a method that effectively measures the performance of these organizations. While research has addressed organizational performance at the micro, or single-actor level for universities or companies and at the regional or national macro level, the middle level where the NSF centers reside is largely missing. The bulk of the cooperative research center studies use either case-based methods or bibliometric data to measure traditional research outputs. Many are excellent studies; however, they only focus on a piece of the performance measurement problem. There is a need for more research to understand how to measure performance and compare performance of cooperative research centers formed in a triple-helix type partnership involving government, industry and academia. This research begins to fill these gaps by examining outputs from a balanced perspective and introducing a hierarchical decision model that uses both quantitative and qualitative metrics for a holistic study. The proposed outcome of this research is a performance measurement scoring system that can be used for science and engineering focused research centers. The method is demonstrated using the NSF IUCRC model.

144. Hallam, C., B. Wurth, and W. Flannery. 2014. "Understanding the System Dynamics of the University-Industry Technology Transfer Process and the Potential for Adverse Policy Creep." IEEE, 2014 Portland International Conference on Management of Engineering & Technology, edited by D. F. Kocaoglu, T. R. Anderson, T. U. Daim, D. C. Kozanoglu, K. Niwa and G. Perman, 1129-1136. New York.

Numerous investigators have explored the growth and value of the technology transfer process from universities to industry. Regional and national organizations have extolled the virtues of technology transfer and the growth in technology entrepreneurship has been touted as a major contributor to regional economic development. The characteristics and structure of technology transfer organizations and processes has been discussed in literature, but from a policy perspective the effects of technology transfer policy decisions have not been modeled for their impact. This paper provides a systems dynamics approach to modeling the technology transfer process, tuned using data from the Association of University Technology Managers (AUTM) annual report. The systems dynamics model shows that a pure internal focus of a technology transfer office policy on short term licensing revenue maximization via tough licensing terms will result in a suboptimal revenue position for the university, and that a relaxation of these terms actually leads to a more optimal returns position for the university. This has broad impacts on the technology transfer process, and suggests further modeling scenarios that may introduce secondary dynamics.

145. Haustein, Stefanie, Timothy Bowman, Kim Holmberg, Andrew Tsou, Cassidy Sugimoto, and Vincent Larivière. 2014. "Tweets as impact indicators: Examining the implications of automated "bot" accounts on Twitter: Tweets as Impact Indicators: Examining the Implications of Automated "bot" Accounts on Twitter." *Journal of the Association for Information Science and Technology* no. 67. doi: 10.1002/asi.23456.

This brief communication presents preliminary findings on automated Twitter accounts distributing links to scientific papers deposited on the preprint repository arXiv. It discusses the implication of the presence of such bots from the perspective of social media metrics (altmetrics), where mentions of scholarly documents on Twitter have been suggested as a means of measuring impact that is both broader and timelier than citations. We present preliminary findings that automated Twitter accounts create a considerable amount of tweets to scientific papers and that they behave differently than common social bots, which has critical implications for the use of raw tweet counts in research evaluation and assessment. We discuss some definitions of Twitter cyborgs and bots in scholarly communication and propose differentiating between different levels of engagement from tweeting only bibliographic information to discussing or commenting on the content of a paper.

146. Ho, Mei Hsiu-Ching, John S. Liu, Wen-Min Lu, and Chien-Cheng Huang. 2014. "A new perspective to explore the technology transfer efficiencies in US universities." *The Journal of Technology Transfer* no. 39 (2):247-275. doi: 10.1007/s10961-013-9298-7.

Universities play a critical role in the complex technology transfer process that facilitates technology transformation from pure research activities to commercialization. The literature has recently focused on whether universities are efficient in this process. With a two-stage perspective, this study explores the required capabilities for universities to be efficient in technology transfer process. To explore the efficiencies in different stages of technology transfer, we apply a 2-stage process DEA method. The model considers 2 inputs, 2 intermediate variables, and 3 output variables from the Association of University Technology Management database. These variables represent funding resource, patenting activities, and licensing and entrepreneurships. Technology transfer in the 2-stage perspective includes the research innovation stage and the value creation stage. The results show that achieving efficiency in the 2 technology-transfer stages requires many different innovation capabilities; thus, most efficient universities only perform efficiently in one of the two stages. When mapping the relative site of universities in the reference network, we found that efficient universities in the research innovation stage are in a more centralized location than those in the value creation stage. By contrast, in the value creation stage, efficient universities can be identified as different reference groups for specific inefficient universities. The network visualization also helps to explain that universities must consider their relative advantages and capabilities to reach efficiency goals in different stages. The comparison between the large-scale group and the small-scale group also showed that a resource scale is critical for universities to accumulate different required capabilities for efficiencies in both stages.

147. Kellard, N. M., and M. Sliwa. 2016. "Business and Management Impact Assessment in Research Excellence Framework 2014: Analysis and Reflection." *British Journal of Management* no. 27 (4):693-711. doi: 10.1111/1467-8551.12186.

The evaluation of research impact is likely to remain an important element of research quality audits in the UK for the foreseeable future. With this paper, we contribute to debates on impact and relevance of business and management studies research through an analysis of Research Excellence Framework 2014 impact scores within the business and management unit of assessment. We offer insights into the organizational contexts of UK business schools within which impact is produced, drawing attention to the issues of linkages with research intensity, grant income generation, research team size, career stage and gender of academics, and whether impact activity is focused on private or public sector organizations and national or international reach. We put forward recommendations for managers responsible for business schools and higher education policymakers regarding management and organizational policies and processes, as well as possible changes to the rules guiding future research excellence audits.

148. Perkmann, Markus, Andy Neely, and Kathryn Walsh. 2011. "How Should Firms Evaluate Success in University-Industry Alliances? A Performance Measurement System." *R&D Management* no. 41. doi: 10.1111/j.1467-9310.2011.00637.x.

While firms increasingly engage in formal alliances with universities, there is a lack of tools to assess the outcomes of such collaborations. We propose a performance measurement system for university-industry alliances. We derive a success map from existing research on university-industry relations, indicating the causal relationships underpinning successful alliances. The success map distinguishes between different process stages, including inputs, in-process activities, outputs and impacts. We discuss specific measures for each of these stages, and how they should be deployed. The resulting framework includes both prospective and retrospective measures and subjective and objective measures. It provides research and development managers with a tool for assessing university-industry alliances that is prospective, reliable and multi-dimensional.

149. Perkmann, M., R. Fini, J. M. Ross, A. Salter, C. Silvestri, and V. Tartari. 2015. "Accounting for universities' impact: using augmented data to measure academic engagement and commercialization by academic scientists." *Research Evaluation* no. 24 (4):380-391. doi: 10.1093/reseval/rvv020.

We present an approach that aims to comprehensively account for scientists' academic engagement and commercialization activities. While previous research has pointed to the economic and social impact of these activities, it has also been hampered by the difficulties of accurately quantifying them. Our approach complements university administrative records with data retrieved from external sources and surveys to quantify academic consulting, patenting, and academic entrepreneurship. This allows us to accurately account for 'independent' activity, i.e., academic engagement and commercialization outside the formal university channels and often not recorded by universities. We illustrate this approach with data for 10,000 scientists at Imperial College London. Results indicate that conventional approaches systematically underestimate the extent of academic scientists' impact-relevant activities by not accounting for independent activities. However, with the exception of consulting, we find no significant differences between individuals involved in supported (university-recorded) and independent activity, respectively. Our study contributes to work concerned with developing appropriate and accurate research metrics for demonstrating the public value of science.

150. Piva, Evila, and Cristina Rossi-Lamastra. 2013. “Systems of indicators to evaluate the performance of university-industry alliances: a review of the literature and directions for future research.” *Measuring Business Excellence* no. 17 (3):40-54.

Despite evaluating the performance of university-industry alliances being extremely important, scholars have not developed any structured and commonly accepted systems of indicators aimed at measuring the results of these collaborations. In this article, the aim is to review the literature on the evaluation of the performance of university-industry alliances and to identify a series of issues that future studies on this topic should take into account.

151. Reed, Mark S., Sophie Duncan, Paul Manners, Diana Pound, Lucy Armitage, Lynn Frewer, Charlotte Thorley, and Bryony Frost. 2018. “A common standard for the evaluation of public engagement with research.” *Research for All* no. 2 (1):143-162. doi: 10.18546/RFA.02.1.13.

Despite growing interest in public engagement with research, there are many challenges to evaluating engagement. Evaluation findings are rarely shared or lead to demonstrable improvements in engagement practice. This has led to calls for a common 'evaluation standard' to provide tools and guidance for evaluating public engagement and driving good practice. This paper proposes just such a standard. A conceptual framework summarizes the three main ways in which evaluation can provide judgements about, and enhance the effectiveness of, public engagement with research. A methodological framework is then proposed to operationalize the conceptual framework. The standard is developed via a literature review, semi-structured interviews at Queen Mary University of London and an online survey. It is tested and refined<i> in situ</i> in a large public engagement event and applied<i> post hoc</i> to a range of public engagement impact case studies from the Research Excellence Framework. The goal is to standardize good practice in the evaluation of public engagement, rather than to use standard evaluation methods and indicators, given concerns from interviewees and the literature about the validity of using standard methods or indicators to cover such a wide range of engagement methods, designs, purposes and contexts. Adoption of the proposed standard by funders of public engagement activities could promote more widespread, high-quality evaluation, and facilitate longitudinal studies to draw our lessons for the funding and practice of public engagement across the higher education sector.

152. Rhaiem, Mehdi. 2017. “Measurement and determinants of academic research efficiency: a systematic review of the evidence.” *Scientometrics* no. 110 (2):581-615. doi: 10.1007/s11192-016-2173-1.

What is academic research efficiency and what determines the differences between scholars’ academic research efficiency? The literature on this topic has evolved exponentially during the last decades. However, the divergence of the approaches used, the differences in the bundles of outputs and inputs considered to estimate the efficiency frontiers, and the differences in the predictors of efficiency variability among scholars that are considered in prior studies, make it interesting to have an overview of the literature dedicated to this topic. Relying on a systematic review of empirical studies published between 1990 and 2012, this article proposes and discusses a framework which brings together a set of outputs and inputs related to academic research efficiency, and the individual, organizational, and contextual factors driving or hampering it. The ensuing results highlight several avenues which would help university administrators and policy makers to better foster academic research efficiency, and researchers to better channel their efforts in studying the phenomenon.

153. Rubenstein, Albert H. 2009. "Models and metrics for the technology transfer process from federal labs to application and the market." IEEE, PICMET 2009 Portland International Conference on Management of Engineering & Technology. pp. 2760-2770.

The author and his colleagues have worked with over a dozen federal agencies (as well as many industrial firms) on the process of getting new technology out of their labs and into their own innovation programs and/or into the broader markets of industry and other agencies. The focus of this paper is on metrics and flow models for the outputs, at each stage of the process, and the barriers and facilitators that impede or enhance the flow. It deals with the notorious "Valley of Death" that slows or sinks the flow of items of technology at various stages of the R&D/Innovation (R&D/I) process. It suggests a systematic methodology for identifying and measuring the impacts, outputs, barriers, and facilitators encountered in the flow. Criteria trees are suggested for connecting stage outputs to the Critical Success Factors (CSFs) of the operating units, parent organizations, and other sponsors and clients served by the labs. Some examples of common barriers and facilitators are given, including: the over-focus of many Tech Transfer Offices on "paper" Intellectual Property (IP), such as patents and licenses vs. "real" outputs and impacts such as new products and applications of technology that are transferred to and adopted by the various types of potential users of the technology. Specific examples are also drawn from studies by the author and his colleagues in the fields of: aerospace and automotive research; agriculture; transportation; healthcare; military R&D; and environment, energy, and materials R&D.

154. Sani, Nsbm, and N. I. B. Arshad. 2015." Towards A Framework to Measure Knowledge Transfer in Organizations." Edited by M. I. M. Ariff, M. N. Abdullah, Skna Rahim, N. I. Arshad, J. Jaafar and I. A. Aziz, 2015 International Symposium on Mathematical Sciences and Computing Research. New York: IEEE.

Knowledge transfer has become a common initiative in organizations to share knowledge. However, the act of measuring knowledge transfer is rarely being

measured by the organizations. This is due to the fact that there are lacks of guidelines such as model or framework to measure the process of knowledge transfer. Therefore, the main objective of this study is to adopt a framework (HOT-fit) that could guide practitioners in measuring knowledge transfer with the presence of information technology (IT) as an enabler. Significantly, this study will explore how technology would be impactful in the process of knowledge transfer. In the process of coming out with the adopted proposed framework, a deep literature studies into previous works have been conducted. Since the HOT fit evaluation framework were firstly proposed and experimented for the Health Information System (HIS), this study is focusing on extending the work by Maryati et. al into another perspective which is Knowledge Management System (KMS) specifically in knowledge transfer processes. The three fit factors which are human, organizational and technology have been brought into different view and being interpret in terms of knowledge transfer process accordingly. Results from this literature studies will lead to a proposed framework that could be used for measuring knowledge transfer practices. The adopted framework will then be assessed by conducting case study in selected organizations that implement Knowledge Management initiatives. The findings of this research will be significant to organizations in determining the strengths and weaknesses of their knowledge transfer practices as well as to be able to conduct it effectively with the support of current technologies.

155. Schuelke-Leech, Beth-Anne. 2013. "Resources and research: An empirical study of the influence of departmental research resources on individual STEM researchers involvement with industry." *Research Policy* 42, no. 9: 1667-1678.

This paper investigates the influence of departmental level characteristics and resources on individual involvement with industry using a national survey of STEM faculty. An integrative model of industry involvement is developed and tested that integrates a multi-level perspective on university-industry relations. Three measures of industry involvement are tested: the amount of time a researcher spends with industry, the number of activities a researcher engages in, and the intensity of those activities. Results of the model show that the quality of human capital in a researcher's home department is a significant influence on industry involvement. Non-federal R&D expenditures and direct industry funding also positively increase the likelihood of industry involvement. Policy and managerial implications of the results are discussed.

156. Seppo, Marge, and Alo Lilles. 2012. “Indicators measuring university-industry cooperation.” *Discussions on Estonian Economic Policy* no. 20 (1): 204.

The aim of this paper is to describe the indicators for measuring different types of collaboration activities between universities and industry. Popular indicators for measuring university-industry cooperation are the number and amount of patents or licences, but these do not express the knowledge transfer and university-industry cooperation most adequately, as the collaboration and knowledge transfer also takes place through other types of cooperation. Although it is easier use input

and output indicators for measuring university-industry cooperation, the focus should be on the economic impact of the collaboration. Additionally, relationship-based indicators should also be used. In Estonia different input factors are widely used. As university-industry cooperation is an input in innovation processes, the desired outcome should be a higher level of innovation, productivity, competitiveness, and growth, which has to be considered in the development of policies.

157. Sigurdson, Kristjan, Creso M. Sá, and Andrew Kretz. 2015. "Looking under the street light: limitations of mainstream technology transfer indicators." *Science and Public Policy* 42, no. 5: 632-645.

This study investigates the use of university technology transfer reporting standards developed under the aegis of the US-based Association of University Technology Managers (AUTM) in Canada. Given the importance to policy-makers internationally of improving the contributions of universities in transferring technology to industry, these indicators are regarded as critical to informing the policy debate. We analyze federal science and technology policy and identify how these metrics have influenced the framing of policy problems and alternatives. Next, a micro-level analysis of Canada's largest research university unveils several major weaknesses of the survey. Our study points to the need for a more critical use of the AUTM licensing data in the Canadian policy debate, and provides recommendations on the future development of these indicators and their use in public policy.

158. Tijssen, R. J. W. 2018. "Anatomy of use-inspired researchers: From Pasteur's Quadrant to Pasteur's Cube model." *Research Policy* no. 47 (9):1626-1638. doi: 10.1016/j.respol.2018.05.010.

Pasteur's Quadrant model, published by Stokes in 1997, presents a two-dimensional abstract conceptual framework that proved immensely helpful to study and discuss institutional and policy arrangements in science. However, during the last 10 years the PQ model was also applied in a series of large-scale, survey-based studies worldwide to classify individual modern-day researchers according to their research orientation and performance. This paper argues that such applications are inadequate to capture key characteristics of individual researchers, especially those within the heterogeneous 'Pasteur type' group who engage in 'use-inspired' basic scientific research. Addressing this shortcoming, Pasteur's Cube (PC) model introduces a new heuristic tool. Departing from a three-dimensional conceptual framework of research-related activities, the model enables a range of typologies to describe and study the large variety of academics at today's research-intensive universities. The PC model's analytical robustness was tested empirically in two interrelated 'proof of concept' studies: an exploratory survey among 150 European universities and a follow-up case study of Leiden University in the Netherlands. Both studies, collecting data for the years 2010-2015, applied a metrics-based taxonomy to classify individual academic researchers according to four performance categories: scientific publication output, research collaboration with the business sector, patents filings, and being engaging in entrepreneurial activities. The collective results of both studies provide more clarity on relevant subgroups of use-inspired researchers. The PC model can be used to guide empirical, metrics-based investigations of research activities and productivities, applies this approach to two case studies, and demonstrates the utility of the method while also reinforcing and enriching the growing body of literature showing that cross-sectoral and cross-functional research activities are more scientifically productive than research carried out in isolation of the context of use. Introducing the 'Crossover Collaborator' subtype helps to explain why Pasteur type researchers tend to outperform other types of researchers in terms of publication output and citation impact.

159. Tran, Thien Anh. 2016. "Decision-Making Tools: University Technology Transfer Effectiveness." *Hierarchical Decision Modeling*: Essays in Honor of Dundar F. Kocaoglu, edited by Tugrul U. Daim, 255-274. Cham: Springer International Publishing.

Academic knowledge and technology transfer has been growing in importance both in academic research and practice. A critical question in managing this activity is how to evaluate its effectiveness. The literature shows an increasing number of studies done to address this question; however, it also reveals important gaps that need more research. One novel approach is to evaluate the effectiveness of this activity from an organizational point of view, which is to measure how much knowledge and technology transfer from a university fulfills the mission of the institution. This research develops a hierarchical decision model to measure the contribution values of various knowledge and technology transfer mechanisms to the achievement of the mission. The performance values obtained from the university under investigation are applied to the model to develop a Knowledge and Technology Transfer Effectiveness Index for that university. The Index helps an academic institution assess the current performance of its knowledge and technology transfer with respect to its mission. This robust model also helps decision makers discover areas where the university is performing well, or needs to pay more attention. In addition, the university can benchmark its own performance against its peers in order to set up a roadmap for improvement. It is proved that this is the first index in the literature which truly evaluates the effectiveness of university knowledge and technology transfer from an organizational perspective. Practitioners in the area of academic technology transfer can also apply this evaluation model to quantitatively evaluate the performance of their institutions for strategic decision-making purposes.

160. Vaidya, Varun Y., Amar P. Kadaba, Alex Nieves, Fumin Shi, Limin Wang, Yi-Ling Chen, Shuqian Yu et al. 2011. "Emerging metrics in technology transfer I. Case studies in the life sciences." *International Journal of Technology Transfer and Commercialisation* 11, no. 1-2: 110-136.

Technology transfer (TT) from academia to industry is one of the key components that is required in the translation of basic research discoveries into commercial opportunities that benefit humanity. This paper examines the TT process at four premier universities and research institutions across the USA: Harvard University, Emory University, the University of Wisconsin-Madison, and The Scripps Research Institute. In this inaugural publication in a series of related publications studying multiple aspects of TT, we develop a variety of initial metrics and ratios measuring critical factors contributing to the success of TT and provide a generic model that can address certain bottlenecks in the process and enhance its efficiency.

161. Vargiu, Andrea. 2014. “Indicators for the Evaluation of Public Engagement of Higher Education Institutions.” *Journal of the Knowledge Economy* no. 5 (3):562-584. doi: 10.1007/s13132-014-0194-7.

The expression "third mission" is generally used to refer to universities’ direct and indirect contribution to society. Some authors maintain the idea that a relevant aspect of third mission concerns public engagement of universities. Relevance and visibility of institutions’ as well as scholars’ public engagement is connected with the possibility of accounting for it. The debate about the evaluation of teaching and research is quite advanced and so are assessment instruments and techniques (although far from producing generalized consensus). Confrontation on the assessment of public engagement lags behind, although some significant advancements exist. The paper presents and discusses possible indicators for the evaluation of public engagement of universities, on the basis of comparison between three reports that were chosen after analysis of both mainstream publishing and grey literature. Indicators for institutional public engagement proposed by those three reports are subsumed under a common framework which encompasses them within six domains, such as: mission, governance and overarching institutionalized strategies for public engagement; research; student engagement and educational outreach; dissemination; accessibility and use of facilities; community partnerships, stakeholders’ relations and participation in external activities. Conclusions identify a shortlist of indicators based on validity and feasibility. Some integration will also be proposed in the light of critical aspects pointed out in discussion.

162. Vaz de Almeida, Manuela, João J. M. Ferreira, and Fernando A. F. Ferreira. 2018. “Developing a multi-criteria decision support system for evaluating knowledge transfer by higher education institutions.” *Knowledge Management Research & Practice*:1-15. doi: 10.1080/14778238.2018.1534533.

This study sought to develop a multiple-criteria decision support system for evaluating transfers of knowledge from higher education institutions (HEIs) to society at large. Drawing on a panel of knowledge transfer specialists, we developed the evaluation system by completing the three phases of the multiple-criteria decision analysis (MCDA) approach. The structuring phase used the

strategic options development and analysis (SODA) methodology and cognitive mapping techniques. The evaluation phase applied the measuring attractiveness by a categorical-based evaluation technique (MACBETH), which allowed us to evaluate HEIs? local and overall performance. The third phase consisted of formulating recommendations. Assuming a constructivist process-oriented stance, this research included a real-world application of the proposed system to Portuguese public HEIs. Our study demonstrates that HEI administrators can use the techniques applied to make strategic decisions when seeking to foster the transfer of knowledge to society at large.

163. von Kortzfleisch, Harald F. O., Matthias Bertram, Dorothée Zerwas, and Manfred Arndt. 2015. "Consideration of Knowledge and Technology Transfer Characteristics for Research Evaluation." *Incentives and Performance: Governance of Research Organizations*, edited by Isabell M. Welpe, Jutta Wollersheim, Stefanie Ringelhan and Margit Osterloh, 449-463. Cham: Springer International Publishing.

Knowledge and Technology Transfer (KTT) is currently becoming the third mission for the scientific community in addition to research and education. Therefore, there is a growing need to evaluate the impact of KTT, both directly and indirectly, on industry and society. However, despite the growing importance of KTT and the considerable amount of research that has already been conducted in this field, existing approaches to research evaluation primarily focus on quantitative determinants (e.g., number of publications, patents and licenses, number of collaboration projects with industry, or of companies founded) thereby neglecting transfer-oriented aspects of research evaluation. Therefore, in this article we investigate the characteristics of KTT, and to what extent they are taken into account by existing research evaluation approaches. Our results confirm that, up until now, KTT has been infrequently considered as an approach toward the evaluation of current research. Existing evaluation approaches focus on quantitative determinants, but to some extent they fail to realize that those determinants are not equally appropriate for evaluating KTT in different scientific disciplines or traditions. Based on our results, we call for more integrative and systematic research, building a foundation to meet the requirements of the growing importance of KTT in research evaluation.

8. Research Parks

164. Liang, Wen-Jung, Chao-Cheng Mai, Jacques-François Thisse, and Ping Wang. 2019. "On the Economics of Science Parks." *NBER Working Paper Series* (February). https://www.nber.org/papers/w25595.pdf

Science parks play a growing in knowledge-based economies by accommodating high-tech firms and providing an environment that fosters location-dependent knowledge spillovers and promote R&D investments by firms. Yet, not much is known about the economic conditions under which such entities may form in equilibrium without government interventions. This paper develops a spatial equilibrium model with a competitive final sector and a monopolistic competitive intermediate sector, which allows us to determine necessary and sufficient conditions for a science park to emerge as an equilibrium outcome. We show that strong localized knowledge spillovers, high startup costs, skilled labor abundance, or low commuting costs make intermediate firms more likely to cluster and a science park more likely to form. We also show that the productivity of the final sector is highest when intermediate firms cluster. As the decay penalty, firms' startup and workers' commuting costs become lower, science parks will eventually be fragmented.

9. Research Data

165. Campbell, Stephen, Stephanie Shipp, Tim Mulcahy, and Ted W. Allen. 2009. "Informing public policy on science and innovation: the Advanced Technology Program's experience." *The Journal of Technology Transfer* 34, no. 3: 304-319.

The Advanced Technology Program (ATP) collected a unique source of data from highly innovative firms beginning in 1993. These data follow the OECD's guidelines for collecting innovation data and provide important insights for understanding the innovation process within firms. Although the data are not representative of the population of firms, there is sufficient number of firms in the dataset to test hypotheses and to provide a starting point for calls for innovation metrics. Because of the confidential nature of the data, ATP worked with the National Opinion Research Center (NORC) to create a Data Enclave so that researchers could remotely access the ATP data in a secure environment. To initiate the use of ATP data in the Data Enclave, the ATP program funded researchers to undertake research projects that use ATP data. Other organizations have joined the Data Enclave, including the Department of Agriculture and the Kauffman Foundation.

166. Tsou, Andrew, Timothy D Bowman, Ali Ghazinejad, and Cassidy R Sugimoto. 2015. "Who tweets about science?" Paper read at Issi.

Twitter is currently one of the primary venues for online information dissemination. Although its detractors portray it as nothing more than an exercise in narcissism and banality, Twitter is also used to share news stories and other information that may be of interest to a person's followers. The current study sampled tweeters who had tweeted at least one link to an article in one of four leading journals, with a focus on studying who, precisely, these tweeters were. The results showed that approximately 76% of the sampled accounts were maintained by individuals (rather than organizations), 67% of these accounts were maintained by a single man, and 34.4% of the individuals were identified as possessing a Ph.D, suggesting that the population of Twitter users who tweet links to academic articles does not reflect the demographics of the general public. In addition, the vast majority of students and academics were associated with some form of science, indicating that interest in scientific journals is limited to individuals in related fields of study.

167. Wolfe, Raymond. 2017. “Business R&D Performed in the United States Reached $356 Billion in 2015.” National Science Foundation 17-320 (August). https://www.nsf.gov/statistics/2017/nsf17320/.

Businesses spent $356 billion on research and development performance in the United States in 2015, a 4.4% increase over the $341 billion spent in 2014. Funding from the companies' own sources was $297 billion in 2015, a 5.0% increase from the $283 billion spent in 2014. Funding from other sources was $59 billion in 2015 and $58 billion in 2014. Data for this InfoBrief are from the Business R&D and Innovation Survey (BRDIS), developed and cosponsored by the National Center for Science and Engineering Statistics within the National Science Foundation and by the U.S. Census Bureau.

10. International Technology Transfer

168. Bolling, M., and Y. Eriksson. 2016. “Collaboration with society: The future role of universities? Identifying challenges for evaluation.” *Research Evaluation* no. 25 (2):209-218. doi: 10.1093/reseval/rvv043.

In order to evaluate who benefits, and how, from collaboration between universities and society, it is necessary to develop solid evaluation models. The Swedish Governmental Agency for Innovation Systems (VINNOVA) has been commissioned by the Swedish government to present an evaluation model for university-society collaboration, which is intended to be included in the future distribution of funding to Swedish universities. This makes Sweden an interesting example of the challenges associated with the implementation of a national evaluation model for university-society collaboration. The objective of this study is to identify challenges for evaluation of university-society collaboration in an academic context. We analyse the actual implementation process of a national evaluation system for university-society collaboration, by putting Swedish policy in relation to international research. The results suggest that there is broad knowledge on the complexity of university-society collaboration, and of the difficulties associated with evaluation, even if certain aspects, like the importance of teaching, networking, and gender aspects, are often overlooked. However, the discussion tends to focus on the construction of relevant indicators, while there is a widespread lack of discussion and agreement on the objectives and goals of university-society collaboration, as well as discussions on how to define the concept. The importance of these aspects is illustrated by the difficulties in Sweden with developing a legitimate assessment system for university-society collaboration.

169. Fini, Riccardo, Kun Fu, Marius Tuft Mathisen, Einar Rasmussen, and Mike Wright. 2017. “Institutional determinants of university spin-off quantity and quality: a longitudinal, multilevel, cross-country study.” *Small Business Economics* no. 48 (2):361-391. doi: 10.1007/s11187-016-9779-9.

The creation of spin-off firms from universities is seen as an important mechanism for the commercialization of research, and hence the overall contribution from universities to technological development and economic growth. Governments and universities are seeking to develop framework conditions that are conductive to spin-off creation. The most prevalent of such initiatives are legislative changes at national level and the establishment of technology transfer offices at university level. The effectiveness of such initiatives is debated, but empirical evidence is limited. In this paper, we analyze the full population of universities in Italy, Norway, and the UK; three countries adopting differing approaches to framework conditions, to test whether national- and university-level initiatives have an influence on the number of spin-offs created and the quality of these spin-offs. Building on institutional theory and using multilevel analysis, we find that changes in the institutional framework conditions at both national and university levels are conductive to the creation of more spin-offs, but that the increase in quantity is at the expense of the quality of these firms. Hence, the effect of such top–down changes in framework conditions on the economic impact from universities seems to be more symbolic than substantive.

170. Gardner, P. L., A. Y. Fong, and R. L. Huang. 2007. *Measuring the impact of knowledge transfer from public research organizations: A comparison of metrics used around the world*. Edited by J. Chen, Q. R. Xu and X. B. Wu, ISMOT'07: Proceedings of the Fifth International Symposium on Management of Technology, Vols 1 and 2: Managing Total Innovation and Open Innovation in the 21st Century. Hangzhou: Zhejiang Univ Press.

Technology transfer has been used very generally to describe the movement of ideas, equipment, and people among institutions of higher learning, the commercial sector and the public. However, this conventional approach is now evolving into the broader concept of knowledge transfer, which describes the movement of knowledge, ideas, concepts and techniques from a formative location, generally, institutions of advanced education, out to all areas of the social and economic environment. This paper will examine both traditional and innovative methods of quantifying and qualifying the benefits of knowledge transfer around the world.

171. Grimpe, Christoph, and Heide Fier. 2010. "Informal university technology transfer: a comparison between the United States and Germany." *The Journal of Technology Transfer* no. 35 (6):637-650. doi: 10.1007/s10961-009-9140-4.

Existing literature has confined university technology transfer almost exclusively to formal mechanisms, like patents, licenses or royalty agreements. Relatively little is known about informal technology transfer that is based upon interactions between university scientists and industry personnel. Moreover, most studies are limited to the United States, where the Bayh-Dole Act has shaped the institutional environment since 1980. In this paper, we provide a comparative study between

the United States and Germany where the equivalent of the Bayh-Dole Act has come into force only in 2002. Based on a sample of more than 800 university scientists, our results show similar relationships for the United States and Germany. Faculty quality which is however based on patent applications rather than publications serves as a major predictor for informal technology transfer activities. Hence, unless universities change their incentives (e.g., patenting as one criterion for promotion and tenure) knowledge will continue to flow out the backdoor.

172. Grimpe, Christoph, and Katrin Hussinger. 2013. "Formal and Informal Knowledge and Technology Transfer from Academia to Industry: Complementarity Effects and Innovation Performance." *Industry and Innovation* no. 20 (8):683-700. doi: 10.1080/13662716.2013.856620.

Literature has identified formal and informal channels in university knowledge and technology transfer (KTT). While formal KTT typically involves a legal contract on a patent or on collaborative research activities, informal transfer channels refer to personal contacts and hence to the tacit dimension of knowledge transfer. Research is, however, scarce regarding the interaction of formal and informal transfer mechanisms. In this paper, we analyze whether these activities are mutually reinforcing, i.e., complementary. Our analysis is based on a comprehensive data-set of more than 2,000 German manufacturing firms and confirms a complementary relationship between formal and informal KTT modes: using both transfer channels contributes to higher innovation performance. The management of the firm should therefore strive to maintain close informal relationships with universities to realize the full potential of formal KTT.

173. Gulbrandsen, M., and E. Rasmussen. 2012. "The use and development of indicators for the commercialisation of university research in a national support programme." *Technology Analysis & Strategic Management* no. 24 (5):481-495. doi: 10.1080/09537325.2012.674670.

Governments in most countries have set up specialised programmes to support the commercialisation of academic research. A key challenge is to develop indicators that are able to measure operation and impact. This study shows how different indicators are used to satisfy different stakeholders of a Norwegian support programme. Policy intervention is supposed to lead to additionality related to input, behaviour and output. While the support programme uses input and behavioural measures as strategic tools for its operation, policy makers are mostly preoccupied with output measures. This study illustrates how indicators develop over time, partly co-evolving with the development of the programme and the national commercialisation infrastructure. Indicators serve as incentives for the agents involved, but they may also influence the strategies of the programme that established them. The external signalling effect of indicators remains central, while its use in daily operations becomes less important with time and experience.

174. Rosli, Ainurul, and Federica Rossi. 2016. "Third-mission policy goals and incentives from performance-based funding: Are they aligned?" *Research Evaluation* no. 25 (4):427-441. doi: 10.1093/reseval/rvw012.

In competitive knowledge-based economies, policymakers recognize the importance of universities' engagement in third mission activities. This article investigates how a specific policy approach to encourage third mission engagement—the use of performance-based funding to reward universities' success in this domain—aligns with the broader goals of third mission policy. Considering the case of the UK, the first country to have implemented a system of this kind, we analyse how the system has come into being and how it has evolved, and we discuss whether its implementation is likely to encourage universities to behave in ways that are aligned with the goals of third mission policy, as outlined in government documents. We argue that the system encourages universities to focus on a narrow range of income-producing third mission activities, and this is not well aligned with the policy goal to support a complex innovation ecosystem comprising universities with different third mission objectives and strategies. The article concludes by proposing possible avenues for achieving greater alignment between incentives and policy goals.

175. Tran, Thien, Tugrul Daim, and Dundar Kocaoglu. 2011. "Comparison of technology transfer from government labs in the US and Vietnam." *Technology in Society* 33, no. 1-2: 84-93.

Technology transfer from the government sector to industry has emerged as an important activity in developed and developing countries as governments are increasing their funding for the national innovation systems with an objective of developing technologies which will improve and enhance the country's national competitiveness. However, this endeavor requires good technology transfer practices from the government R&D facilities to industry. Developed countries have embarked on this process for the past two decades and have gained some success, but further improvements are still needed. This paper compares the status of government technology transfer in a developed country, the US, and that in a developing country, Vietnam.

176. Van Looy, Bart, Paolo Landoni, Julie Callaert, Bruno van Pottelsberghe, Eleftherios Sapsalis, and Koenraad Debackere. 2011. "Entrepreneurial effectiveness of European universities: An empirical assessment of antecedents and trade-offs." *Research Policy* no. 40 (4):553-564. doi: https://doi.org/10.1016/j.respol.2011.02.001.

The phenomenon of entrepreneurial universities has received considerable attention over the last decades. An entrepreneurial orientation by academia might put regions and nations in an advantageous position in emerging knowledge-intensive fields of economic activity. At the same time, such entrepreneurial orientation requires reconciliation with the scientific missions of academia. Large-scale empirical research on antecedents of the entrepreneurial effectiveness of universities is scarce. This contribution examines the extent to which scientific

productivity affect entrepreneurial effectiveness, taking into account the size of universities and the presence of disciplines, as well as the R&D intensity of the regional business environment (BERD). In addition, we assess the occurrence of trade-offs between different transfer mechanisms (contract research, patenting and spin off activity). The data used pertain to 105 European universities. Our findings reveal that scientific productivity is positively associated with entrepreneurial effectiveness. Trade-offs between transfer mechanisms do not reveal themselves; on the contrary, contract research and spin off activities tend to facilitate each other. Limitations and implications for future research are discussed.

177. Vinig, T., and D. Lips. 2015. "Measuring the performance of university technology transfer using meta data approach: the case of Dutch universities." *Journal of Technology Transfer* no. 40 (6):1034-1049. doi: 10.1007/s10961-014-9389-0.

The objective of this study is to empirically measure the performance of Dutch university's technology transfer. Dutch universities are ranked high on research output but there is scarce evidence about the commercialization of research-based innovation. We present a novel approach to measure the performance of university technology transfer using meta data analysis. We use data on research output as meta-data to estimates the potential for technology transfer, and data about the actual technology transfer projects as measured by patents, license agreements and spin-offs. We tested our model for Dutch universities and validated it using data from private and state universities in the US. Our results suggest that most Dutch research universities have poor performance while technical Dutch universities and academic medical center perform well. We pilot-tested our model for selected US universities and the result confirm the validity of our approach. Our approach contributes to the literature on university technology transfer by adding a novel approach for measuring performance of university technology transfer while taking into account university research as the potential for technology transfer.

Appendix D. Implementation Options for Developing Learning Agendas

To help guide the development of agency learning agendas, OMB identified four components of evidence—policy analysis, program evaluation, foundational fact-finding, and performance measurement (Figure D-1). Related to performance measurement, this paper described the intramural R&D qualitative and quantitative measures and metrics that Federal agencies already collect and report through their annual technology transfer reports. These collection activities are continual and ongoing. However, gaps exist in the measuring performance of extramural R&D funding and technology transfer activities as well as broader mission impacts. Performance measurement complements other components of evidence—measures that are tracked can be used to evaluate and inform policy, such as the legal, regulatory, and administrative activities to understand how they may enhance or hinder technology transfer outcomes; specific program outcomes can be identified to connect how they support an agency's strategic technology transfer goals; and foundational fact-finding research and descriptive information can identify how many and which communities are engaged in an agency's technology transfer activities and innovation ecosystems.

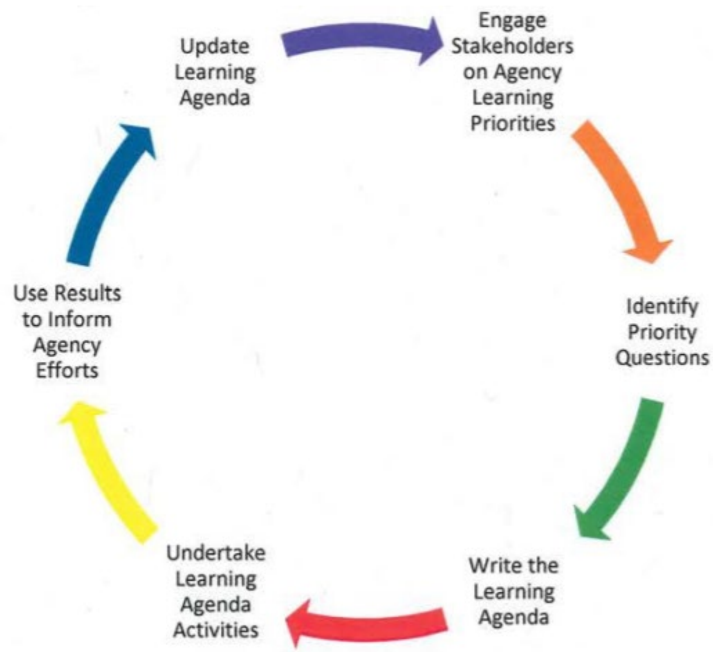
Source: GSA. n.d. "Evidence Act Toolkit: A Guide to Developing Your Agency's Learning Agenda," as modified from OMB 2019.

Figure D-1. Interdependent Components of Evidence

In practice, the process for developing a learning agenda can include the following (see Figure D-2):

> gathering stakeholders; reviewing the literature for what is already known about [a] topic; identifying and prioritizing the right questions to improve program effectiveness; developing a plan for answering those questions; implementing studies and analyses; involving key stakeholders; and acting on the findings through dissemination and diffusion of evidence around what works, for whom, and under what circumstances to program managers and agency leadership (USAID n.d.).

Agencies can use the process of developing a learning agenda as a means to identify gaps in data collection and analytical approaches for informing policymaking. This process can be applied to both short-term and long-term scales, with continuous updates to the learning agenda based on increasingly matured understanding of the efficacy of technology transfer activities.



Source: OMB. "Phase 1 Implementation of the Foundations for Evidence-Based Policymaking Act of 2018: Learning Agendas, Personnel, and Planning Guidance," OMB M-19-23, 2019.

Figure D-2. Example Learning Agenda Process

An example applying OMB's framework to address the some of the challenges mentioned in this paper is provided in Box D-1: Example of Learning Agenda Elements to Address General Federal Technology Transfer Evaluation Challenges. In terms of a strategic goal, an agency or technology transfer office may be interested in optimizing their resources, understanding they have limited staff and funds to execute their activities. Relevant questions include how they decide on the most impactful and effective means of performing their activities, in particular when impacts vary depending on the technologies, research communities, disciplines, and industries involved. Some activities that might be useful to address the priority questions include establishing working groups and identifying where data collection and further study could help fill the gaps. Example timeframes for answering the priority question could involve 3-month sprints to establish topics in learning agenda activities and a data collection plan—and more intense 6-month efforts to collect the information and analyze and report the findings. In addition, tools to be used can include multi-method approaches, including use of interviews, surveys, literature review. A review of anticipated challenges and possible solutions is useful to prepare for execution of a learning agenda, such as new policies, cyber infrastructure, and other resources that may be needed for the effort.

Box D-1: Example of Learning Agenda Elements to Address General Federal Technology Transfer Evaluation Challenges

- **Context**: The process of Federal technology transfer, whereby research discoveries, in the form of knowledge, capabilities, and technologies are transferred to other parties, is critical to the Federal Government ensuring that funding to support R&D ecosystems provides benefits to taxpayers and leads to societal impacts. Federal technology transfer resources should be maximized to their fullest extent to achieve maximum ROI, value to agency missions, and broader impacts.
- **Learning Agenda Questions**: How can Federal technology transfer processes be improved? How can outcomes across varied disciplines and industries be appropriately assessed and benchmarked? How can the Federal Government optimize the allocation of technology transfer resources? What activities lead to the most efficient or effective impacts to specific technology transfer goals or missions? What data collection is needed to address temporality concerns and improve tracking of connections between outputs leading to outcomes of interest, such as publications, patents, licenses, standards, training, workforce, startups, economic growth, and social welfare, over time and across varied scales (e.g., national and international)? What information should be maintained and made accessible to advance continuous learning?
- **Proposed Activities Needed to Address the Questions**: Activities to address these questions may span the range of evidence-building activities, including establishment of interagency groups, stakeholder engagement, workshops, roadmapping and planning exercises, and studies to fill information gaps. These activities should be integrated into broader learning agenda activities already underway across the Federal Government, in consultation with Evaluation Officers and OMB to help guide and provide progress on those efforts.
- **Timeline**: 3 months to establish interagency topics of interest for learning agenda activities; 3–6 months to develop data collection plan; 6–8 months to collect data; 6 months to conduct analysis and report findings.
- **Proposed Tools, Methods, and Analytic Approaches**: Qualitative and quantitative analysis can be employed for each of the activities. Approaches will depend on the scope and nature of the activity, for instance, policy analysis, modeling, or outcome evaluations. Multi-method approaches, such as analysis of relevant databases, interviews, and literature reviews, can be used to collect and analyze information.
- **Existing or Potential New Data Needed**: Expansion of intramural and extramural data collection on inputs, such as technology transfer funding and other resources, outputs, collaborations, and short- and long-term outcomes of interest.
- **Challenges and Proposed Solutions**: These efforts may require new infrastructure capabilities, for instance a repository of data collection tools and new systems to monitor, store, and analyze the data collected across agencies. Coordination of resources for common data infrastructure across the Federal Government could be supported through an interagency working group of the L2M Subcommittee. Differing Federal agency missions, disciplines, technologies, and industries hampers comparability. Development of a taxonomy that classifies the landscape of Federal technology transfer activities and their expected outcomes and development of relevant discipline- or industry-specific metrics could improve comparability and benchmarking.

Other Considerations for the Development of Learning Agendas

In many ways, agencies may already perform activities supporting the development of a learning agenda for technology transfer. The development of learning agendas can build upon existing efforts related to strategic planning and budgeting, stakeholder engagement and communication, and data collection. The Evidence Act Toolkit created by the General Services Administration (GSA) may provide additional reference materials for agencies to consider when developing learning agendas specific to their technology transfer activities, including a workbook and sample templates.[28]

- **Alignment of a Technology Transfer Learning Agenda with Strategic Planning and Budgeting**—Efforts to develop a Federal-wide or agency-level learning agenda specific to technology transfer should consider and align with strategic planning and R&D priorities already identified at the national or agency levels, as appropriate. Federal agencies develop and continually update strategic plans and priorities related to their R&D and innovation goals. These strategic plans provide information about priorities for R&D investments and direct budgeting decisions. Although these may not be specific to technology transfer, they may include technology-transfer-related goals, such as the advancement of certain technologies, scientific fields, and research communities in support of their missions. These plans may be in the form of strategic roadmaps, blueprints, implementation plans, and other planning and policy documents that are updated on an annual, biannual, quadrennial, or decadal basis, or longer.
- **Engagement and Communication with Stakeholders**—The development of learning agendas may involve stakeholder engagement and other communication and outreach efforts to understand the landscape of technologies, markets, and opportunities in which further evidence is needed. Federal agencies solicit public or targeted community group perspectives via Requests for Information and other solicitations and notices; workshops, roundtables, listening sessions, and various other engagement activities; and through the use of Federal Advisory Committees, federally funded research and development centers, and expert panels, such as those convened under the National Academies of Sciences, Engineering, and Medicine. These inputs inform agency leadership and policymakers in the development of their strategic plans, priorities, and budget decisions.
- **Data Collection and Expectation Setting—**As suggested by the Commission on Evidence-Based Policymaking, “learning agendas can be used to communicate research priorities to external partners to help catalyze targeted evidence-building activities outside the Federal Government” (Commission on Evidence-Based Policymaking 2017). A learning agenda in this case can communicate the targeted evidence-building strategies and how those activities are expected to inform the strategic priorities for technology transfer. Existing strategic planning efforts could be leveraged when developing Federal-wide or agency-specific learning agendas (refer to Box D-2: USDA’s Science Blueprint Communicates Evidence-Building Efforts). Agencies already use key performance indicators, targets, and

[28] Evidence Act Toolkits: https://oes.gsa.gov/toolkits/.

descriptive milestones in their strategic planning and reporting of progress toward their technology transfer goals, which could be leveraged to understand where there are gaps in information and how a learning agenda could support advancing those efforts (Performance.gov n.d.).

Box D-2: USDA's Science Blueprint Communicates Evidence-Building Efforts

Agency-level strategic planning documents can communicate specific goals and metrics associated with information collection for technology transfer activities. For instance, USDA's Science Blueprint underscores the importance of building evidence by articulating specific goals for related activities under each of its objectives and strategies (USDA 2019). It outlines the value of "science-based, data-driven decisions and [communication of] the impacts of those decisions to our stakeholders." Evidence-building goals in the Science Blueprint include the expansion of reporting on and analysis of the adoption and deployment of technologies, fostering effective methods for evaluating quantitative information from research programs, and increasing the use of research outcomes, among others.

Some leverage points for agencies to consider as they start developing their learning agendas include:

- Involving the agency's Evaluation Officer and the OMB Evidence Team—Each of the 22 agencies covered under the CFO Act must post who their Evaluation Officers are on their websites. Some agencies have dedicated Evaluation Offices in which an Evaluation Officer most likely resides. In other agencies, the Evaluation Officer may be closely connected with the finance or budget office, a data office, or in a policy or strategic planning shop—for instance under a Director, Administrator, or other agency head's office. For HHS, the Evaluation Officer is the Assistant Secretary for Planning and Evaluation. For USDA, it is the Director for the Budget and Program Analysis. While NIST is not a CFO Act agency covered under the Evidence Act, the DOC is. At DOC, the Evaluation Officer is the Chief Data Officer.

  In addition, OMB's Evidence Team remain useful resources for agencies as they consider applying a learning agenda for their technology transfer activities. The Evidence Team has been at the forefront of developing the Federal guidance for learning agendas.

- Integrating technology transfer priorities into draft learning agendas—While there has been continued planning since the Evidence Act to develop agency-level draft learning agendas, there may be opportunities to inform its development or future updates to these plans. In addition to working with their agency's Evaluation Officers, technology transfer officials may wish to identify ways to integrate their learning agendas into the broader agency-level agendas being developed under the Evidence Act. For instance, an agency's learning agenda plans are due to OMB by September 2021. This presents an opportunity to explicitly outline how technology transfer activities align with the agency's broader goals and mission, and at the minimum, begin the discussion for integrating technology transfer in these efforts.

- Coordinating development across agencies and existing working groups—There is an opportunity to coordinate and share development and progress on learning agendas across Federal technology transfer offices. This could help create a community of experts that are continuously learning from each other on the topic. Shared resources can provide models for future efforts or as new technology transfer offices decide to pursue their own learning agendas.
- Engaging with established research communities—Engaging with established research communities, such as across federally funded research and development centers (e.g., STPI) and the academic Science of Science research community, can provide technology transfer offices with additional expertise—including trained evaluators—to support their learning as they strengthen their own evidence-building capacity.

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Abbreviations

API	application programming interface
CAP	Cross-Agency Priority
CRADA	collaborative research and development agreement
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOT	Department of Transportation
ERC	Engineering Research Center
FLC	Federal Laboratory Consortium for Technology Transfer
GPS	global positioning system
GSA	General Services Administration
HUD	Department of Housing and Urban Development
IDA	Institute for Defense Analyses
I-O	input-output
L2M	lab-to-market
MEP	manufacturing extension partnership
MTA	material transfer agreement
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
ORTA	Office of Research and Technology Applications
OSTP	Office of Science and Technology Policy
PART	Program Assessment Rating Tool
PMA	President's Management Agenda
R&D	research and development
ROI	return on investment
SBDC	Small Business Development Center
SBIR	Small Business Innovation Research
SMRB	Scientific Management Review Board
ST5	Strategy Team Five
STPI	Science and Technology Policy Institute
STTR	Small Business Technology Transfer
TRL	technology readiness level
USDA	U.S. Department of Agriculture
USGS	United States Geological Survey

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

To assist in measuring the effectiveness of Federal technology transfer activities, the Office of Science and Technology Policy (OSTP) requested that the Science and Technology Policy Institute (STPI), in coordination with the National Science and Technology Council's Lab-to-Market (L2M) Subcommittee's Strategy Team Five interagency working group, develop this paper. The paper consists of three sections: an overview of reporting mandates and Federal technology transfer metrics provided in annual reports, a description of common challenges in assessing the value of Federal technology transfer activities, and suggested approaches to address these challenges. Appendices provide additional information and resources to support continued exploration and implementation of the approaches described in this paper, including an annotated bibliography of 177 published articles and reports related to assessing the value of R&D and technology transfer intended to serve as an informational resource for Federal technology transfer practitioners.

15. SUBJECT TERMS

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