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Identifying NIST Impacts on Patenting: A Novel Data Set and Potential Uses

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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.

Key words: economic impact; innovation metrics; patent citations; technology transfer.

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1. Introduction: NIST and Inventive Activity

The mission of the National Institute of Standards and Technology (NIST) is to "promote U.S. innovation and industrial competitiveness." To meet this mission, NIST scientists produce a great variety of scientific and technical outputs. NIST scientists patent and publish in peer-reviewed journals, but they also produce additional technical outputs such as Standard Reference Data (SRD), Standard Reference Materials (SRMs), NIST Technical Series Publications, and a variety of other less formal technical outputs. Omitting the impacts of this broader set of NIST outputs excludes key technology transfer tools relied upon by NIST scientists. Unfortunately, that is exactly what many traditional innovation measures do.

Patents are one widely used measure of innovation and invention; NIST has historically measured its impact on inventive activity by counting the number of patents issued each year to NIST-employed

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inventors. Annually, the number of NIST-assigned patents[1] varies, but, as Fig. 1 shows, is rarely over 20. This narrow measure misses many types of NIST technical outputs and does not indicate when other inventors use NIST science.

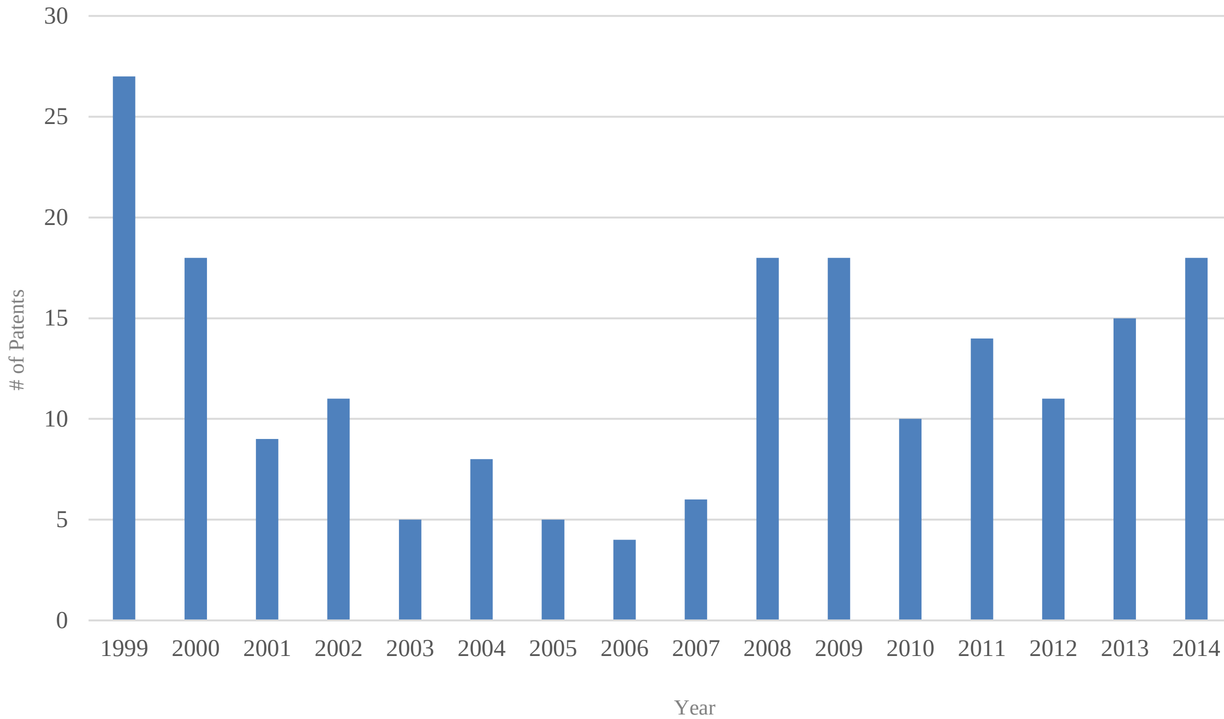

Fig. 1. NIST-Assigned Patents.

Patent references, on the other hand, do indicate use of prior scientific and technical outputs. In the United States, it is the duty of patent applicants and their attorneys to cite all prior art at the time of the patent application. Economic research finds that patent references to prior art, such as patents and publications, are an important indicator of knowledge flow. However, inventors also use NIST data and reference materials to calibrate their scientific equipment, use NIST software and algorithms, and cite less formal outputs such as NIST workshop presentations. Therefore, to fully measure knowledge flow from NIST science we identify references to a broader array of technical outputs beyond NIST-assigned patents and NIST-authored peer-reviewed publications. A narrower focus solely on NIST-assigned patents likely understates the true impact of NIST on inventive activity.

In light of the limitations of counting only NIST-assigned patents, and spurred on by the 2011 Presidential Memorandum—*Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses*—NIST adopted [1] a new and broad definition of technology transfer that would capture the multiple vectors used by the institute to transfer knowledge and capabilities to its stakeholders.

"Technology transfer is the overall process by which NIST knowledge, facilities, or capabilities in measurement science, standards, and technology promote U.S. innovation and industrial competitiveness in order to enhance economic security and improve quality of life. [This] NIST definition of technology transfer encompasses many means of transferring technology. Thus, it includes knowledge transfer, the act of transferring knowledge from one individual to another by means of mentoring, training, documentation, or other collaboration. Commercialization, another means of technology transfer, is the adoption of a

[1] The United States Patent and Trademark Office keeps data on both patent inventors and patent ownership, assignment. Typically, NIST retains or shares ownership of intellectually property but at times through prior or subsequent agreement ownership of NIST-invented IP is assigned to a third party. For simplicity, we refer to all NIST-invented IP as NIST-assigned IP.

technology into the private sector through a business or other organization and is also included within the proposed definition."

With this new definition of technology transfer, new metrics need to be developed to enable the measurement and assessment of the full scope of NIST's technology transfer activities. As a first step in developing these new metrics, NIST worked with an independent third-party to construct and analyze [2] a group of new datasets containing NIST technical outputs and indicating the usage of these outputs. Together, these data comprehensively examine NIST's impact on inventive activity. This paper presents findings from the analysis of these novel data and identifies potential new metrics for more accurately assessing NIST's impact on inventive activity.

2. Using Citation Analysis to Identify Impacts on Inventive Activity

As noted, in the United States, patent applicants and their attorneys have a duty to reference (or 'cite') all prior art, of which they are aware, that may affect the patentability of their invention. Additionally, patent examiners may also add references to patents. Patent citation analysis centers upon the links between generations of research that are made by these prior art references. Jaffe and de Rassenfosse [3] provide a recent comprehensive review of research that analyzed the economic value of citations, the value of citation as indicators of knowledge flows, and numerous other topics. This research notes the frequent use of patent-to-patent citations, government interest searches, and, more recently, patent-to-paper citations. A notable absence from this prior work is the analysis of patent citations to technical reports and other varieties of scientific outputs that are frequently used by researchers. For public research institutes such as NIST, this previously overlooked class of scientific output represents a significant portion of the laboratory scientific outputs and an important technology transfer tool. Table 1[2] shows the variety of technical outputs identified in these data.

Patent citation analysis has been used extensively to trace knowledge flows and technological developments. Jaffe and Lerner [4] and Jaffe and Trajtenberg [5] provide additional reviews and critiques of patent citation analysis. Even if these references are a "noisy" indicator [6], studies show there is a strong positive correlation between citations and technological importance [7] as indicated by awards [8], expert judgement [9], and continued payment of maintenance fees [10]. Research has also found a positive relationship between patent citation indicators and business financial performance.[3] Additionally, patent-to-publication citations have been used to indicate application of science to technology, [11, 14] as well as measure knowledge transfer from public [15] and federal scientific institution [16-21]. Roach and Cohen [15] conclude that references to non-patent publications are a better indicator of knowledge flow than patent-to-patent citations. Finally, Breitzman [22, 23] uses patent references to demonstrate knowledge transfer from voluntary consensus standards.

As noted above, a key limitation in prior work is the limited focus on patent citations to other patents and peer-reviewed publications in technology transfer. A significant portion of NIST scientific outputs lie outside these two categories. NIST produces a wide variety of research outputs such as SRMs, SRD, NIST Technical Series publications, workshop presentations, and other informal scientific outputs. A novel and important contribution of this analysis is, for the first time, to explore potential connections between this broader range of scientific and technical outputs and invention. Table 1 provides an overview and examples of the variety of NIST scientific and technical outputs that have been cited by patents. The table also demonstrates the difficulty of using non-patent references (NPRs) as they are free form text and do not have a standardized citation format.

[2] The scheme used to classify technical reports and other varieties if scientific outputs, defined as grey literature in this report, was developed by inspecting and categorizing the results of patent citation searches. The authors would like to thank Nicole Kuehl of the Technology Partnerships Office and Heather Evans of the Program Coordination Office for their contributions to this effort.

[3] Research has examined correlation with market valuations [11], stock price movements [12], as well as sales and profitability [13].

Table 1. NIST Technical Outputs: Types and Cited Examples as Appearing in Patents

Traditional Technical Outputs	
Type of Technical Output	**Sample Citations to NIST Output**
1. NIST-Assigned Patents	US Patent Number 05356756, Application of microsubstrates for materials processing
2. NIST-Government Interest Patents	US Patent Number 07330404, Near-field optical transducers for thermal assisted magnetic and optical data storage, Seagate Technology Plc
3. NIST-Authored Peer-Reviewed Publications	Dulik, Evaluation of Commercial and Newly synthesized Amine Accelerators for Dental Composites , J. Dent. Res. 58 (4): 1308 1316, (1979).
Grey Literature	
Type of Technical Output	**Sample Citations to NIST Output**
4. Educational Networking	Self-Organizing Neural Network Character Recognition on a Massively Parallel Computer, Wilson et al, NIST, International Joint Conference on Neural Networks, Proceeding, II, pp. 325 329, Jun. 1990, San Diego, Calif
5. Software/Standard Reference Databases/Algorithms	NIST, "Advanced Encryption Standard (AES)", FIPS Publication 197, 52 pages, Nov 26, 2001. http://www.nsrl.nist.gov/, National Software Reference Library, printed from website May 15, 2012, 1 page.
6. Standard Reference Materials/Resource Materials/General Information	NBS SRM-484, Magnification Standard Reference Material, NBS RM-100 Resolution Test Specimens published by Office of Standard Reference Materials, Nat'l Bur. Stands, Washington D.C
7. NIST Technical Series Publications (not peer-reviewed journal)	Stevens, Nat'l Bur. Stands Technical Note 112, Automatic Character Recognition A State of the Art Report, May, 1961. pp. 109 113, 152.
8. Joint Partnership Publications (not peer-reviewed journal).	"Thermal Characterization of Electronic Packages--Standardization Activities Status", Frank F. Oettinger, NIST, EIA JEDEC JC-15 Committee on Electrical and Thermal Characterization of Semiconductor Packages and Interconnects, Sep. 26, 1991.
9. Other NIST publications	Planar Near Field Measurements on High Performance Array Antennas, by A. C. Newell, et al., 1974, Nat'l Bur. Stands, Boulder, Colorado.
10. Memoranda/Correspondence/Inquiries	Peter L. Bender, Nat'l Bur. Stands, Private Communication, 1978.
11. "Other"	Sifting Through Nine Years of NIST Clock Data with TA2, Marc A. Weiss, Time and Frequency Division, NIST and Thomas P. Weissert, LiteroPhysics.

3. Methodology

To trace knowledge flow and transfer using citation analysis we identify citation links within U.S. patents ("citing patents") to earlier NIST scientific and technical outputs ("cited NIST outputs"). The citing patents draw from a database of all granted U.S. patents and published U.S. patent applications from 1969 to 2015. This database contains detailed information including inventors, assignees, titles, abstracts, patent classifications, and application and issue dates. In addition, this database contains all prior art references listed on the front page of patents, including references to earlier patents and to other non-patent literature.

Prior art references to items other than patents are typically referred to as Non-Patent References (NPRs). These NPRs can be to any published document, including scientific journal articles, conference papers, standards documents, and references to less formal "publications" such as brochures and even personal communications. NPRs are cited in patents as free text. Therefore, NPRs are much more difficult to work with than patent references as inventors are not required to use a standard referencing format. However, it is this detailed prior art reference information that makes large-scale citation studies possible.

Citation studies typically begin with detailed information on the research outputs that may ultimately be cited by inventors. Researchers then devise search strategies to identify these research outputs in citing patent NPRs. Table 2 details the sources and methodology for such detailed data on NIST technical outputs. We use existing NIST administrative data maintained by the NIST Technology Partnerships Office that contains detailed information on each patent application and patent issued to NIST employees. We also leverage a novel database containing all NIST-peer-reviewed publications since 1900 constructed using Thomson-Reuter's Web of Science.[4] This data set contains key detailed data on the publication (authors, affiliations, journal name, article title, article abstract) as well as the number of citations to the article within peer-reviewed literature. For the remaining broad categories of NIST technical outputs, inventions resulting from research funded by NIST but performed by third parties and NIST-authored grey literature (See Table 1 above and definition below), we lack such detailed lists of NIST outputs and therefore must devise an alternative strategy.

It is these alternative strategies that allow us to move beyond the narrow areas of NIST-owned patents and formal peer-reviewed publications. These additional search strategies allow us to capture references to inventions created by third parties using NIST funding. More importantly, this approach allows us to identify references to NIST research outputs such as SRMs, SRD NIST Technical Series publications, NIST workshop presentations, and other less formal technical outputs which we collectively define as NIST "grey literature." The analysis examines the role of grey literature as a whole and considers the impact of distinct types of technical outputs as detailed in Table 1 above. Where a Government contractor retains U.S. domestic patent rights, the contractor is under an obligation to indicate that the government has certain licensing rights to the invention.[5] We created the list of patents produced by NIST funded research by searching the Government Interest section of patents for all variants of the NIST name while accounting for potential term confusion.[6] While NPRs to journal articles do not typically list author affiliations, references to NIST grey literature typically either identify NIST or its websites, or contain keywords uniquely associated with NIST. For this reason, we were able to search NPRs of all U.S. patents (1969–June 2015) for NIST name variants accounting for possible term confusion and other keywords related to NIST research outputs as detailed in Table 2.

Identifying references within citing patents to cited NIST-assigned patents and cited NIST Government Interest patents is straightforward. Citing patents lists the patent numbers of each cited patent, so we simply search for those patent numbers listed in NIST technical output databases. For NIST peer-reviewed publications, identifying the citing patent references to NIST outputs is slightly more complicated. Because NPRs are not standardized (see Table 1), there are many possible variants and abbreviations of journal names. To match the NPR citations to the standardized NIST publication data, we leverage a proprietary journal name thesaurus and scored field matching algorithm that compares the journal name, article title, and author name. Low scores indicate a match on relatively few criteria and are not considered matches. Moderate scores are manually inspected to ensure a correct match, and high scores are considered a correct match. Details are provided in Breitzman and Thomas [2].

References to these varied NIST outputs indicate that businesses and other organizations have adopted and used NIST knowledge, facilities, or capabilities in their own inventions. For three of the four broad categories identified in Table 2, we have detailed data on the entire universe of that type of technical output. We have a complete list of every NIST patent (NIST-assigned and NIST Government Interest) and peer-reviewed publication whether or not they are eventually referenced. We also have detailed information such as author/inventor, title, abstract, publication year, and citation information for each technical output. For grey literature, we only have data on those publications that are subsequently referenced. Because the source of the data is the actual unstructured NPR within citing patents, the data need to be further cleaned and parsed to produce even the most basic analytical values.

[4] NIST subscribes to the Science Citation Index Expanded and Conference Proceedings Citation Index- Science databases. Because NIST does not maintain a historic database of all peer-reviewed publications, the publications database was created using the Organization-Enhanced search feature.

[5] Where a Government contractor retains U.S. domestic patent rights, the contractor is under an obligation by virtue of 35 U.S.C. 202(c)(6) to include the following statement at the beginning of the application and any patents issued thereon:"This invention was made with government support under (identify the contract) awarded by (identify the Federal agency). The government has certain rights in the invention."

[6] Jaffe and Lerner [24] demonstrate both assignees and government interest sections need to be searched to identify the complete set of government inventions. Indeed, the authors demonstrate that in order to identify the outputs from intramural research both patent sections need to be searched.

Table 2. NIST Technical Outputs: Sources and Methodology

NIST Technical Output Data	Source/Methodology	Citation Identification Methodology
1. NIST-Assigned Patents	NIST Technology Partnerships Office, administrative data	Search Prior Art References of all U.S. patents (1969–June, 2015) for exact patent number in NIST TPO administrative data.
2. NIST Government Interest Patents	Search the Government Interest field of all U.S. patents (1969–July, 2015) for various forms of the full agency name – National Institute of Standards and Technology.[7]	Search Prior Art References of all U.S. patents (1969–June, 2015) for exact patent number in NIST scientific and technical output data.
3. NIST Peer-Reviewed Publications	Thompson-Reuter's Web of Science[8] (Science Citation Index Expanded and Conference Proceedings Citation Index-Science), organization enhanced search, 1900-2015	Scored field matches between non-patent references of all U.S. patents (1969–June, 2015) and NIST-authored publications using a proprietary journal name thesaurus.[9]
4. NIST Grey Literature Publications	Not Available	Search non-patent references of all U.S. patents (1969–June, 2015) for keywords related to NIST, such as NBS, Nat*Bur*St*, Nat*Inst*St*, FIPS, Fed*Inf*Proc*St*, NIST*, etc., accounting for possible term confusion

For this work we attempt to construct only the most basic analysis variables for grey literature publications. Namely, we attempt to identify the total number of patent citations to a particular grey literature output, and publication year for each grey literature output. To identify the total number of citations for each document, we remove all special characters and spaces from the NPR text field and compare the first 50 characters of the text field. We consider any two citations with identical initial 50 characters to be the same grey literature publication.[10] In addition to this, we use certain keywords common to certain NIST publications (e.g., "FIPS" AND "180-2") to further identify individual publications.[11] The end result is that of the 8468 citations to grey literature publications, we identified 2998 unique publications, 941 of which had been cited multiple times. Identifying publication year, assuming it was present in the unstructured NPR, was straightforward. We were unable to identify publication year for just 841 of the 8468 grey literature cited publications. The lag, or time between publication of the cited grey literature and subsequent issuance of a citing patent, ranged from 0 to 81 years.

4. Impact and Potential Use of Data

The primary purpose of this project was to produce a novel dataset that can be used to identify usage of NIST scientific and technical outputs and analyze a host of formal and informal technology transfer practices. This paper describes the data, presents descriptive results, and develops limited findings based on the descriptive analysis. Causal analysis and formal analysis of explicit technology transfer practices are left for future work.

4.1 Measuring the Magnitude and Breadth of NIST Impacts

Figures 2 and 3 show the magnitude of NIST impact on inventive activity and highlight the diverse channels through which these impacts are felt. In total, there are over 34,000 references to NIST research outputs between 1970 and June 2015. The plurality of these references are to NIST peer-reviewed

[7] Searching the Government interest section for "NBS or Nat*bur*" identifies four patents (Patent Numbers: 4447743; 4836869; 4974113; 4987526) issued between 1975 and 1990 that were omitted from this analysis.
[8] A commercially available product is identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by NIST, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.
[9] Details of the scored matching system are provided in the Breitzman and Thomas [2].
[10] We examined stricter 75 and 100 character matches but rejected these as they failed to correctly match documents.
[11] The computer code is available upon request.

publications, but references to NIST grey literature and Government Interest patents[12] each account for over 25 % of the references. Over time, the number of annual citations has risen. In 2014, there were more than 4500 references in more than 3000 unique patents.

Given overall increases in patenting and natural growth in the collection of NIST outputs, normalization of citations or comparison to other similar institutions is needed to identify the extent to which these trends indicate an increase in impact or relevance, rather than general trends in patenting and an accumulation of NIST outputs. Breitzman and Thomas [7] examine citations to NIST patents using established normalization techniques. While NIST-assigned patents underperform patents with a similar technological focus and age, the limited number of patents—just 122 patents between 2005 and 2014—diminishes the significance of this result. On the other hand, NIST Government Interest patents are cited over 60 % more frequently than expected. A key contribution of this work is to measure citations to scientific outputs beyond NIST patents. Due to the novelty of this effort, there are no established normalization techniques for patent-to-publication citations. Therefore, patent to NIST paper and patent to NIST grey literature citation trends are compared to publications from a selective group of journals and a leading academic institution, respectively. By comparing growth rates relative to the number of citations in 2000, we control for differences in the volume of annual output. The growth rate in NIST publication citations has outpaced the growth in patent citations for a highly selective group of patents and publications. The growth in references to NIST grey literature has outpaced the growth in references to grey literature from the Massachusetts Institute of Technology (MIT).[13]

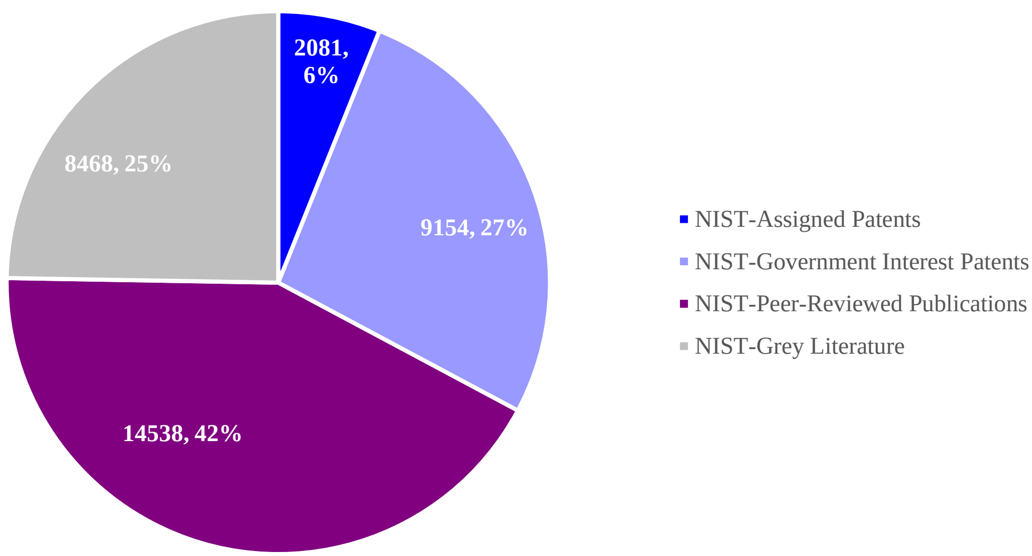

Fig. 2. Citations to NIST Technical Outputs 1975-2014.

[12] The data demonstrate that over 90 % of the patents identified through the Government Interest search are attributable to NIST extramural programs. Citations to these patents are a NIST impact but not indicative of technology transferred from NIST laboratory research programs.

[13] Due to a lack of established benchmarks and normalization approaches for publications and grey literature, growth rates in publication and grey literature citation rates were compared to previous work as detailed by Breitzman and Thomas [2]. Ideally, normalization would utilize the total number of publications, peer-reviewed and grey literature, produced, but this is difficult if not impossible particularly in the case of grey literature which includes many informal technology transfer tools including even private communications.

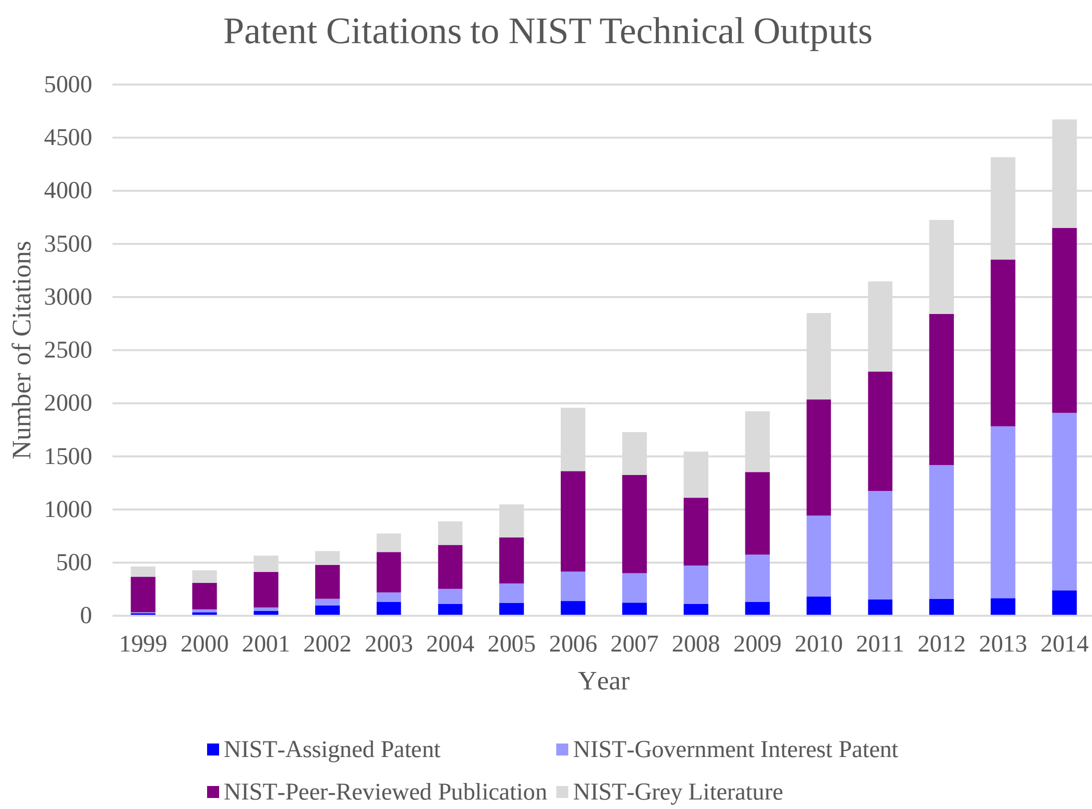

Fig. 3. Citations to NIST Technical Outputs by Type of Cited Output.

Patent citations, references within patents to previous NIST laboratory technical outputs, are an important indicator of knowledge transfer and indicate usage of NIST science. Further, citations demonstrate the breadth of how NIST impacts invention and innovation. Significantly, over 90 % of NIST's impact on invention and innovation occurs through NIST peer-reviewed and non-academic publications.

Breitzman and Thomas [2] report that citations to NIST peer-reviewed publications grew faster than citations from the most prolific patenting companies to papers in leading journals. Similarly, citations to NIST grey literature grew almost nine-fold between 2000 and 2014. This is higher than the growth rate associated with citations to MIT grey literature. Breitzman and Thomas [2] find the performance of NIST technical outputs "impressive."

4.2 Measuring the Variation of Usage of NIST Technical Outputs

The data can also be used to examine citation patterns across different companies, industries, and technology sectors. This allows us to identify whether different stakeholder groups cite different types of NIST technical outputs. Breitzman and Thomas [2] examine the more detailed categorization identified in Table 1 and present results for various companies, industries, and technologies. For brevity, Fig. 4 only shows the results by industry, and uses the broad grey literature classification scheme rather than the eight detailed categories listed in Table 1. The results clearly show that particular industries rely on a variety of NIST technical outputs, and there is significant variation across industry inventors with respect to the type of NIST technical output cited. So, while industrial equipment relies heavily on peer-reviewed publications, the software industry relies more frequently on grey literature. Although not presented here, similar results

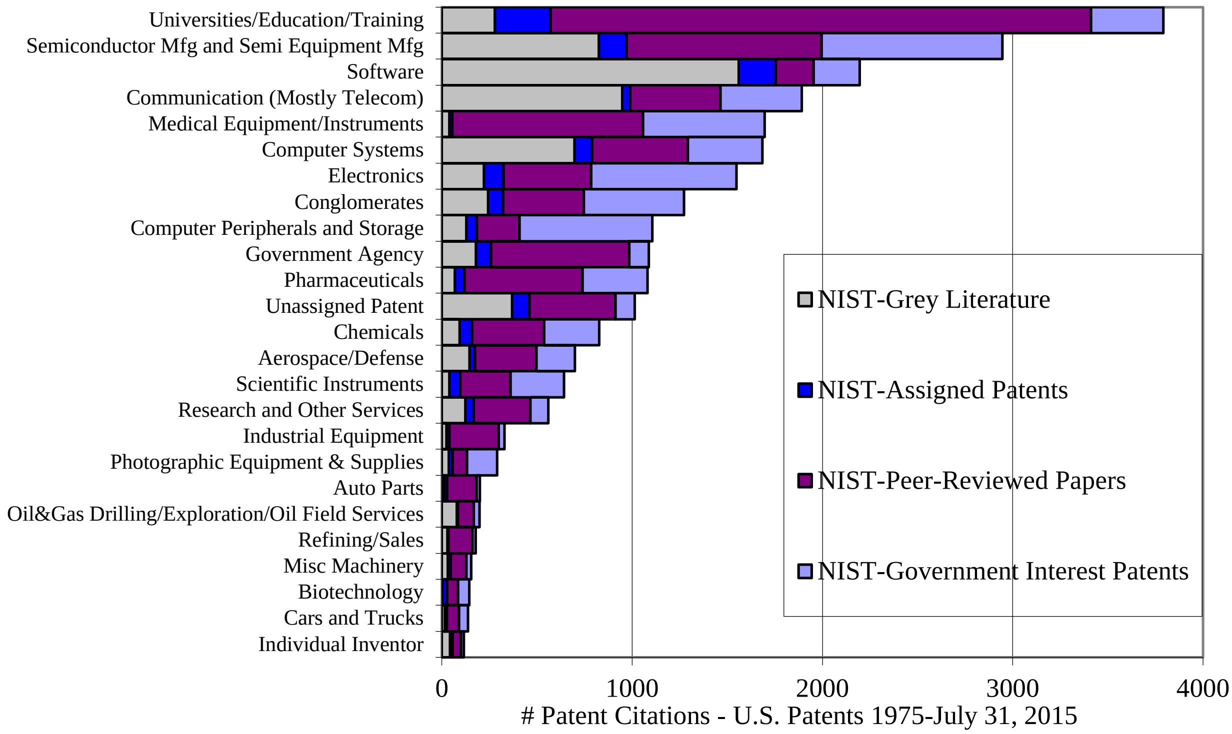

Fig. 4. References to NIST Technical Outputs by Industry.

hold when analyzing citations across companies and technology classification. Different types of NIST technical outputs, different technology transfer tools, are used by different sectors and companies. Breitzman and Thomas [2] show that companies within the same industry rely upon different types of NIST technical outputs. To the extent that NIST relies on a limited set of technology transfer tools (e.g., reliance on publications to the exclusion of technical outputs), there is a risk that NIST knowledge and capabilities will not be transferred to and adopted by businesses and other organizations. Similarly, technology transfer policies that promote one mechanism (e.g., patents) over other technology transfer tools could have the unintended consequence of reducing NIST's impacts on industry invention. Finally, the results demonstrate the importance of including grey literature in any analysis of NIST technical outputs. Nearly all industries use grey literature as a technology transfer tool and for some such as software, communication, and computer systems, grey literature plays an outsized role in technology transfer.

4.3 Measuring the Distinction between Scientific and Technological Impact

The data can also be used to focus explicitly on NIST intramural research activities and the associated patent citations. For example, Fig. 5 plots citations to NIST peer reviewed publications and examines the correlation between patent and peer-reviewed literature citations. The chart[14] shows how many times each peer-reviewed publication was cited by a patent and how many times it was cited by a publication. For example, the marker near the lower right-hand corner shows a NIST article that was cited 4500 times by

[14] Two outlier publications are not presented in this chart. The patent and publication citations (# patent citations, # paper citations) for these two papers were (277, 3715) and (85,13151) respectively. The first was the paper with the greatest number of patent citations and the latter had the greatest number of paper citations.

other articles, but has been referenced by one patent as prior art. The figure shows there is generally a positive correlation between patent and paper citations. Of the 3582 papers that are cited as prior art in patents, 93.4 % are cited by at least one paper as well. However, the figure also makes it very clear that there are papers that are highly cited by other publications, but not cited as prior art in patents. Similarly, there are NIST papers that have a notable number of patent references, yet have not received a single citation within the peer-reviewed literature. The result indicates that there may be different drivers for scientific and technological impact. Citations within peer-reviewed literature are a common indicator of scientific impact, and patent citations are a commonly used indicator of innovation and technological impact. The results above demonstrate that there are NIST publications highly cited by either patents or publications, but not both. In Fig. 5, there is a concentration of publications along each axis. Given this distinction between scientific and technological impact, measuring NIST impact exclusively though indicators of scientific impact may not ensure that NIST meets its mission to promote U.S. innovation and industrial competitiveness.

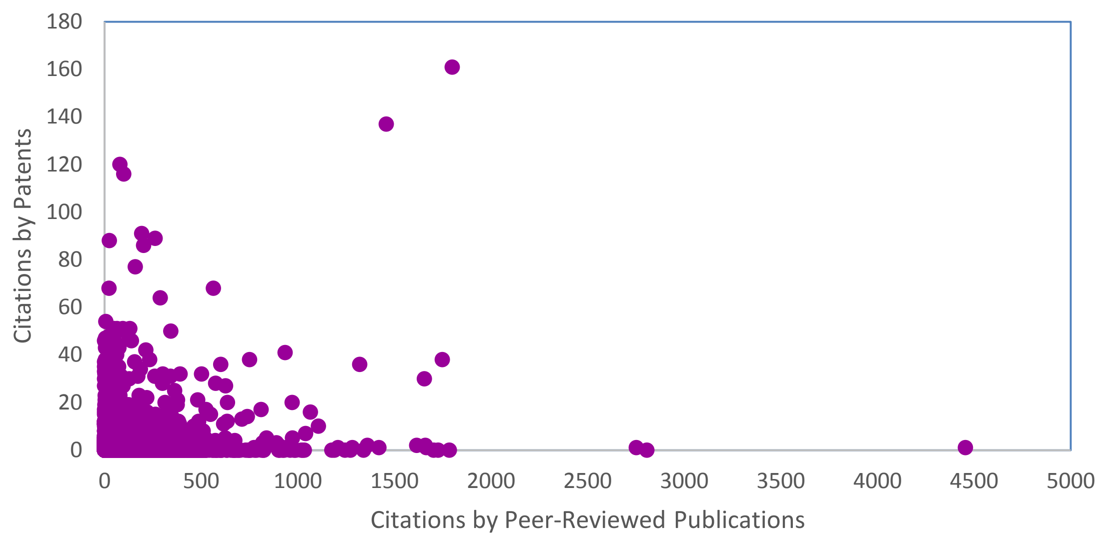

Fig. 5. NIST Peer-Reviewed Publications: Citations by Publications and Patents.

4.4 Measuring the Usage and Timeliness of NIST Technical Outputs

By using the publication and issuance dates available for patents and peer-reviewed publications as well as the date and grouping data for grey literature, the data can be used to analyze total patent citations to particular NIST laboratory technical outputs as well the timeliness of these laboratory outputs. Figure 6 demonstrates that when NIST scientific outputs are cited by patents, they are generally cited by a limited number of patents. This is particularly true for NIST publications. While 43 % of NIST-assigned patents are cited more than 10 times, just 7 % of cited NIST peer-reviewed publications and 4 % of cited NIST grey literature publications receive more than 10 citations. The fact that even when peer-reviewed publications and grey literature are cited by inventors, only a limited number of inventors cite that particular output is a bit surprising. Prior research has found that individual NIST technical outputs impact multiple firms, even competing firms, across entire industries and supply chains.[15]

[15] See Link and Scott [25] for reviews of NIST economic impact case studies. These studies demonstrate that shared usage among organizations of particular NIST standards, measurement technologies, test methods and other scientific outputs is both typical and critical to realizing economic impacts.

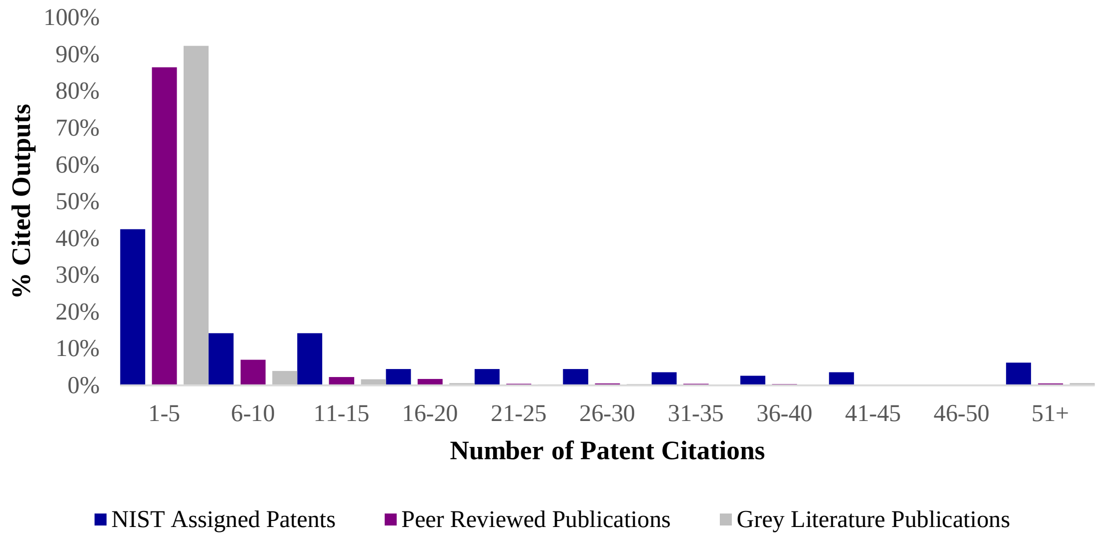

Fig. 6. Total Patent Citations per NIST Technical Output.

Figure 7 presents data on the time between publication of the NIST output and subsequent citation by a patent. NIST-assigned patents are often cited as prior art in the year the patent is issued, but NIST peer-reviewed publications and grey literature are typically initially cited by patents eight years after publication. Because knowledge embodied in patents has already been reduced to practical application, it is not surprising that the initial lag of patent-to-patent citations is shorter than patent-to-publication citations. Notably, nearly 40 % of NIST publications are published 10 or more years prior to receiving their initial patent citation. Among cited publications, 9 % are published 25 or more years prior to their initial patent citation. Indeed, the data show that the time to initial citation can be as long as 11 years for NIST-assigned patents, 106 years for NIST publications, and 57 years for NIST grey literature. In total there are 2799 NIST patents, peer-reviewed publications, and grey literature publications that have been cited by multiple patents. For this group of NIST outputs, as many as 19 years, 29 years, and 33 years lapsed between the initial and final patent citation to an individual NIST output, respectively. Together, these data on the timing of the publication of NIST technical outputs and subsequent references by citing patents suggest that particular NIST research outputs remain valuable to inventors for extended periods of time.

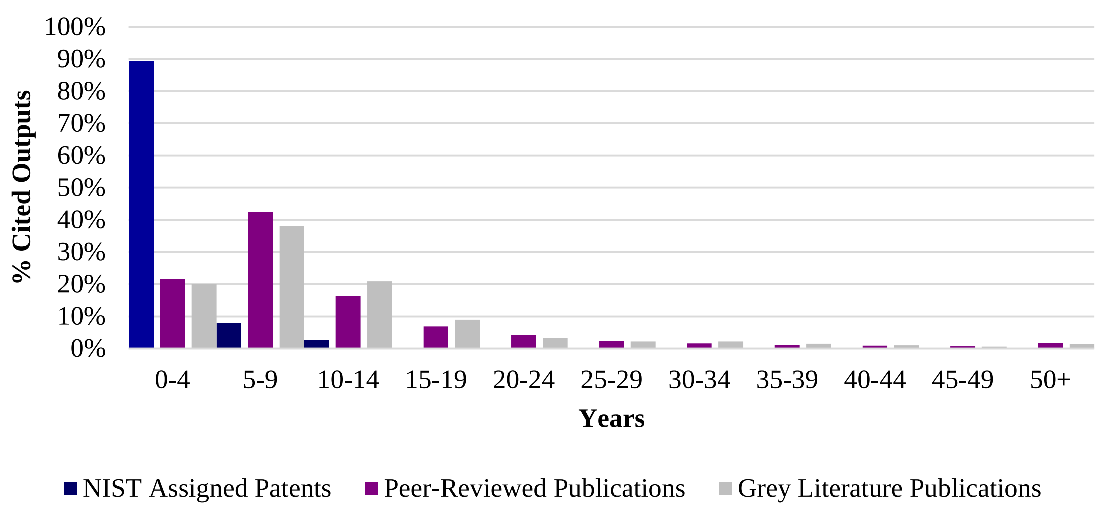

Fig. 7. Time to first Patent Citation.

4.5 Potential Impact Metrics and Connections to Technology Transfer

The data on patent citations to NIST research outputs suggest a number of metrics beyond simple counts of NIST scientific and technical outputs, such as NIST-assigned patents or NIST peer-reviewed publications. Counting patent references to NIST technical outputs, measuring the percentage of NIST technical outputs that are cited by patents, identifying the median number of citations, and the estimating the lag between the production and citation of NIST technical outputs are potentially valuable metrics. Further, these metrics may create the incentive to engage in activities that encourage the transfer and usage of NIST technical outputs. Table 4 summarizes the data and presents both traditional metrics related to the production of NIST technical outputs, as well as several novel metrics related to the usage of these NIST technical outputs.

Patent references to NIST technical outputs indicate usage of NIST science. As noted above, economic research finds that patent references to previously issued patents and publications are an important indicator of knowledge flow. The data show that the 197 patents assigned to NIST have been cited over 2000 times. Similarly, the 54,066 papers authored by NIST researchers have been cited 14,538 times as prior art in patents. In total, NIST grey literature generated 8468 patent citations. These citations indicate substantial usage of NIST science.

The varied rate and frequency with which technical outputs are cited in patents suggests the need for further metrics. While 63.5 % of NIST inventions are subsequently cited by patents, 6.6 % of NIST-authored papers are cited as prior art. This 6.6 % is noticeably greater that the Popp's [27] finding that 1.7 %–2.3 % of alternative energy publications are cited by U.S. patents. Measuring the percentage of technical outputs that are cited by patents may focus efforts on the dissemination of NIST science.

The final two columns in Table 4 present summary statistics for those NIST technical outputs that are ultimately cited by patents. While the maximum number of citations indicates that there are highly cited NIST technical outputs, the median number of citations indicates that technical outputs are typically cited by only a few patents. This finding runs contrary to Link and Scott's [24] findings regarding the infrastructural nature of NIST scientific and technical outputs. This divergence suggests that there may be opportunities to increase the impact of NIST's current technical outputs on private sector invention.

Similarly, measuring the time between the production of NIST technical outputs and usage as indicated by patent citations may be beneficial. While it is widely recognized that different fields have different timelines [26], there is little research regarding the time it takes for publications to be cited by inventors. Popp [27], who finds it typically takes as long as 22 years for increases in energy R&D funding to result in patent citations to energy publications, is a notable exception. Table 3 shows there can be a number of years before NIST technical outputs are first cited and that particular NIST technical outputs continue to be cited for rather long time periods. Together, these data indicate that there may be opportunities to increase citations in patents to NIST technical outputs by engaging in explicit technology transfer activities to disseminate NIST science.

Table 3. Patent Citations to NIST Laboratory Technical Outputs

NIST Laboratory Output	**Total Output**	**Total Patent Citations**	**% Cited by Patents**	Cited NIST Outputs	
				Median (Maximum) Number of Citations	Median (Maximum) Years Prior to Initial Citation
NIST-Assigned Patents	197	2,081	63.5 %	6 (233)	0 (11)
NIST Peer-Reviewed Publications	54,066	14,538	6.6 %	1 (277)	8 (106)
NIST Grey Literature	N/A[16]	8,468	N/A	1 (336)	8 (84)

[16] The total output of grey literature and citation rates are not applicable metrics. Because grey literature includes personal communication, workshop presentations and other informal scientific communication it is impossible to assemble a complete list or even count of such outputs.

Perhaps more importantly, the results demonstrate that these impacts on invention and innovation do not arise quickly or easily. For those NIST outputs that are cited by patents, the median time between publication and citation is eight years for peer-reviewed and grey literature publications. The difference between the typical time for citations to NIST-assigned patents and NIST publications, peer-reviewed literature and grey literature, is not surprising. Publications typically embody basic science, and time is needed to reduce this scientific knowledge to practical application as reflected in a patent. However, the skewed distribution of the time to initial citation and the extended time periods over which certain outputs continue to be cited in patents suggest further opportunities to increase patent citations to NIST through explicit technology transfer activities.

Practitioners frequently refer to technology transfer as a "contact sport" that requires interaction between developers and users of scientific knowledge [28]. Implementing a broad definition of "technology transfer" that recognizes the breadth of channels through which NIST knowledge, capabilities, and facilities impact stakeholder's demands increased participation in, and attention to, the dissemination and transfer of NIST's scientific outputs. Indeed, the Federal Technology Transfer Act of 1986 declared "Technology transfer, consistent with mission responsibilities, is a responsibility of each laboratory science and engineering professional." Such efforts may decrease the time until inventors cite NIST science and increase the likelihood and frequency that NIST outputs are cited. Increased focus on the dissemination of peer-reviewed and non-academic publications can increase NIST's impact on invention and innovation from current scientific outputs. Importantly, a focus on the transfer of the knowledge embodied in scientific outputs through outreach, collaborations, and other explicit technology transfer activities can facilitate increased impact of research activities without altering the nature of the research.

5. Limitations and Future Work

The data and analysis presented here are purely descriptive and do not reflect any analysis of causality with respect to patent citations. Further, there is no attempt to explicitly examine the role and impact of formal or informal technology transfer activities such as cooperative research and development agreements, co-authorship, or any of the other approaches taken by NIST scientific and technology transfer professionals. This future work will analyze the roles of researchers, technical leaders, technology transfer professionals, and other NIST organizations in technology transfer. The data presented here are a necessary first step to performing such analysis.

Recent analysis examined the impact of a subset of NIST SRD products by identifying citations in publications and patents [29, 30]. For patent citations, the authors searched for references in both the non-patent prior art and the patent description and specification. Table 4 replicates this methodology for a limited set of search terms. The results show that searching NPRs for citations to NIST may only capture a limited number of the textual references to NIST contained within patents. The data analyzed in this paper identified approximately 22,000 unique patents that cite NIST. The feasibility analysis presented in Table 4 indicates that as many as 10 thousand additional patents cite NIST in the body of the patent but not as prior art. While the methodology and analysis represent presented here represent a clear improvement of prior approaches, these data continue to understate the true impact of NIST on inventive activities. Perhaps of greater concern, Table 4 shows that certain types of NIST outputs such as SRMs and SRDs are frequently cited in the body of patents but not as prior art. Analysis of laboratory impacts that systematically excludes certain types of laboratory outputs not only underestimates true NIST impacts but also potentially leads to errant policy analysis. Extending the methodology to search patent description and specification is critically important.

Table 4. Sample Full Text Patent Searches

Search Terms	Total Results	% Accurate NIST Attribution	% Identified with Other Reference Search
refprop	80	100 %	11 %
webbook AND nist	34	100 %	15 %
srm AND nist	245	100 %	7 %
nist OR "national institute of standards and technology"	7697	92 %*	16 %*
"national bureau of standards"	3164	100 %*	4 %*

*Based on inspection of 100 search results

6. Conclusions

As noted earlier, the number of patents issued each year to NIST-employed inventors understates NIST's true impact on invention, and does not indicate usage of NIST scientific output by other inventors. In contrast, economic research finds that patent references to prior art and publications are an important indicator of knowledge flow. Prior research has analyzed the role of patent citations to other patents and peer-reviewed publications in knowledge and technology transfer. However, a significant portion of NIST scientific outputs lie outside these two categories. NIST produces a wide variety of research outputs such as Standard Reference Materials, Standard Reference Data, NIST Technical Series publications, workshop presentations, and other informal scientific outputs defined in this analysis as "grey literature." This research represents the first time that citation analysis has been employed to identify the role and impact of this more complete set of federal laboratory technical outputs.

The variety of NIST technical outputs considered in this analysis closely corresponds to the technology transfer tools identified in NIST's response to the 2011 Presidential Memorandum on Technology Transfer. The data show that NIST's impact on invention is at least two orders of magnitude greater than indicated by only counting NIST-assigned patents. Further, identifying citations to NIST outputs indicates usage of NIST research by inventors and other stakeholders. 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 technical outputs. Therefore, reliance on a limited set of technology transfer tools by either researchers (e.g., excess reliance on publications) or policy makers (e.g., excess focus on inventions and formal intellectual property protection) creates a risk that NIST knowledge and capabilities will not be transferred to and adopted by businesses and other organizations.

The results also indicate the high quality of NIST scientific and technical outputs. The growth rate in citations to NIST publications and grey literature outpaces prestigious and highly selective comparison groups. Because different NIST stakeholders rely on different types of scientific outputs [2], it is important to capture this broad set of NIST outputs. Table 1 shows the total number of patents assigned to NIST inventors, the total number of peer-reviewed publications authored by NIST researchers, and an indicator of the volume of grey literature outputs.

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 altering the character of this research. Measuring patent citations to NIST research focuses attention on the usage of scientific knowledge. Further, measuring the citation rate, citation volume, and citation timeliness creates the incentive to increase participation in and attention to the dissemination and transfer NIST science.

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