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Connecting Defense Basic Research to Industrial Innovation

Mapping the Diffusion of Federally Funded Research into Patented Technology

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MEDIA QUERIES: Rachel Sutherland, NDIA Director of Public Affairs & Communications at rsutherland@NDIA.org

Authors / Contributors

Author

Logan Whitehair
Horizon Research Fellow, NDIA ETI

Dr. Evan E. Johnson
Research Assistant Professor of Public Policy at UNC–Chapel Hill and founder of Arclight Analytics

Production

Zachariah Chou
Copywriter & Editor, NDIA

Eve Dorris
Director, IPO, NDIA

Alexander Feeser
Creative Director, NDIA

Vince Lim
Graphic Designer, NDIA

NDIA ETI Executive Director

Dr. Arun Seraphin
Executive Director, NDIA ETI

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Executive Summary

U.S. federal investment in basic research has historically served as a foundation for long-term technological development, economic growth, and national security. Within the Department of Defense, basic research funding supports the upstream scientific knowledge base from which future defense capabilities emerge. However, evaluating the downstream effects of these investments remains difficult. Basic research often produces benefits through long, indirect, and distributed pathways that are not easily captured through conventional evaluation tools. As a result, defense research decision-makers have limited empirical visibility into how funded scientific outputs propagate into later technological development.

This paper develops a reproducible, open-data method for observing the downstream technological uptake of defense-funded research through patent-paper linkages. The approach links scientific publications funded by the Air Force Office of Scientific Research (AFOSR), Army Research Office (ARO), Defense Advanced Research Projects Agency (DARPA), and Office of Naval Research (ONR) to patents that cite those publications as non-patent literature. Using OpenAlex, PatentsView, and the Reliance on Science dataset, the analysis constructs agency-level indicators of technological diffusion for papers published between 2010 and 2015. The indicators include total patent citations, distinct citing patents, distinct patent assignees, and patent citations per publication.

The findings show variation in patent uptake across agencies. DARPA funded publications exhibit the highest total patent citation count and citations-per-publication measure, suggesting that their research portfolio has exhibited greater diffusion both in aggregate and after accounting for publication volume. ONR and AFOSR also show substantial diffusion, while ARO has a smaller absolute scale of technological uptake. These differences suggest that defense research agencies occupy distinct positions within the broader defense science and technology ecosystem. Moreover, 25 to 27 percent of all patent citations across all agencies come from companies within the defense industrial base. These statistics indicate that the relevance of basic research for defense is not concentrated within a single agency's portfolio but is instead a structural feature of the broader defense science and technology enterprise. The results also show that defense basic research operates more as a distributed knowledge system rather than a linear transition pipeline.

These findings support the use of patent-linked outcome metrics as complementary tools for defense research portfolio evaluation. These metrics provide scalable, standardized indicators into how funded research diffuses into the technological domain. By linking funding, publications, patents, and assignees, defense research organizations can develop a more empirical view of how scientific knowledge propagates into national security technologies.

Introduction

U.S. federal investment in science and technology has historically played a central role in driving American innovation and technological development. Basic research funding from federal agencies is typically justified by well-established economic arguments emphasizing the inability of private capital markets to sustain investments in technologies with long time horizons, high uncertainty, and diffuse returns. As a result, decisions about how to allocate public research funding are inherently portfolio-level decisions made under conditions of deep uncertainty.

In practice, these investments are executed through a distributed institutional system that extends well beyond federal agencies themselves. Basic research is largely performed extramurally by universities, national laboratories, private firms, and other research organizations, with funding flowing through a network of grants, contracts, and other collaborative arrangements. The technological value of these investments is therefore not realized within a single institution, but emerges through a complex process of knowledge production, dissemination, and downstream application. For agencies tasked with advancing mission-relevant capabilities, measuring how funded research ultimately contributes to the meaningful outcomes is a persistent measurement problem.

This problem is particularly salient for the U.S. Department of Defense (DoD), where organizations such as the Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)) must allocate marginal resources across competing research areas without direct visibility into how basic research propagates into defense-relevant technologies. Funding decision-makers evaluate technology portfolios by analyzing historical funding levels, using expert judgment, and assessing agency mission statements and direction from senior leaders, but they do not generally involve empirical methods for assessing downstream technological uptake or mission impact.

However, the diffusion of scientific knowledge presently leaves observable traces. In particular, patents frequently reference scientific publications as part of the prior art underlying new inventions. This fact creates a large-scale, publicly-accessible data record of the contributions of research to technological development across institutions. While these traces are well-documented in the open-source domain, they have not been systematically translated into standardized indicators for research portfolio evaluation.

This paper demonstrates that patent-paper linkages can be used to fill this gap. We develop a reproducible, open-source data pipeline that connects agency funded scientific publications to downstream patented inventions and the companies that own them. From these linkages, we construct funding agency indicators of technological uptake that capture the volume, breadth, and intensity of diffusion into the patent system. These indicators provide a measurable and comparable signal of the propagation of research products into further applied research and development, enabling systematic observation of downstream outcomes regardless of funding source.

By converting patent-paper linkages into agency portfolio metrics, this approach provides a new empirical basis for evaluating public research investments and offers a practical tool for decision-makers seeking to align basic research funding with observable technological outcomes.

Historical Context: Why Governments Fund Basic Research

Our work is situated within a long history of U.S. public research and development (R&D) investments. Government support for basic research is often justified by observations about how knowledge functions as a resource. Once new scientific knowledge is created, it can be easily shared, so many people can benefit from it simultaneously. Because of this, the benefits to society from an invention are often much greater than the profits any one company can capture from its use. Basic research efforts tend to have longer time horizons, involve uncertainty including technical and market risk, and may lead to a number of different products and applications with uncertain time of return on investments. As a result, private companies invest less in this type of research. Government agencies, without these types of expectations on timing and scale of return have historically provided the majority of funding for basic scientific research (Arrow, 1962; Nelson, 1959).

U.S. postwar science policy explicitly tied federal research funding to multiple national objectives. The statutory purposes of the National Science Foundation include advancing "national health, prosperity, and welfare" and security "national defense," signaling that basic research was treated as an investment in national capacity rather than only a private commodity (U.S. Congress, 1950). This intellectual perspective is often traced to Vannevar Bush's *Science, The Endless Frontier*, which argued that government has a legitimate and necessary role in sustaining basic research capacity and developing scientific talent as a foundation for long-term innovation and public well-being (Bush, 1945).

Rather than conducting research exclusively within government laboratories, the U.S. developed a distributed system in which federal agencies fund research performed across universities, national laboratories, private firms, and other institutions. This extramural model reflects both the scale of scientific activity and the importance of leveraging diverse sources of expertise. The postwar system also became highly decentralized across multiple mission agencies and largely focused federal support in basic research, a structure that helped build the strength of U.S. research universities even as later stages of innovation were more diffuse and organizationally fragmented. The outputs of publicly funded research were therefore not confined to a single organization, but instead spread through networks of researchers and institutions. This structure aligns with policy approaches designed to promote knowledge spillovers, human capital formation, and broad-based innovation capacity across the economy (Bush, 1945; OECD, 2015; Bonvillian, 2014).

A second major institutional development that shaped this system was the Bayh–Dole Act of 1980. Prior to its passage, intellectual property resulting from federally funded research was typically owned by the federal government, limiting incentives and mechanisms for commercialization. Bayh–Dole allowed universities and research institutions to retain ownership of inventions arising from federally funded research, significantly expanding technology transfer activity and increasing university patenting. This shift strengthened collaboration between universities and industry, contributed to the growth of research-based startups, and reinforced the role of universities as key intermediaries in the innovation system. As a result, federally funded science became more tightly coupled to downstream technological development and the patent system (Sampat 2006; Mowery et al. 2004).

Historical experience demonstrates that publicly funded research can generate significant downstream technological impact, often in ways that are difficult to anticipate ex ante. The Manhattan Project provides a canonical example of large-scale government investment translating frontier scientific knowledge into a strategic capability under conditions of extreme scientific uncertainty (Department of Energy, 2024). In the decades that followed, mission-oriented research programs continued to produce technologies with broad and enduring impact. For example, early research into lasers, electro-optics, and microelectronics funded by the Defense Advanced Research Projects Agency (DARPA) enabled the development of precision-guided munitions (PGMs). PGMs were later fielded in the joint direct attack munition (JDAM), Javelin, and advanced medium-range air-to-air missiles (AMRAAM). This case illustrates how foundational research in multiple scientific domains can be integrated into operational capabilities that transform warfare (DARPA, 2015).

However, despite the role of basic research in technological development, evaluating the outcome of any specific research activity remains a persistent challenge. The benefits of research are often diffuse, realized across multiple organizations, and subject to significant time lags between initial funding and observable application. Moreover, the pathways through which knowledge translates into technology are indirect and difficult to trace using conventional evaluation methods. Existing approaches used to assess research performance such as raw publication counts, paper citations, and peer review provide insight into scientific output, but offer limited visibility into how that knowledge is ultimately used in technological development. This measurement difficulty has been widely recognized in both policy and research contexts, reflecting the inherent complexity of linking upstream scientific activity to downstream economic and technological outcomes (David, Hall, and Toole, 1999).

Trends in Defense Basic Research Investments

The DoD sustains long-horizon knowledge creation for national defense mission sets through the Research, Development, Test, and Evaluation (RDT&E) funding portfolio. Within the RDT&E portfolio, Budget Activity 6.1 (Basic Research) supports the most upstream components of the defense innovation pipeline. Because the empirical approach in this paper traces links from agency funded publications to downstream patented inventions, understanding how defense basic research funding has evolved over time provides essential context for interpreting the portfolio-level diffusion metrics described throughout.

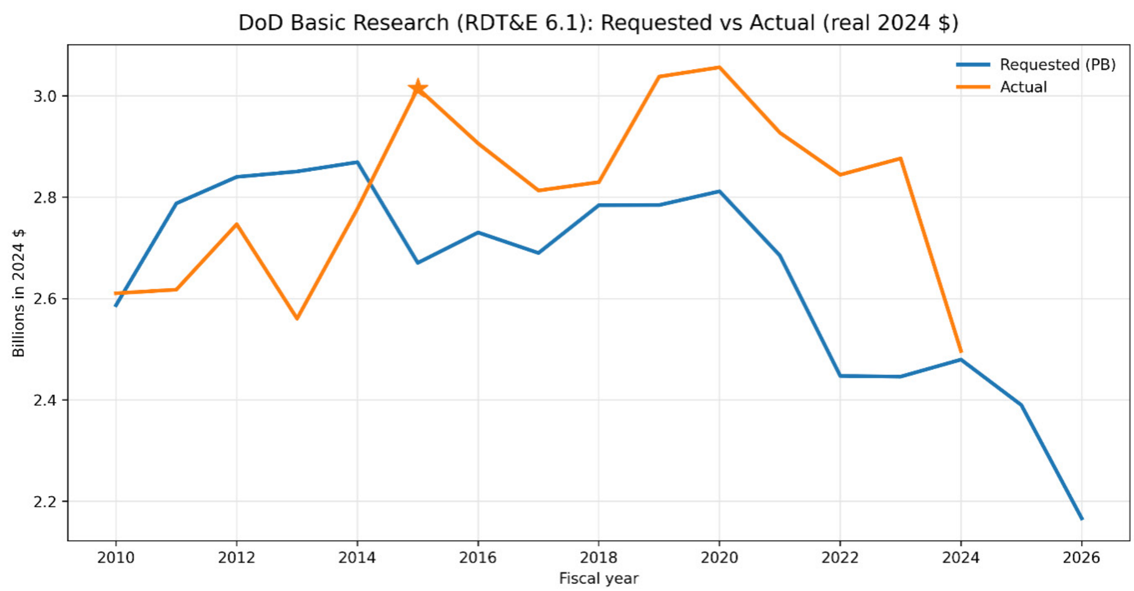

Figure 1[1]

Figure 1 summarizes DoD Basic Research (RDT&E 6.1) funding over time in constant 2024 dollars, comparing the President's Budget request to appropriated levels where available in the year-over-year Exhibit R-1 budget documentation. First, the time series shows that real basic research resources fluctuate meaningfully year-to-year rather than following a smooth trend. Requested funding rises between 2010 and 2014, declines slightly until 2020, and falls sharply between 2020 and 2024. Second, appropriated levels frequently exceed requested levels, indicating that congressional action has often increased BA 6.1 funding relative to the initial request, although the magnitude of this gap varies across fiscal years.

The justification of funding for basic research is challenging for a number of reasons. Basic research is often not tied to specific acquisition programs or operational missions, and the products it enables are typically realized through long, indirect diffusion pathways that are not easily visible or predictable at the time of funding. Moreover, the beneficiaries of the products of basic research are often uncertain and widely dispersed. As a result, even when basic research is strategically valuable, articulating its contribution to mission-relevant technological capacity remains difficult. Therefore, strengthening the evidentiary basis for how basic research translates into downstream technological capabilities is increasingly important for sustaining long-term support of basic research funding.

1 Includes data from Department of Defense, Research, Development, Test, and Evaluation Programs (R-1) for FY2010-2026. We used funding levels from two years before the request year. For example, the FY2017 funding levels are from the FY2019 R-1. FY15 Actual has a star to indicate that the data is from FY16 not FY17.

Literature Review: Measuring the Impact of Public Research

This section reviews three related strands of literature. The first examines government efforts to measure the public R&D investment and its outcomes. The second uses patent citations of scientific research as indicators of knowledge diffusion between science and technology. The third applies patent-paper linkages more directly to questions of science policy and research evaluation.

Taken together, this literature shows that scientific knowledge creation leaves observable downstream traces. However, this literature reveals a critical gap: existing approaches do not produce empirical signals that measure where public R&D diffuses into industry.

Science-of-Science Measurement Efforts

One important strand of this work emerged as STAR METRICS, a federal university initiative developed to improve the government's ability to document the effects of research spending. STAR METRICS attempted to connect federal research awards to downstream outputs such as university employment, workforce participation, and broader economic activity. This project later evolved into the Institute for Research on Innovation and Science (IRIS), which continues to track grants, researchers, publications, and workforce outcomes for participating institutions (National Academies of Sciences, Engineering, and Medicine, 2011).

These efforts represent a major advance in the infrastructure available for understanding public R&D investments and outcomes. They move beyond simple budget tables and into linking federal funding to scholarly outputs, namely publications. More broadly, they are part of the emerging science-of-science field, which seeks to use large-scale data to study how science is produced, organized, and evaluated. Recent infrastructures such as SciSciNet extend this ambition by assembling large linked datasets intended to support replicable research on scientific production and impact (Lin et al, 2023).

At the same time, science-of-science research has also highlighted the limitations of conventional bibliometric measures. Citation distributions are highly skewed and vary substantively across disciplines, meaning that the apparent impact of a publication depends in part on field-specific citation norms rather than a universally comparable measure of value. This point matters for research evaluation because it suggests that publication and citation metrics alone are insufficient for assessing how public research contributes to technological development. Existing systems such as IRIS provide valuable information on grants, publications, and workforce outcomes, but they do not track how scientific knowledge is translated into technological development through the patent system. That omission is consequential for agencies seeking to understand not only whether research is produced, but whether it diffuses into the technology base and operational missions.

Patent Citations as Indicators of Knowledge Diffusion

A large body of research uses patent citations as indicators of knowledge flows between scientific research and technological development. Patents include references to prior art, including scientific publications, which document the knowledge base underlying an invention. These references provide an observable record of scientific research being used in the development of new technologies.

Early empirical work showed that patent citations can be used to trace patterns of knowledge diffusion, including the movement of ideas across organizations and geographic regions (Jaffe, Trajtenberg, and Henderson, 1993). Subsequent studies demonstrated that patents frequently cite scientific literature, particularly in science-based industries, providing direct evidence that scientific research contributes to technological innovation (Narin, Hamilton, and Olivastro, 1997). More recent work suggests that scientific knowledge plays an active role in shaping technological search, with inventors drawing on research to guide the development of new inventions (Fleming and Sorenson, 2004; Nemet, 2012).

While patent citations do not capture all forms of knowledge transfer, they provide one of the few scalable and standardized data sources for observing how scientific knowledge diffuses into the technology base. As a result, they are widely used as a practical proxy for science-to-technology linkages.

Patent-Paper Linkages in Science Policy

There is growing prior research that uses patent-paper linkages for the evaluation of public research and the study of science policy. This work is especially relevant to this paper because it moves beyond the general claim that patents cite science, instead developing data infrastructure and methods for tracing those relationships systematically at scale. Examples include the Reliance on Science dataset created by Marx and Fuegi as well as Ahmadpoor and Jones's science-to-technology network analysis. Together, these studies show that the patent system provides a large-scale record of technology diffusion that can be linked back to scientific research.

Marx and Fuegi are particularly important for the empirical strategy used in this paper. They show that analyses limited to front-page literature citations omit a substantial and systematically different portion of the science-to-technology relationship. By extracting in-text patent-to-article citations from the full text of patents, they produce a much more comprehensive dataset of inventors' reliance on science. Their findings indicate that in-text citations are more temporally distant, more interdisciplinary, and less geographically localized than front-page citations, suggesting that they capture a distinct and economically meaningful dimension of technological reliance on scientific knowledge (Marx and Fuegi, 2022). Related recent work by Verluise et al. strengthens the conceptual importance of this distinction by arguing that in-text citations are often cleaner signals of inventor knowledge than front-page citations, which are more heavily shaped by legal and administrative processes (Verluise et al, 2026).

These advances make patent-paper linkage analysis substantially more useful for policy research. They provide a more complete and defensible basis for observing the role of science in downstream invention. Yet existing approaches still tend to focus on individual inventions, inventor behavior, or research network structure. Informing decisions about the allocation of public research funding requires a different frame of analyses and use of additional data, by identifying science-to-technology linkages and comparing them with agency spending activity. Few studies attempt to convert patent-paper signals into tractable indicators for measuring the impact of public research portfolios, including of defense agencies.

Contribution: Patent–Paper Linkages as a Signal of Downstream Technological Uptake

We develop a reproducible, open-source data pipeline that links defense agency-funded scientific publications to downstream patented inventions through non-patent literature citations. Specifically, we connect research outputs funded by the Air Force Office of Scientific Research (AFOSR), Army Research Office (ARO), Defense Advanced Research Projects Agency (DARPA), and Office of Naval Research (ONR) to patents that cite these publications and to the organizations that own those patents.

The analysis focuses on publications from 2010 to 2015 in an attempt to allow sufficient time for downstream patent citation accumulation while maintaining comparability across agencies. From these linkages, we construct agency-level portfolio indicators that capture observable patterns of technological uptake in the patent system. These indicators are interpreted as evidence of downstream diffusion and use of scientific knowledge, rather than as causal estimates of research impact.

We conceptualize the U.S. defense science and technology (S&T) enterprise as a system in which DoD research organizations primarily fund extramural basic research performed by universities, national laboratories, and other research institutions. AFOSR, ARO, and ONR serve as core sponsors of such research, while service laboratories (e.g., ARL, NRL) conduct most in-house R&D. DARPA similarly funds extramural research but does not perform in-house research, instead supporting projects across a wide range of defense-relevant mission areas (National Academies of Sciences, Engineering, and Medicine, 2014).

Funded research is disseminated through scholarly publications that acknowledge their funding sources (10 U.S.C. § 4027 (2021)). When downstream organizations develop inventions with commercial or strategic value, they may pursue intellectual property protection through patents. These patents must include references to prior art, including scientific publications cited as non-patent literature. Non-patent literature citations serve two primary purposes in patent applications: they differentiate the novelty of an invention or provide technical justification by referencing the scientific basis of the invention. These citations provide an observable record linking patented inventions to the scientific knowledge base that informed them.

In combination, these institutional relationships support the use of patent-paper linkages as a portfolio-level signal of knowledge diffusion, enabling systematic observation of the propagation of agency-funded research into the technological domain.

Data and Methods

Our analysis integrates multiple publicly available data sources to construct a unified dataset linking federally funded scientific research to downstream patented inventions. The primary sources are OpenAlex, PatentsView, and the Reliance on Science dataset.

OpenAlex provides comprehensive metadata on scholarly publications, including titles, abstracts, institutional affiliations, and funding acknowledgments. Because OpenAlex records funding information at the publication level, it enables identification of research outputs supported by specific DoD agencies. PatentsView provides structured data on U.S. patents, including patent identifiers, inventor and assignee information, and classification metadata. In this analysis, PatentsView is used to standardize patent records and attribute patents to their respective assignee organizations.

The Reliance on Science dataset extracts references to scientific literature from patent documents using natural language processing methods. It identifies citations to non-patent literature within patent texts, including in-text references that more directly reflect the scientific knowledge underlying an invention (Marx and Fuegi, 2022).

These datasets are integrated to produce a linked dataset in which each observation represents a relationship between a scientific publication funded by a DoD agency and a patent that cites it. From this linkage structure, we construct a set of agency-level indicators that capture different dimensions of downstream technological uptake.

It is important to note that the DARPA and ONR datasets are the results of programs funding basic research, applied research, and advanced technology development, also known in DoD as "science and technology" activities. It is not clear that the applied research and advanced technology development activities produced significant numbers of open research publications, given the security controls placed on technical data that results from many of the programs. The ARO and AFOSR data sets are the result of significantly smaller funding levels and limited to basic research programs.

Several methodological steps are applied to ensure that these indicators are conservative, interpretable, and comparable across agencies.

First, patent citations are deduplicated at the patent level so that multiple references to the same publication within a single patent do not inflate citation counts. This ensures that each patent contributes at most one citation per referenced publication.

Second, we construct multiple complementary indicators to capture distinct dimensions of technological uptake:

- Total patent citations, which measure the overall volume of downstream references to agency-funded research
- Distinct citing patents, which capture the number of unique patented inventions that draw on that research
- Distinct patent assignees, which measure the breadth of diffusion across different organizations
- Patent citations per publication, which normalize citation volume by the size of an agency's publication portfolio

These measures allow us to distinguish between concentrated and broadly diffused uptake, as well as between large portfolios with moderate uptake and smaller portfolios with high intensity of downstream use.

Third, all indicators are constructed at the agency portfolio level, aggregating across the full set of funded publications associated with each agency during the study period. This aggregation enables direct comparison of the propagation of research funding outcomes into the patent system. Together, these methodological choices produce a tractable and policy-relevant set of indicators that can be used to compare the downstream technological uptake associated with different public research portfolios.

The Data Pipeline

The empirical approach developed in this paper requires integrating multiple heterogeneous data sources that are not natively interoperable: information on federally funded research outputs, patent records, and patent-paper citations maintained in separate systems with different identifiers, structures, and levels of completeness. To address this, we implement a reproducible data pipeline that transforms raw publication and patent records into a unified dataset. At a conceptual level, the pipeline performs three functions:

1. Identification of agency-funded scientific outputs
2. Linkage of these outputs to downstream patented inventions through non-patent literature citations
3. Aggregation of these linkages into portfolio-level indicators of technological uptake

This structure converts fragmented administrative and bibliometric data into a consistent representation of science-to-technology diffusion that can be compared across agencies. Figure 2 provides a schematic overview of this pipeline.

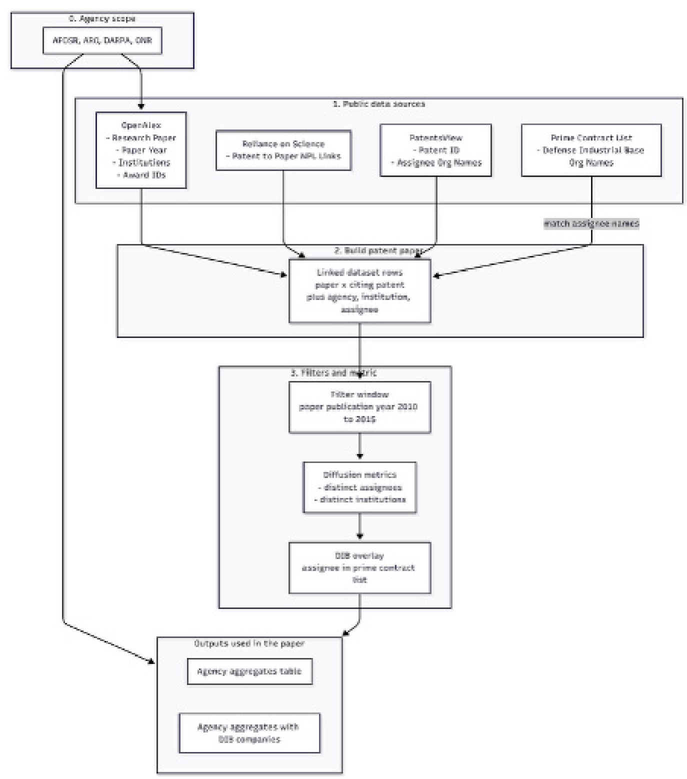

Figure 2

Figure 2 illustrates the computational pipeline used to construct the patent-paper linkage dataset and derive the agency-level indicators reported in this paper. The pipeline integrates multiple open data sources and applies a sequence of filtering, linkage, and aggregation steps to translate raw records into structured measures of downstream technological uptake.

When executed, the pipeline proceeds in four stages.

First, we define the scope of the analysis by identifying the set of DoD research funding organizations of interest: AFOSR, ARO, DARPA, and ONR. These agencies are selected because they serve as major sponsors of extramural basic research and provide a consistent basis for comparing research portfolios.

Second, we construct the patent–paper linkage dataset by integrating OpenAlex, the Reliance on Science dataset, and PatentsView. These sources are joined to produce a unified dataset in which each row represents a scientific publication funded by a given agency and a patent that cites that publication.

Third, the linkage dataset is processed to construct uptake and diffusion metrics. Publications are restricted to those published between 2010 and 2015 to ensure sufficient time for downstream citation accumulation. Patent citations are deduplicated at the patent level and counts of distinct patents and distinct assignees are computed to capture the breadth of technological uptake.

Fourth, the resulting measures are aggregated at the agency level to produce portfolio indicators. Citation counts are normalized by total publication volume to generate patents-per-publication metrics. Additional overlays match patent assignee organizations to firms in the defense industrial base (DIB) using data from the government's System for Award Management (SAM.gov) website, enabling analysis of the extent to which downstream uptake occurs among defense-relevant organizations.

The final outputs consist of agency-level indicators of patent-linked uptake, along with DIB-specific overlays that provide additional policy-relevant context.

Taken together, this pipeline converts raw publication and patent records into structured, interpretable indicators that capture how federally funded research propagates into patented technology across agency portfolios.

Findings

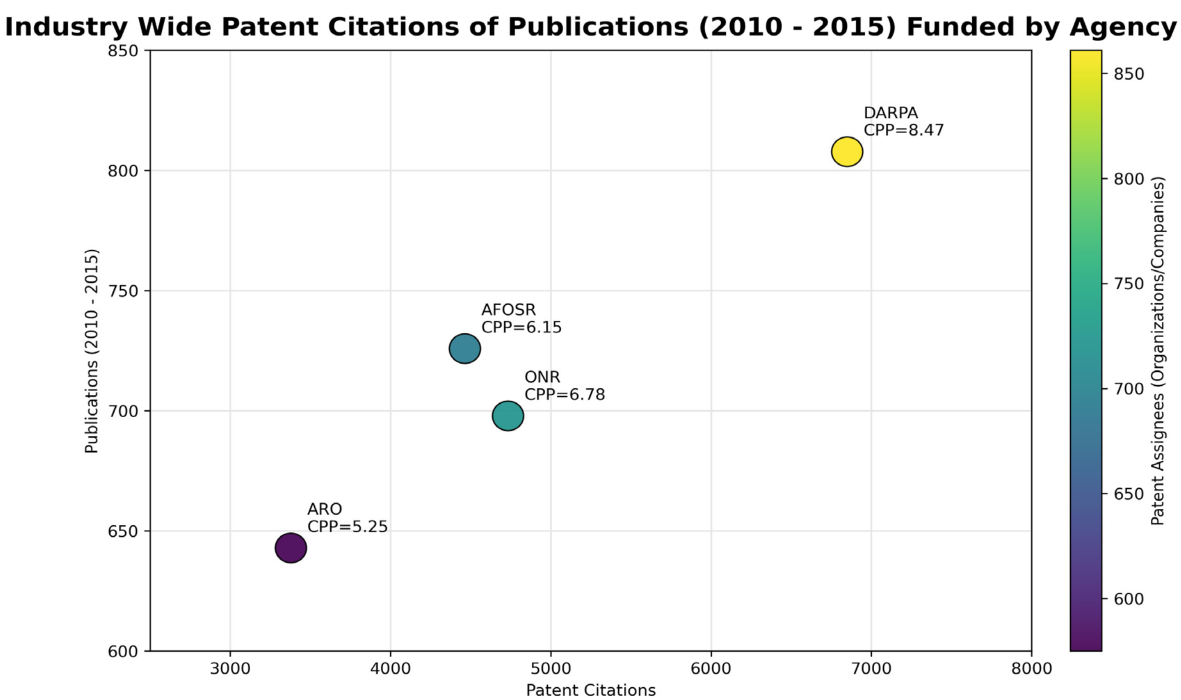

Figure 3

Figure 3 presents the aggregate agency comparison as a scatterplot of total patent citations and publications. Publications are the number of unique agency funded papers published between 2010 and 2015, total patent citations are the total number of patent references to those papers, and CPP is calculated as total patent citations divided by publications. In the figure, the horizontal axis reflects the overall scale of downstream patent uptake, while the vertical axis reflects the relative intensity of that uptake after accounting for publication volume. Each data point also has a citations per publication (CPP) label. CPP is a simple normalized measure of downstream uptake intensity, showing how frequently the average paper in an agency's portfolio is cited by patents. The color gradient on the side of the figure reflects the total number of distinct patent assignees that cite research within the agency's portfolio and is a measure of the diffusion of research into industry.

Figure 3 shows substantial cross-agency variation in downstream technological uptake. DARPA stands apart with both the highest total patent citation count and the highest CPP. The CPP metric indicates that DARPA's research portfolio is more intensively cited on a per-publication basis and cited by a larger number of patent assignees within industry. These differences are consistent with the view that the agencies occupy distinct positions within the defense research portfolio and that patent-paper linkages offer a useful empirical way to observe those differences. For example, the observed CPP differences might be a reflection of the "high payoff, high risk" strategy that shapes DARPA's research funding resulting in research publications with broader applicability to uses across industry. They may also result from the fact that the DARPA portfolio measured here is primarily from applied research and advanced technology development programs, which by definition should be closer to transition into acquisition and therefore more relevant to industry.

Defense Industrial Base (DIB) Patent Citations of Publications (2010 to 2015) Funded by Agency

Agency	Patent Citations of Publications from Research Funded by Agency	DIB Patent Citations of Publications	DIB Share of Patent Citations of Publications	DIB Companies Citing Publications
Air Force Office of Scientific Research	4,463	1,130	25.0%	130
Army Research Office	3,376	929	27.5%	98
Defense Advanced Research Projects Agency	6,847	1,851	27.0%	128
Office of Naval Research	4,731	1,217	25.7%	124

Table 1

Table 1 extends the aggregate agency analysis by isolating the share of downstream patent activity attributable to firms in the defense industrial base. Using a SAM.gov list of companies that received prime DoD contracts during the period from 2010 to 2015, the figure identifies which citing patents and assignees belong to companies with observable defense contracting relationships. This provides a relevant view by not only showing whether agency funded research is cited in the patent system, but the extent to which that uptake occurs among firms that are connected to the defense acquisition ecosystem.

The aggregate DIB statistics suggest that a meaningful minority of the patent uptake associated with each agency's funded research occurs within the defense industrial base, though the degree varies across agencies. DARPA funded research is associated with the largest absolute number of DIB patent citations, with 1,851 distinct DIB patents citing DARPA-funded publications, followed by ONR with 1,217, AFOSR with 1,130, and ARO with 929. In absolute terms, this indicates that DARPA's research portfolio generates the strongest observable connection to downstream patenting activity among defense-relevant firms, consistent with its broader pattern of high patent uptake in the full sample. ONR and AFOSR also exhibit substantial DIB-linked uptake, while ARO remains smaller in absolute scale.

When expressed as a share of all distinct citing patents, however, ARO has the highest DIB patent percentage at 27.5 percent, followed closely DARPA at 27.0 percent, ONR at 25.7 percent, and AFOSR at 25.0 percent. This metric can be viewed as an indicator of the likelihood of transition of research products into the defense industrial base, and could result from alignment of research areas with industry needs, strong communication between the academic and industrial communities, or other factors.

A similar pattern appears in the assignee data. AFOSR funded research is cited by the largest number of DIB companies in absolute terms, with 130 firms citing AFOSR funded publications, followed closely by DARPA with 128 and ONR with 124, while ARO is cited by 98 DIB firms. These figures indicate that all four agencies support research that diffuses into a substantial number of defense relevant patenting organizations. When measured as the share of all citing assignees, AFOSR has the highest DIB company share at 18.7 percent, compared to 17.1 percent for ONR, 17.0 percent for ARO, and 14.8 percent for DARPA. Significantly lower percentages of agency research being cited by defense industry might indicate a research portfolio aligned to dual-use research and technology and is positioned for transition across a broader cross-section of the innovation ecosystem.

The relatively narrow range of DIB patent percentages across agencies (25 to 27.5 percent) suggests structural regularity in the type of scientific knowledge being produced by the defense basic research enterprise. Despite small differences in the downstream uptake across agencies, the share of that uptake attributable to defense-relevant firms remains largely constant. This indicates that the outputs of extramural defense basic research, regardless of funding agency, contain a relatively stable proportion of knowledge that is relevant to the defense industrial base. Agencies do not appear to differ in relevance of the research products they are funding to defense applications.

From a systems-level perspective, this pattern suggests that defense relevance is not highly concentrated within the portfolio of any single agency but is instead an emergent property of the broader defense S&T enterprise. The agencies in our analysis have different mission sets, but these missions are equally important for the DIB. Additionally, the extramural defense basic research system appears to generate a consistent share of knowledge that is applicable to defense technology development, even as agencies vary in scale, mission orientation, and position along the basic-to-applied research spectrum. This implies that cross-agency differences in patent uptake (DARPA's higher patent uptake) reflect differences in the overall diffusion of research outputs, rather than systematic differences in their defense applicability.

Figure 4 and Figure 5 below provide a system-level view of the propagation of extramural defense basic research funding through the scientific ecosystem, and its stimulation of downstream patent activity.

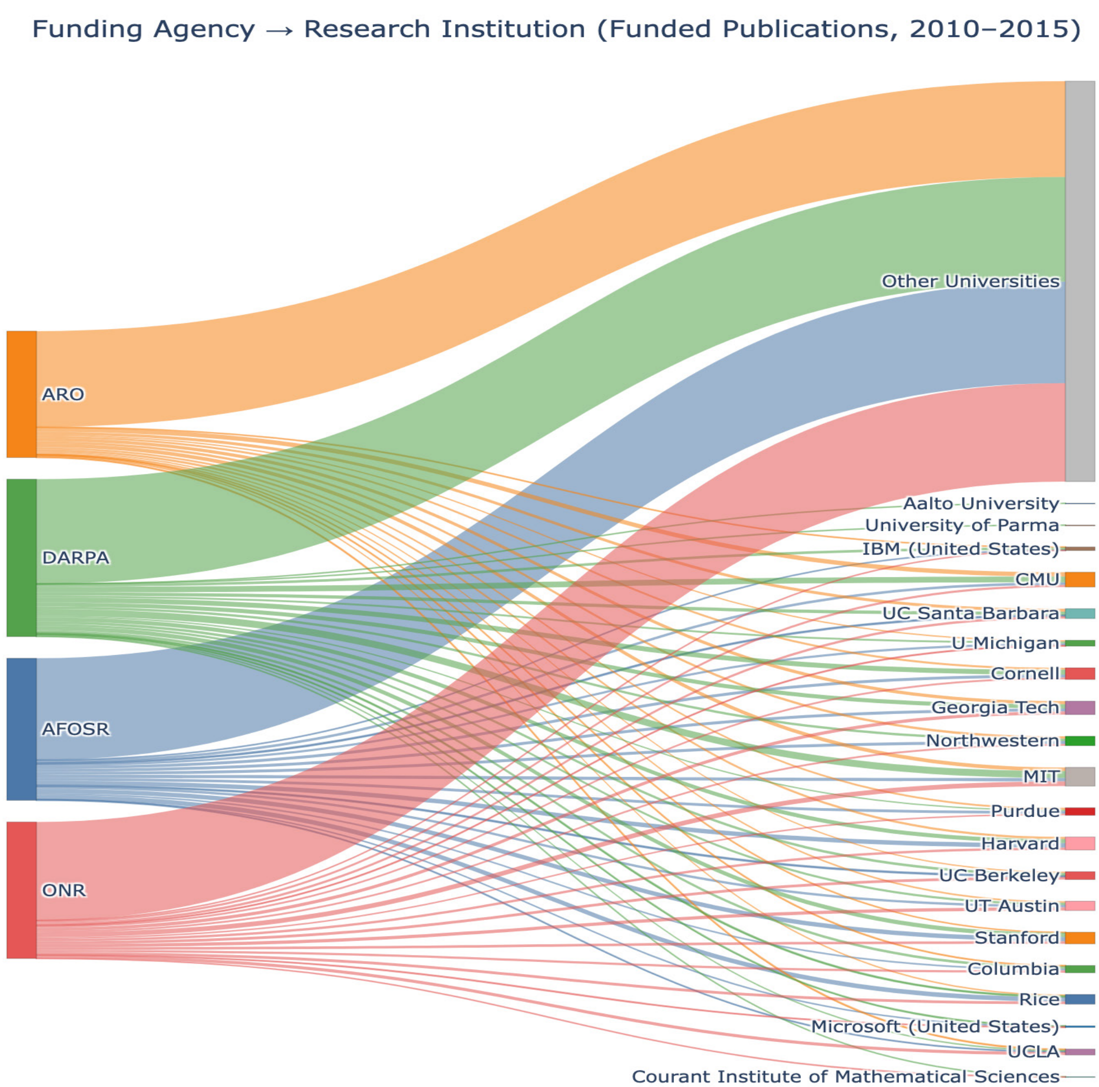

Figure 4

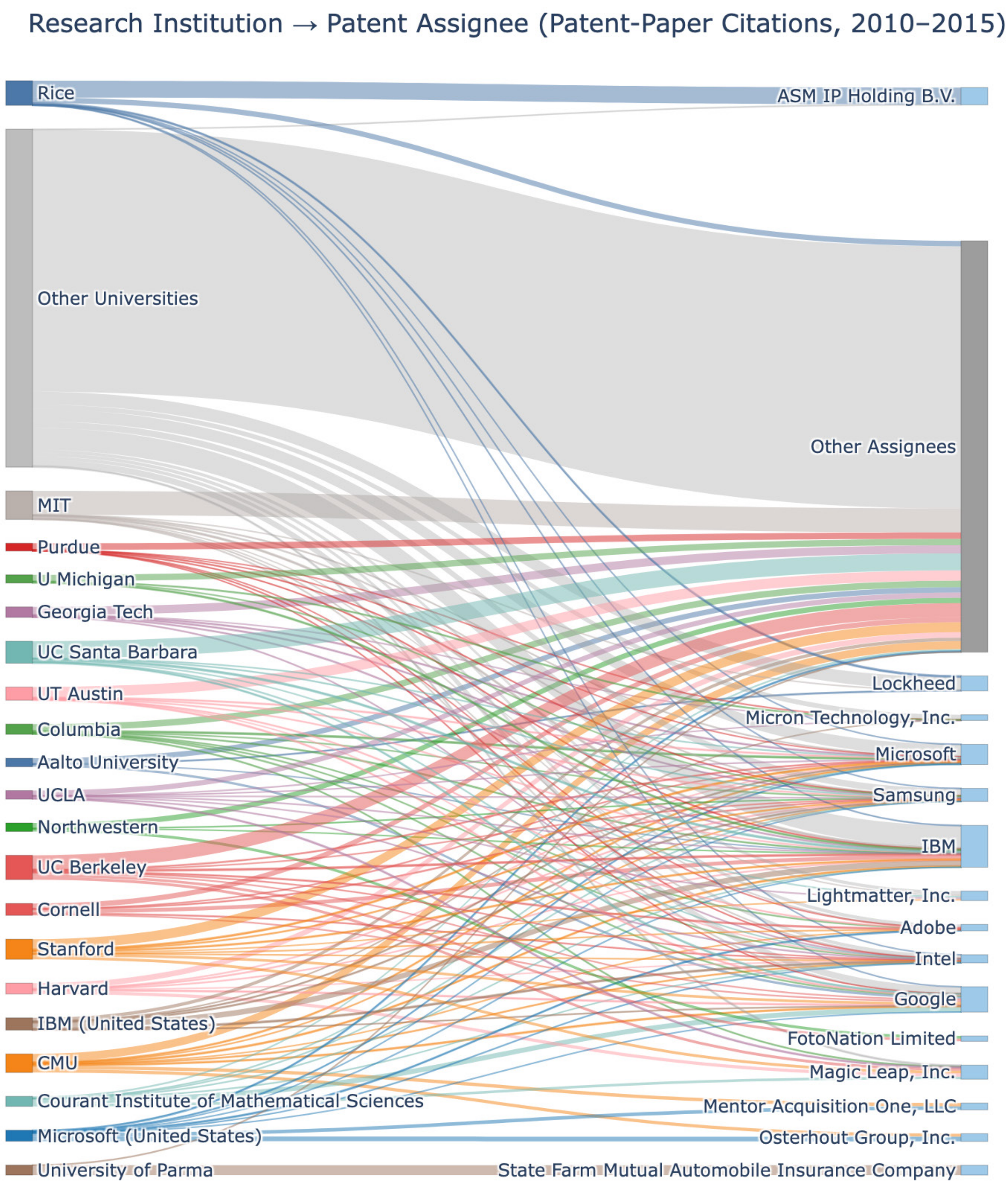

Figure 5

Figure 4 links agencies to research institutions and shows that funding from AFOSR, ARO, DARPA, and ONR is broadly distributed across a large number of universities, including a relatively small set of patent stimulating institutions that produce research leading to a large percentage of the patent citations. This structure suggests that while the extramural defense research enterprise engages a wide academic base, a smaller number of institutions serve as primary hubs leading to patent production within the agency's portfolios.

Figure 5 links research institutions to patent assignees and demonstrates that the knowledge produced by these institutions diffuses widely across the industrial landscape. Rather than flowing linearly from individual universities to specific firms, patent citations reveal a many-to-many network in which firms draw on scientific outputs from multiple institutions, and individual institutions contribute to a diverse set of downstream actors. Although large technology firms such as IBM, Intel, and Google appear as prominent recipients of the products of this set of basic research activity, the majority of citations are distributed across a broad set of assignees, indicating that the diffusion of defense funded research is both widespread and heterogeneous.

These results characterize defense basic research as a distributed knowledge system rather than a directed pipeline. Agencies fund a broad and partially concentrated academic research base, whose outputs are subsequently distributed and applied across a wide range of firms. This structure reinforces the interpretation that the impact of basic research is best understood in terms of its contribution to an interconnected innovation network, where value emerges through downstream integration of knowledge rather than direct, one-to-one technology transfer pathways.

Recommendations

Defense basic research funding offices should incorporate patent-linked outcome metrics into existing portfolio evaluation and review processes. Metrics such as distinct patent citations, distinct assignees, and patents per publication provide a systematic way to observe how funded research diffuses into the technological domain and complements qualitative processes to determine basic research funding levels. The results of this analysis demonstrate that although these dimensions of impact are not currently captured in standard evaluation frameworks, they can be measured using openly available data.

Moreover, basic research funding offices should consider building or integrating enterprise tools that provide real-time views into patent citation activity that is linked to their portfolio. Such tools could alert portfolio managers when patents are published and cite research within their portfolio. This could help defense personnel understand how defense-relevant scientific research is being used and could proactively enable the identification of potential transition partners within industry.

Additionally, basic research offices should place greater emphasis on identifying research-performing institutions that consistently translate scientific research into technological applications. Universities and research labs function as critical intermediaries in the innovation ecosystem, and the ability to track which institutions produce research that is subsequently cited by patents provides a new dimension for evaluating performance. Incorporating this information into funding decisions would allow program managers to align resources to performers that have consistently demonstrated the ability to diffuse scientific knowledge into the patent system, if that is consistent with the mission of the research program. This in turn would create incentives for research institutions to seek out industry partnerships and increase patent citation activity.

Program managers should also treat DIB-linked patent uptake as an additional system-level diagnostic rather than a direct optimization target. The analysis shows that approximately one quarter of patent citations to defense-funded research originate from companies within the DIB, and that this share is relatively consistent across agencies. This stability suggests that defense relevance emerges as a structural property of the broader defense science and technology ecosystem. Program managers could also examine how research efforts that generated significant patent citations were selected and executed, and how the research institutions worked to promote industry engagement and stimulate patent activity.

Implementation of these recommendations would help drive a shift toward more quantifiable and outcome-oriented basic research portfolio management, in which observable signals of downstream impact are used to complement existing evaluation approaches while preserving the long-term and exploratory nature of extramural defense basic research.

The nation's military has been built on the intellectual property developed by decades of basic research, coupled with the innovation of defense and commercial industry. Tracking the pathway between scientific innovation and industrial output is possible through analysis of observable activities, funding, research publications, and patents. Use of these datasets and analyses would improve the efficiency of future research investments and the ability to transition scientific discoveries into national security capabilities.

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Appendix

The following charts use research topics that were funded by defense agencies as the unit of analysis. The research topics were derived using OpenAlex's proprietary bidirectional encoder recursive transformer (BERT) model that classifies research papers based on the semantic similarity of the text. Citations per publication (CPP) is a metric frequently used in the charts and is derived by dividing total citations by publication count.

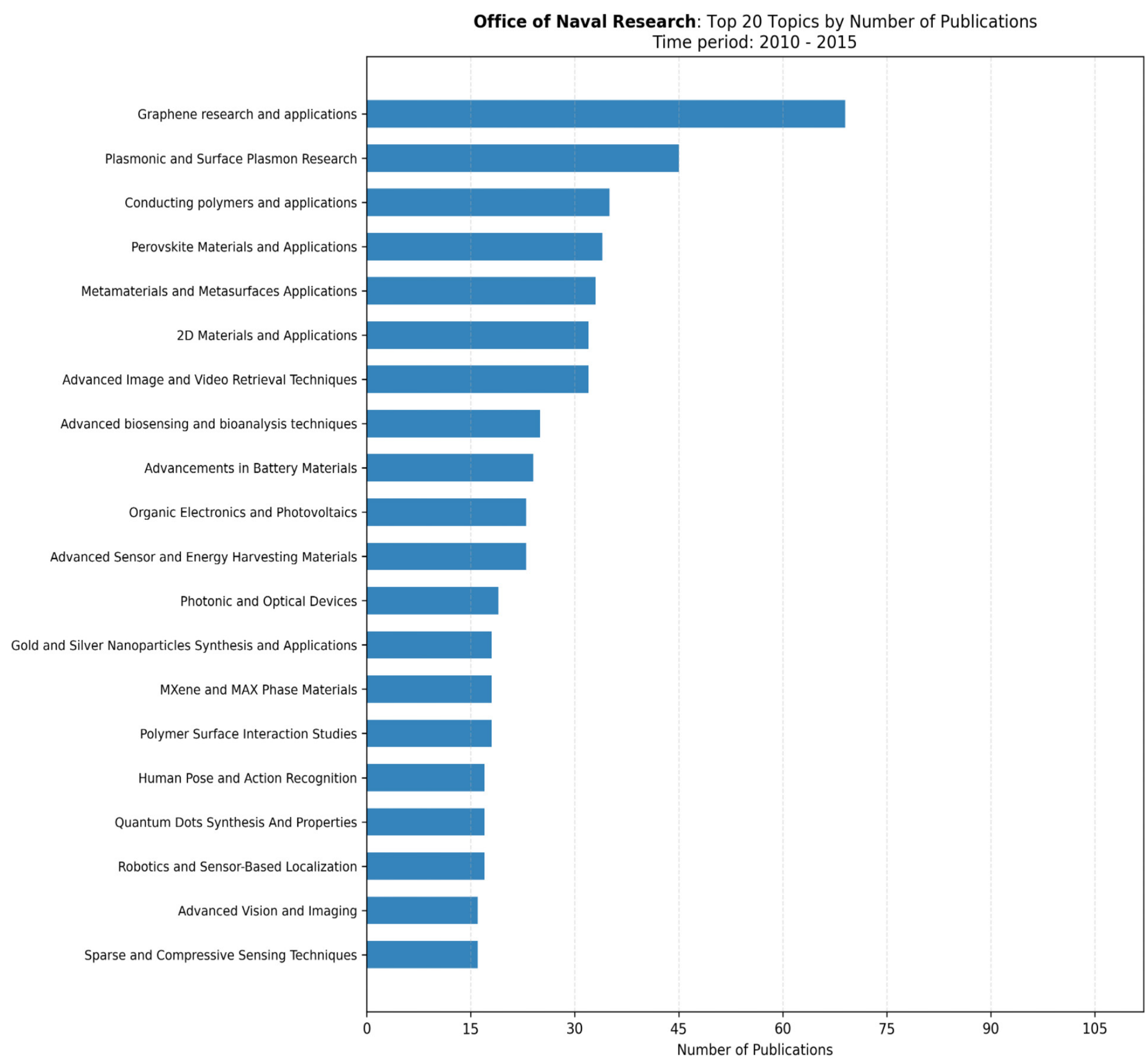


Figure 6

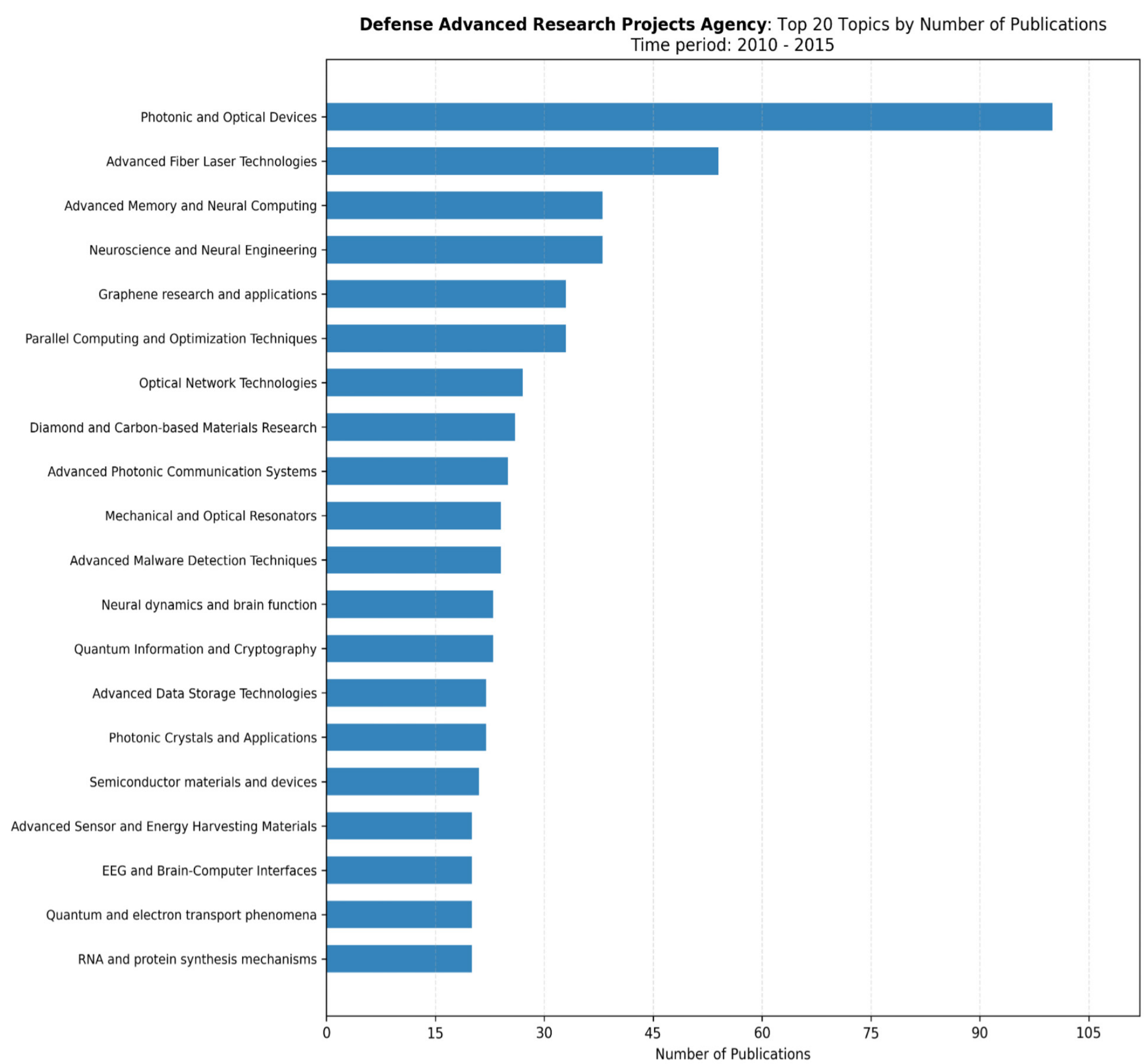
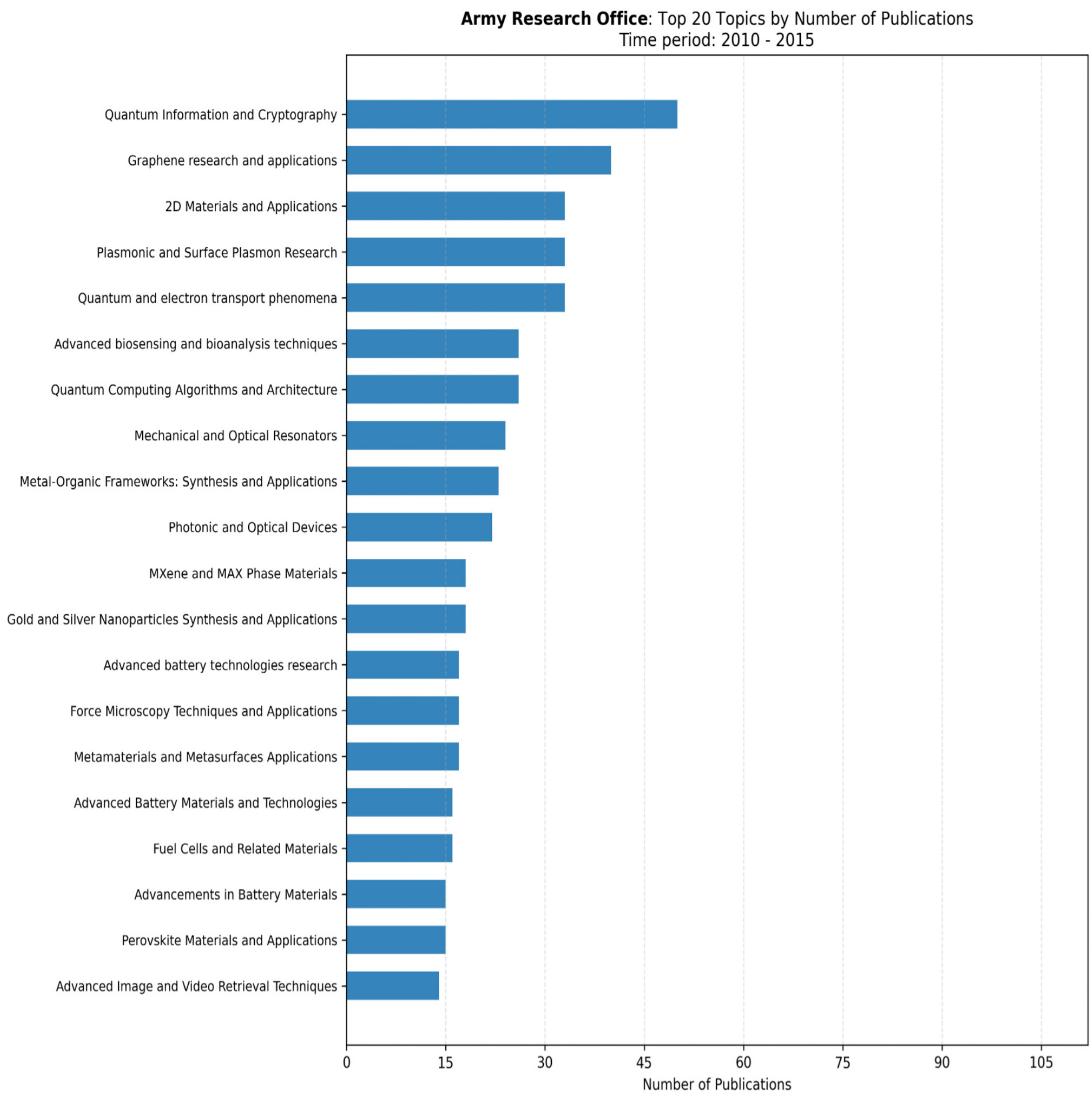

Defense Advanced Research Projects Agency: Top 20 Topics by Number of Publications
Time period: 2010 - 2015
Photonic and Optical Devices
Advanced Fiber Laser Technologies
Advanced Memory and Neural Computing
Neuroscience and Neural Engineering
Graphene research and applications
Parallel Computing and Optimization Techniques
Optical Network Technologies
Diamond and Carbon-based Materials Research
Advanced Photonic Communication Systems
Mechanical and Optical Resonators
Advanced Malware Detection Techniques
Neural dynamics and brain function
Quantum Information and Cryptography
Advanced Data Storage Technologies
Photonic Crystals and Applications
Semiconductor materials and devices
Advanced Sensor and Energy Harvesting Materials
EEG and Brain-Computer Interfaces
Quantum and electron transport phenomena
RNA and protein synthesis mechanisms
0
15
30
45
60
75
90
105
Number of Publications

Figure 7


Army Research Office: Top 20 Topics by Number of Publications
Time period: 2010 - 2015
Quantum Information and Cryptography
Graphene research and applications
2D Materials and Applications
Plasmonic and Surface Plasmon Research
Quantum and electron transport phenomena
Advanced biosensing and bioanalysis techniques
Quantum Computing Algorithms and Architecture
Mechanical and Optical Resonators
Metal-Organic Frameworks: Synthesis and Applications
Photonic and Optical Devices
MXene and MAX Phase Materials
Gold and Silver Nanoparticles Synthesis and Applications
Advanced battery technologies research
Force Microscopy Techniques and Applications
Metamaterials and Metasurfaces Applications
Advanced Battery Materials and Technologies
Fuel Cells and Related Materials
Advancements in Battery Materials
Perovskite Materials and Applications
Advanced Image and Video Retrieval Techniques
0
15
30
45
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75
90
105
Number of Publications

Figure 8

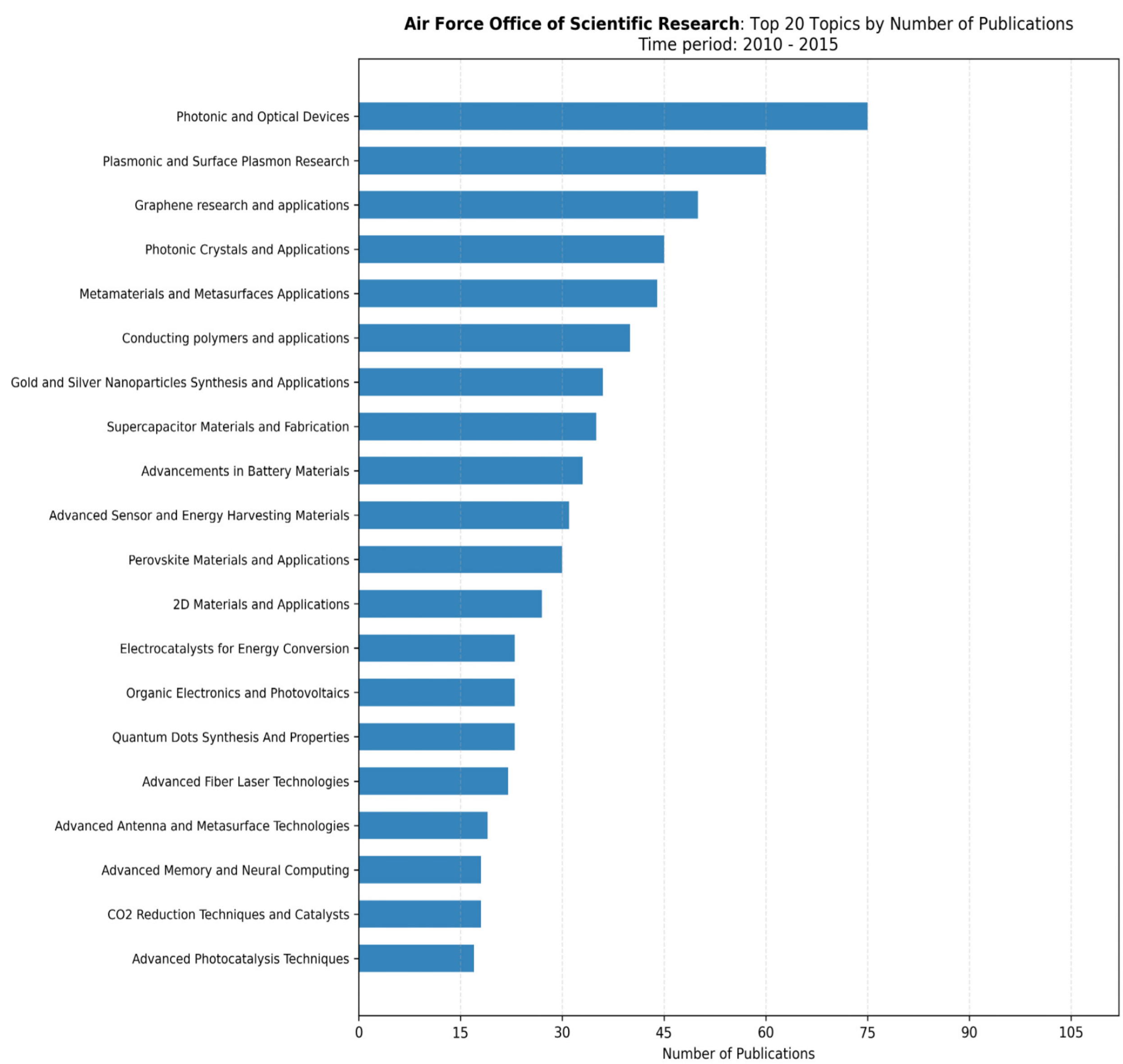

Figure 9

Figures 6 through 9 show the most frequently funded research topic areas by ONR, DARPA, ARO, and AFOSR.

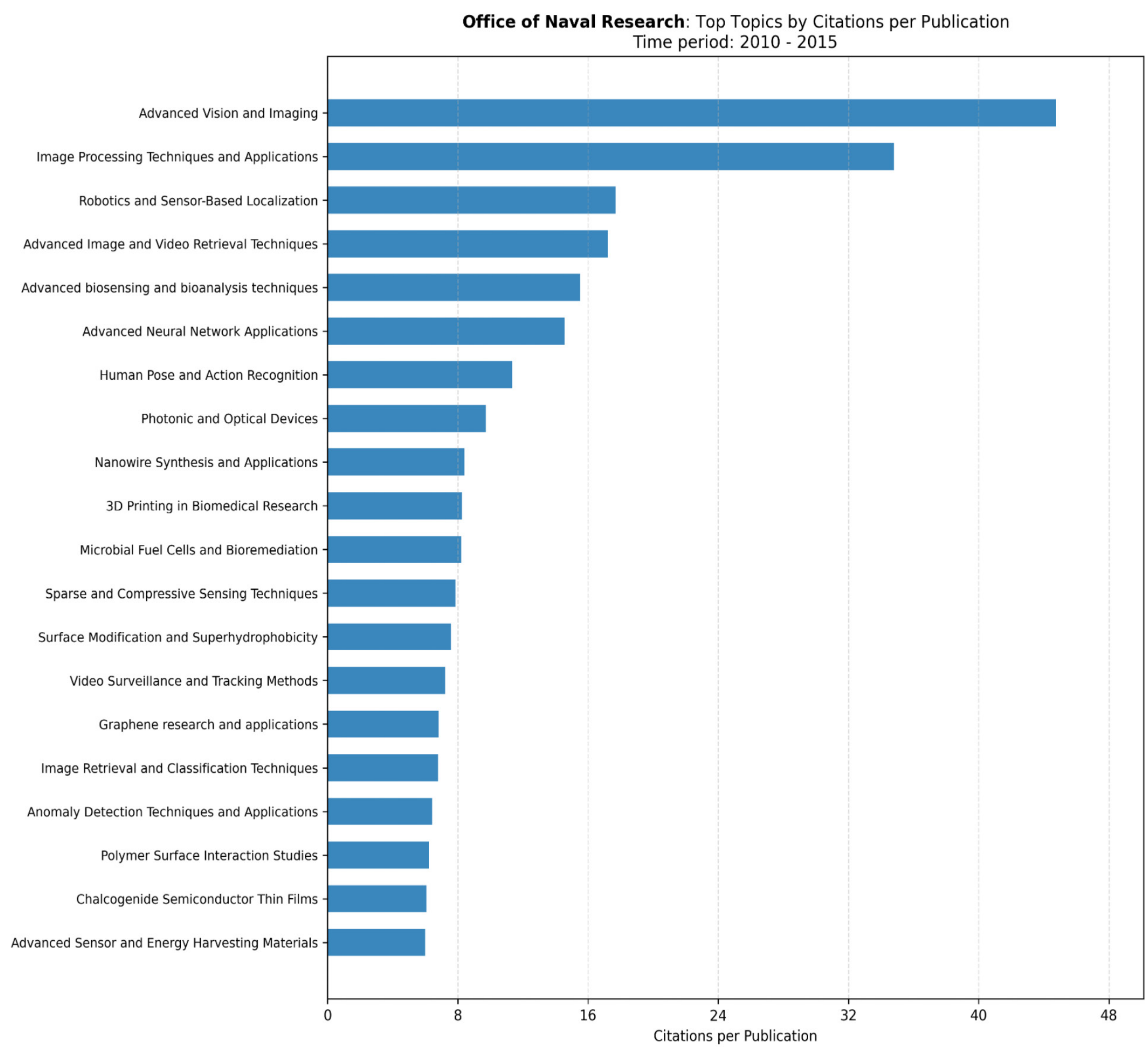

Figure 10

Figure 10 ranks the top 20 topics by citations per publication (shown as the x-axis) for ONR, among topics with at least 10 publications. The leading topic is advanced vision and imaging at 44 CPP (n = 16). Other top performers are image processing techniques and applications (34 CPP, n = 10) and robotics and sensor-based localization (17 CPP, n = 17). Topics that combine relatively high CPP intensity with stronger publication volume include: advanced image and video retrieval techniques (17 CPP, n = 32) and advanced biosensing and bioanalysis techniques (15 CPP, n = 25).

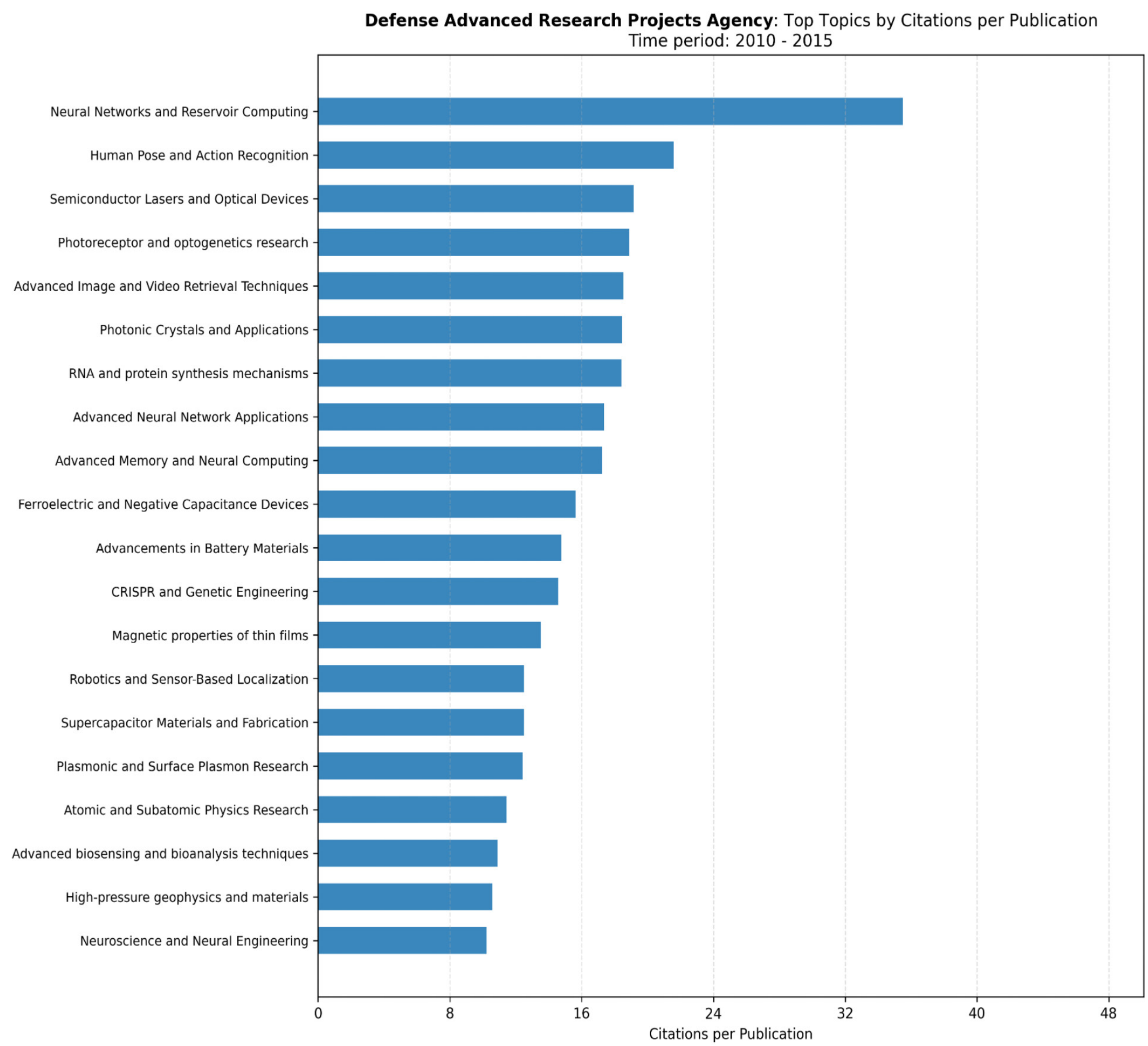

Figure 11

Figure 11 ranks the top 20 topics by citations per publication (shown as the x-axis) for DARPA, among topics with at least 10 publications. The leading topic is neural networks and reservoir computing at 35 CPP (n = 10). Other top performers are Human Pose and Action Recognition (21 CPP, n = 10) and semiconductor lasers and optical devices (19 CPP, n = 14). Topics that combine relatively high CPP intensity with stronger publication volume include: photonic crystals and applications (18 CPP, n = 22) and RNA and protein synthesis mechanisms (18 CPP, n = 20).

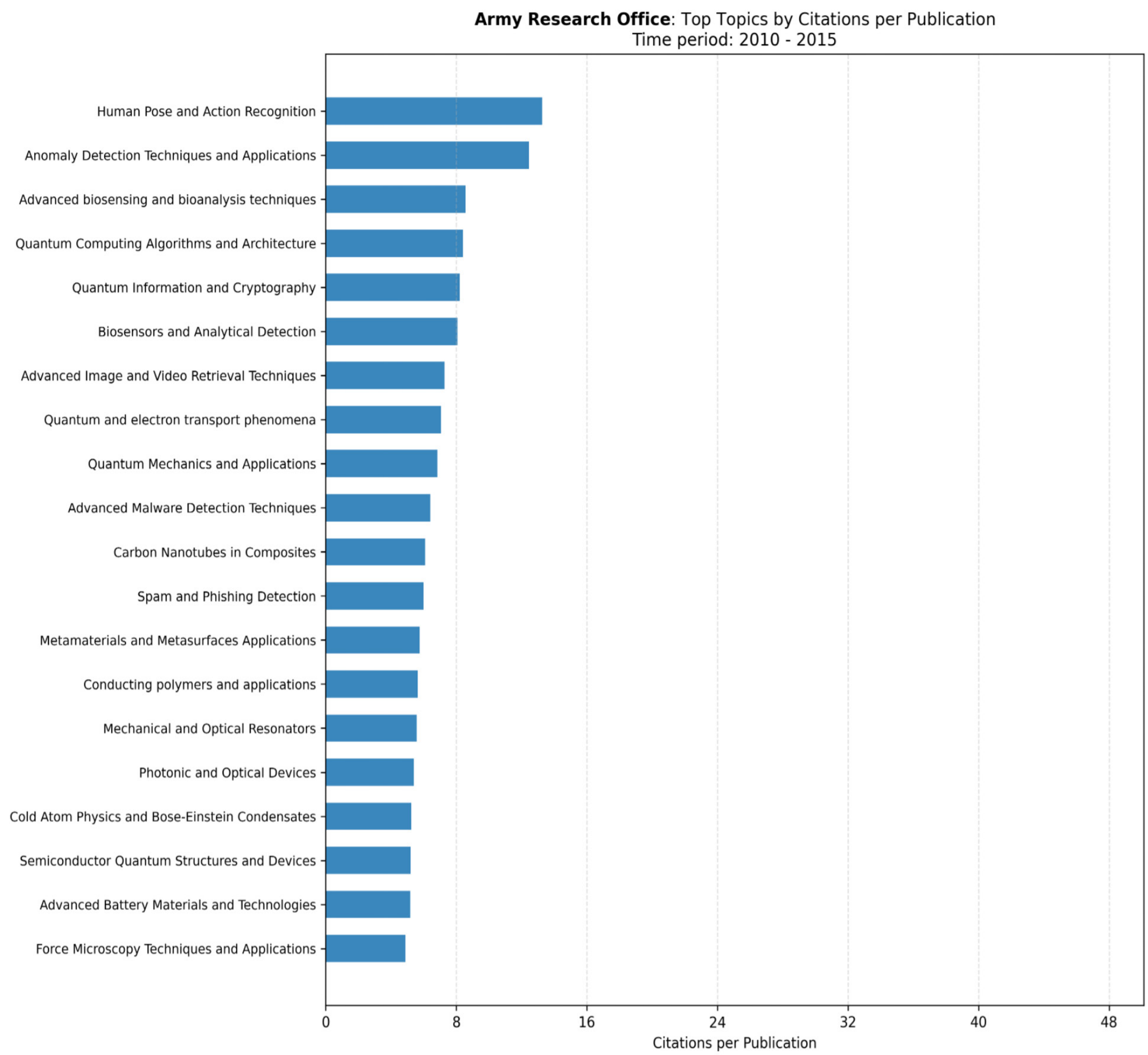

Figure 12

Figure 12 ranks the top 20 topics by citations per publication (shown as the x-axis) for ARO, among topics with at least 10 publications. The leading topic is human pose and action recognition at 13 CPP (n = 11). Other top performers are anomaly detection techniques and applications (12 CPP, n = 13), advanced biosensing and bioanalysis techniques (8 CPP, n = 26), and biosensors and analytical detection (8 CPP, n = 14). Topics that combine relatively high CPP intensity with stronger publication volume include: quantum computing algorithms and architecture (8 CPP, n = 26) and quantum information and cryptography (8 CPP, n = 50).

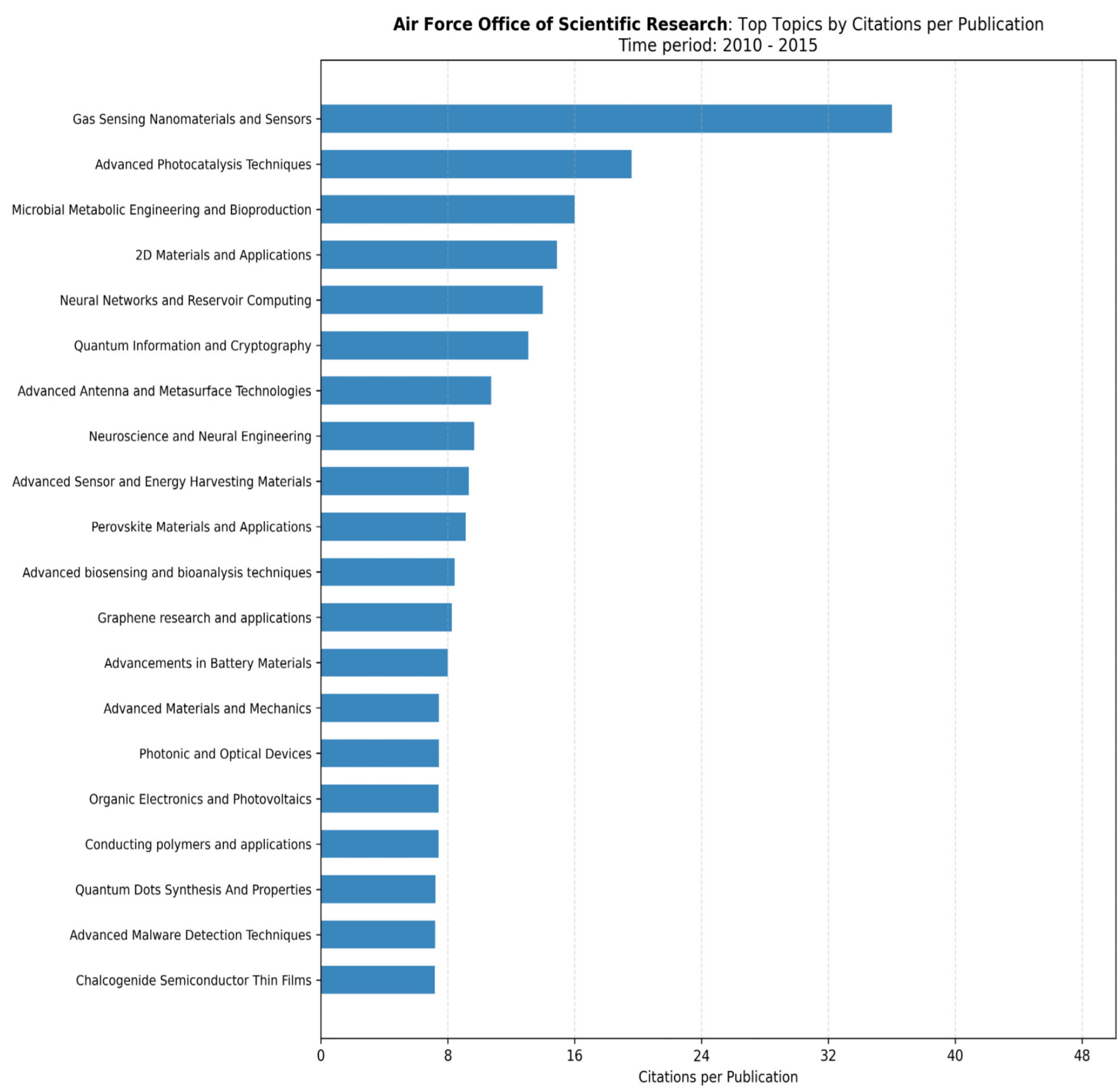

Figure 13

Figure 13 ranks the top 20 topics by citations per publication (shown as the x-axis) for AFOSR, among topics with at least 10 publications. The leading topic is gas sensing nanomaterials and sensors at 36 CPP (n = 10). Other top performers are advanced photocatalysis techniques (19 CPP, n = 17), microbial metabolic engineering and bioproduction (16 CPP, n = 11), and neural networks and reservoir computing (14 CPP, n = 13). Topics that combine relatively high CPP intensity with stronger publication volume include: 2D materials and applications (14 CPP, n = 27) and advanced sensor and energy harvesting materials (9 CPP, n = 31).

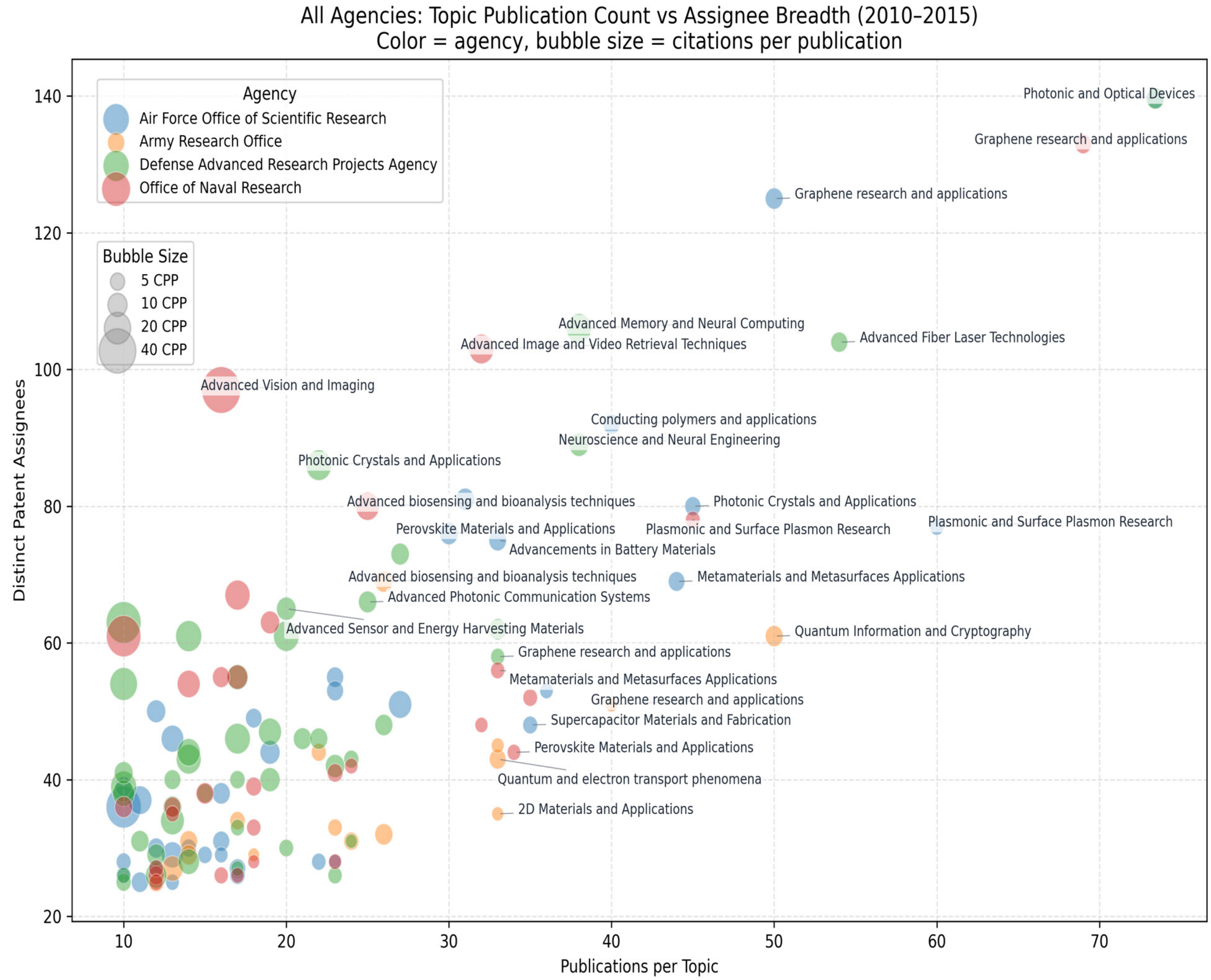

Figure 14

Across all agencies, topic-level patent uptake is highly skewed. A small number of topics combine high citations per publication with relatively modest publication volume, while most topics cluster below roughly 10 citations per publication. The topics with the highest citations per publication appear in areas such as advanced vision and imaging, neural networks and reservoir computing, semiconductor lasers and optical devices, photonic crystals, and advanced memory/neural computing, suggesting that diffusion is concentrated in technically enabling fields with broad downstream applicability. Larger publication-volume topics, such as graphene research, advanced fiber laser technologies, and advanced memory and neural computing, tend to show moderate rather than extreme citations per publication. Bubble size variation also shows that some topics diffuse across a larger set of distinct assignees, reinforcing the interpretation that defense-funded research propagates unevenly through a distributed science-to-technology ecosystem rather than through a uniform or linear transition pathway.

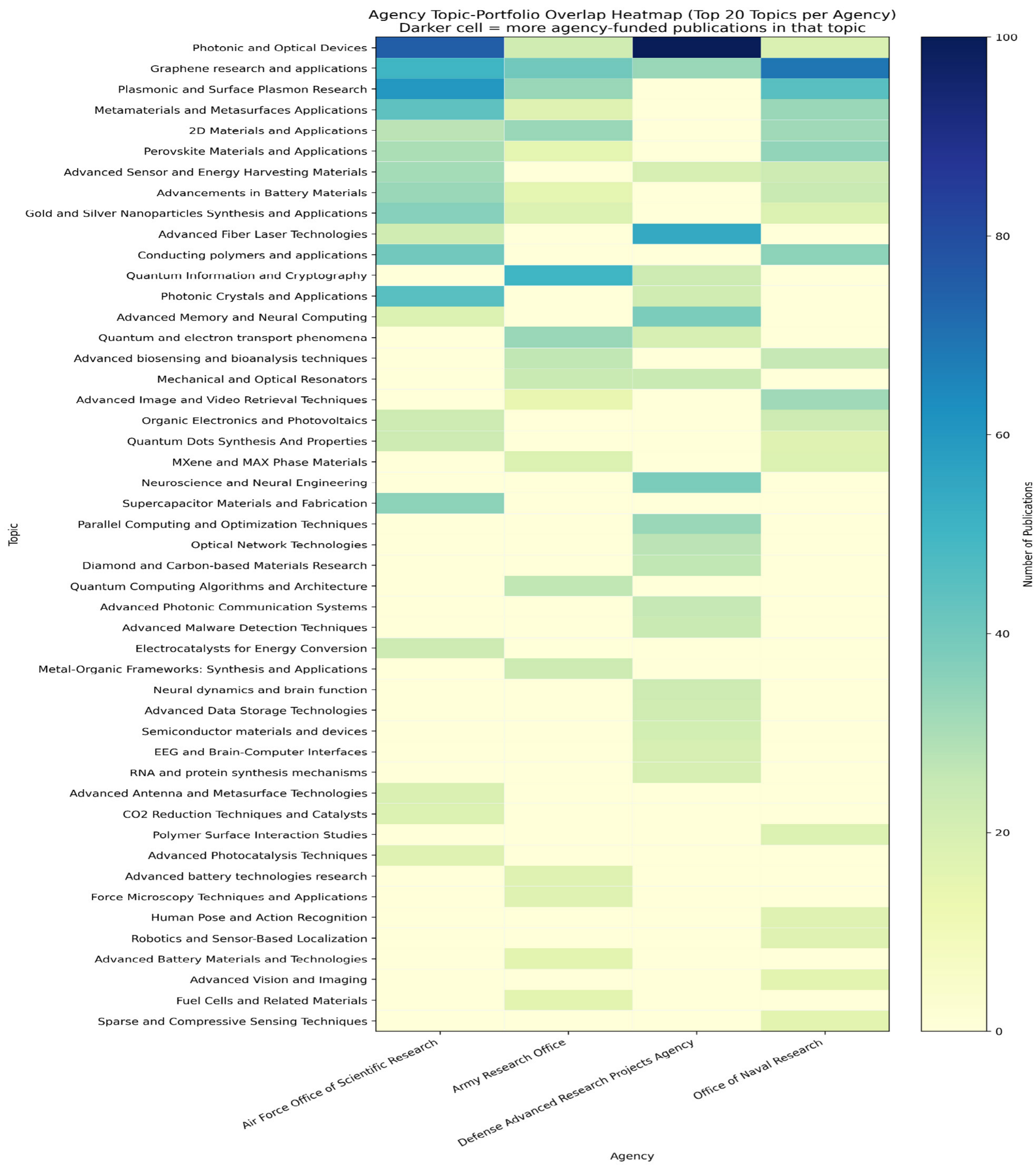

Figure 15

The heatmap shows how portfolios overlap in the research topics they fund across the four defense research agencies. Several technical areas, especially photonic and optical devices, graphene research and applications, plasmonic and surface plasmon research, metamaterials and metasurfaces, 2D materials, perovskite materials, and energy-harvesting materials appear across multiple agencies. This suggests a consistent investment in materials, photonics, and sensing-related research across all agencies. At the same time, the darker cells reveal agency-specific concentrations: AFOSR is especially prominent in photonic and optical devices and related materials topics; DARPA shows strong concentrations in photonics, advanced fiber laser technologies, advanced memory and neural computing, neuroscience and neural engineering, and computing/security-relevant topics; ARO has relatively stronger representation in quantum information, transport phenomena, and selected materials areas; and ONR shows notable activity in graphene, photonics, advanced image and video retrieval, robotics/localization, and sensing-related topics.

About the Authors

Logan Whitehair is a Horizon Research Fellow at the National Defense Industrial Association's Emerging Technologies Institute, where he studies the relationship between federally funded research and downstream technological development. His work focuses on linking scientific publications to patented technologies to understand how basic research diffuses into applied systems, particularly within the defense innovation ecosystem. Previously, he conducted research on artificial intelligence policy and emerging technology governance at the Abundance Institute, and on emerging technology commercialization at the Center for Growth and Opportunity. He holds a multidisciplinary degree in computer science, economics, and sociology from West Virginia University. [LWhitehair@ndia.org]

Dr. Evan E. Johnson is a Research Assistant Professor of Public Policy at UNC–Chapel Hill and founder of Arclight Analytics. He specializes in applied econometrics, data science, and program evaluation, with a focus on innovation, entrepreneurship, and public R&D policy. Dr. Johnson has served as a lead consultant and advisor to the National Academies of Sciences, Engineering, and Medicine, where he evaluates federal innovation and seed funding programs. His work spans sectors including defense, energy, and biomedicine. His research integrates large-scale administrative data with rigorous empirical methods to advance evidence-based policymaking and contribute to the scholarly understanding of innovation systems and public investment. [Evanej@live.unc.edu]

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