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Robert W. Conn
Peter F. Cowhey
Joshua S. Graff Zivin
Christopher L. Martin

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ABSTRACT

Investments in the US Science, Technology, Engineering, Medicine and Innovation (STEMI) enterprise come from many different sectors and their combined effect crucially enhances the nation's competitiveness. Philanthropy is an under-appreciated component of this ecosystem, providing $21.5 billion of research funding at universities and non-profits in 2021 or roughly 42% of the federal outlay at these institutions. In this paper, we argue that these decentralized and diverse set of philanthropic funders alter the incentives and behavior within the US research enterprise to make it more risk tolerant and more innovative than government or business funding alone would yield. It also enables significant innovation in the development of human capital in STEMI areas. We conclude with a comparison of the US research ecosystem to that of China to understand how the two systems differ, with a particular emphasis on the differentiating role that philanthropy may play in influencing the scientific and economic competitiveness of each nation.

Robert W. Conn
University of California, San Diego
9500 Gilman Drive, MC 0519
La Jolla, CA 92093
rconn@ucsd.edu

Peter F. Cowhey
University of California, San Diego
9500 Gilman Drive, MC 0519
La Jolla, CA 92093
pcowhey@ucsd.edu

Joshua S. Graff Zivin
University of California, San Diego
9500 Gilman Drive, MC 0519
La Jolla, CA 92093-0519
and NBER
jgraffzivin@ucsd.edu

Christopher L. Martin
Vela Science
1 Sunningvale Lane
Christchurch 8053
New Zealand
chris.vela.science@gmail.com

Introduction and Synopsis

The United States is resetting its strategic thinking and policies for its Science, Technology, Engineering, Medicine and Innovation enterprise[1] (hereafter, STEMI). This effort derives partly from some worrisome issues in the American economy, such as the fate of US manufacturing of the most advanced semiconductors, and partly from a growing perception that innovation is slowing. Concerns over strategic competition and fundamental political disagreements with China have further charged the policy discussion.

This paper advances the reassessment by improving our understanding of how US investments that are made by various sources in our STEMI enterprise influence the behavior, scientific and technical productivity, and innovation efforts of the system. These investments are the "upstream" drivers of the dynamics of the system.

Frequently, this exercise focuses on aggregate funding levels measured as the percentage of total Gross Domestic Product (GDP) that is dedicated to Research and Development (R&D). Sometimes, the focus is on the funding by government and on its distribution across different STEM fields, particularly as priorities change between basic and applied research in fields of geostrategic importance. The CHIPS and Science Act[2] signed into law in August 2022 is an example of rebalancing budgets between basic, applied, and development priorities.

These research investment metrics are important. It is significant if the US devotes less of its national economy to R&D than its peers. It matters if we neglect key research fields in our investments or neglect certain sources of R&D investment themselves. However, we have framed our investigation into the investment drivers of R&D within the framework of the scholarly literature focused on national innovation systems. In this literature a national innovation system has two major components.[3] There is a basic and applied research stage and an incremental and developmental research stage. The former consists of the

[1] For the purposes of this paper, we will use the definition of STEM used by the National Science Foundation to include all fields of science, engineering, mathematics, and the social sciences. For a longer discussion of the definition of STEM, see page 2 of the Congressional Research Service report (R45223) on the topic, available at https://sgp.fas.org/crs/misc/R45223.pdf

[2] The CHIPS and Science Act. Pub. L. 117-167. Signed into Law, August 9, 2022

[3] The literature on innovation systems is summarized in Daniel Breznitz, Innovation and the State (Yale University Press, 2007)

basic discovery effort of knowledge building for its own sake and the earlier breakthrough stages of applied research, such as Pasteur's discoveries preserving milk from spoilage or the creation of a viable laser. (The NSF refers to these as basic and applied research.) The second stage of incremental innovation and development research ranges from "learning by doing" improvements such as those in the manufacturing system and the later stages of research for commercialization. (The NSF refers to this as experimental development research.)

Our analysis touches on both stages. However, our principal focus is on the health of the basic and applied stages of research and innovation. It is these stages that ultimately drives the frontiers of what is possible over the long term. We shall argue that the US basic and applied research system has a major long-term advantage compared to the rest of world. Identifying the nature of this advantage, and its consequences, is the purpose of this analysis.

Our strategy is to focus on carefully disaggregating the major sources of R&D funding and examining how each investment stream incentivizes different strategies and agendas for research. We focus on investment by emphasizing differences in the implications of business, government, and importantly, philanthropic funding. In particular, building on Conn's 2020[4] paper we explain in detail how science philanthropy plays a much larger role in shaping behavior of our discovery enterprise than is commonly recognized and this is important for the success of the basic stage of research.

Our conclusions rest on two key sets of claims. The first set relates to dissecting the respective funding sources of basic and applied research[5] (as

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[4] Robert W. Conn, "Why Philanthropy is America's Unique Research Advantage", presented at National Academy of Sciences, Feb. 2020. Also, ISSUES in Science and Technology, Aug. 21, 2021. See https://issues.org/philanthropy-science-technology-unique-research-advantage-conn/ and The Next 75 Years of Science Policy, Special Collection of Papers. Issues in Science and Technology. NASEM. (2022). Pp.336-344.

[5] Basic Research, Applied Research and Experimental Development are terms used here (and throughout this paper) as defined by the National Science Foundation (NSF) in https://www.nsf.gov/statistics/randdef/rd-definitions.pdf which is consistent with the OECD definitions as found in its Frascati Manual 2015, https://www.oecd.org/innovation/frascati-manual-2015-9789264239012-en.htm. Specifically, these definitions are: 1) Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. 2) Applied research is original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily toward a specific, practical aim or objective. 3) Experimental development is systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes.

opposed to experimental development) to explain why philanthropy is so critical to the overall enterprise. This is likely to be surprising to many. The analysis requires a deep dive into the national research accounts, which we present in Sections I and II of this paper. We can however briefly highlight the big picture as follows: As of 2021, about 33% of US R&D spending is on basic (15%) and applied (18%) research[6], a share of investment that is quite high compared to other major countries. (Again, the terms "basic" and "applied" are the terms used by the National Science Foundation in its reporting[5,6] .) While the remaining share of spending on development is important, our focus is on the basic and applied research for reasons just stated. Still, we fully agree that efforts to strengthen the US incremental and development stage of research are important.

Business overwhelmingly devotes its spending to development, but its basic and applied research budget is still $127 billion[7] (a bit over one-third more than federal spending for these purposes). As explained in Section I, in a few fields, this arguably makes business a major driver of the entire US basic and applied research effort. However, most business research is siloed (that is, it is used largely for internal projects) and those projects are mainly tied to business strategies because of the fiduciary responsibility of firms. In short, because it is directed toward corporate missions, there is less freedom for pure discovery. This means the largest funders of basic and applied research with a truly broad scope of agendas are the federal government and private philanthropy.

An analysis of all federal expenditures for basic and applied research shows that federal research spending for its own intramural work and its Federally Funded R&D Centers (FFRDCs) together receive about $32 billion per year as of 2021[8]. These efforts are important, but they tend in ways similar to business research, to be largely oriented around functional missions defined by executive leadership. This leaves an important question about where our research system incentivizes research that is largely curiosity driven, responding to the inspirations of individual researchers or groups, rather than responding to direction from some

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[6] National Center for Science and Engineering Statistics (NCSES). 2023. National Patterns of R&D Resources: 2020-21 Data Update. NSF 23-321. Alexandria, VA: National Science Foundation. Available at https://ncses.nsf.gov/pubs/nsf23321. These figures from Tables 3, 4, and 5: Total R&D by All Performers FY2021 (estimate).

[7] Ref. 6: Tables 7 and 8: Basic and Applied research funded by businesses in FY2021 Current Year Dollars. For comparison, Federal funding for basic and applied research to all performers was $92B in FY2021.

[8] Ref. 6: Tables 3 and 4: Basic and Applied research performed by Federal intramural (note this also includes administrative costs for external programs) and FFRDCs in FY2021 Current Year Dollars

form of management. A national budget that strongly supports basic and applied research should benefit from this type of inquiry and the discoveries it engenders.

A further look at federal R&D expenditures (see Section I, Fig. 2) shows that the largest institutional agents for more investigator-driven paths toward high-risk basic and applied discovery are, collectively, research universities and large non-profit research organizations (NPOs). These entities, universities and NPOs, together received $51 billion of the federal outlays for basic and applied research of $92 billion as of FY2021[9]. In short, universities and NPOs are the collective standard bearers for the federal effort on basic and applied research that induces discovery by embracing greater degrees of freedom for researchers in charting their own course.

It is at these very institutions where philanthropy plays such a large role in supercharging the research system. As shown in Section II, the combination of current philanthropic giving and the yield from endowments (which we shall call "legacy philanthropy"[4]) equals about $21.5 billion for 2021 for basic and applied research at both universities and NPOs. (We discuss in detail in Section II.) This is roughly 42% of the federal outlay to these institutions. This surprisingly large percentage means that philanthropic dollars are sufficiently large to influence how the research system operates and performs at these institutions.

Our second set of claims, stated in Sections IV to IX, is that a decentralized and diverse set of philanthropic funders alters incentives and behavior within the US research enterprise. The rise of science philanthropy in the late 19th century catalyzed the creation of a decentralized set of research universities and private, non-profit research institutions[4]. These are the primary performers, along with federally-funded national laboratories, of research within which the present era of philanthropic and governmental support operates.

Today, philanthropic funding alters the portfolio mix of US investments in its STEMI enterprise. From our more than thirty interviews[10], from literature in the area, and from our own experiences, we conclude that philanthropy makes the

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[9] Ref. 6: Tables 7 and 8 FY2021 Current Year Dollars: Higher education received $39.9B and NPOs $11.0B for a total of $51B. The other two major recipients of federal monies are the federal intramural spending at $16.9B and FFRDCs at $14.9B, both larger than the funding to NPOs.

[10] As part of this research, the authors interviewed more than forty people from all areas of the US STEMI enterprise. These included presidents of universities, private non-profits, and foundations, faculty and staff at these institutions, former leaders of science agencies of government, and people familiar with issues related to human capital needs, including diversity, equity, and inclusion.

overall enterprise more risk tolerant and more creative than government or business funding alone would yield. Furthermore, it enables significant innovation in the development of human capital in STEMI areas.

To be sure, every system has risks. Issues of social responsibility, as summarized by Michelson and Falk, confront our nation's decentralized research institutions of public and private universities, and its private, non-profit research institutions[11]. The tendency for institutions with very large endowments to grow those endowments still further raises questions about the resource imbalances that may result from a system so reliant on private funding. And our focus on the existing pattern of research investments and their consequences for systemic behavior does not address such policy issues as the debate over the appropriate tax regime for the very wealthy, a factor influencing philanthropic giving.

We believe that our analysis shows that any rethinking of the US R&D system requires a more precise understanding of how its diverse sources of funding and institutional dynamics influence and drive the system's overall behavior and performance. As we briefly note in our conclusions, our analysis highlights long-term advantages of the United States that should serve it well in preserving its leadership in global STEMI, including China's quest for that leadership.

Before proceeding, we note that our research process has utilized publicly available data for estimating the scale of different kinds of investments in the STEMI ecosystem. However, gaps exist in public reporting of R&D financial data despite the best efforts by the National Science Foundation (NSF) and several private organizations. We have, where necessary, made our own "best estimates" of the missing data. In doing so we benefited from access to confidential data provided by several universities.

In addition, our claims about the impacts of philanthropy on the STEMI ecosystem were tested and informed by more than thirty interviews with leaders across the US STEMI enterprise. The interviewees ranged from leaders of universities and non-profit research institutions to many in America's national academies to former leaders of science agencies in government through to researchers in science and technology and people at philanthropic foundations and organizations.

[11] Evan S, Michelson and Adam F. Falk, "A Vision for the Future of Science Philanthropy", https://issues.org/future-science-philanthropy-sloan-michelson-falk/ and ibid. pp. 351-360.

Despite all this, we acknowledge that this paper is making significant claims based on both quantitative and qualitative evidence, and on some educated financial guesswork. We state our best case firmly in the hope that it will propel the disclosure of more data by universities and NPO's and fresh insights by other researchers.

I. The Evolution of the Research Investments in the US STEMI Ecosystem

The US R&D system has invested significantly in basic and applied research as part of its world leading expenditures on total R&D. As it evolved after 1945, an implicit division of labor emerged in the US system of basic and applied research. The federal government's internal research investments (intramural and FFDRC) and those of the business community have made them the specialized leaders in risky, very large scale, expensive, and long-term efforts in basic and applied research in a handful of highly selective fields. But for the rest of the research landscape, the leadership comes predominantly from universities and NPOs.

Philanthropy plays a special role in driving the performance of the American system of basic and applied research because its support is large, as we will show, and goes primarily to universities and NPO's. This is crucial because the choices made by business and the federal government over the decades have made our research universities and NPOs the primary center of gravity for basic discovery, and these institutions have greater freedom to define agendas and strategies from the bottom up. In these institutions, philanthropy plays a significant role in supercharging the discovery system.

To establish the plausibility of this claim, we do a deep dive into the financials of the US research system. This section and the next analyze the evolution of funding of national research since 1945. Beginning with Section IV, we add analytic context by pointing out how the institutions anchoring the system influence the system's performance and how philanthropy has shaped the structure and performance of these institutions.

Understanding the financial evolution of the current system best begins with noting the general shift of the US research system after 1945 towards one with a heavier emphasis on basic and applied. To illustrate the magnitude of the US commitment to basic and applied research, we use the most recent data available (from 2021) in Fig. 1 to compare the research efforts of the US and China. In regard to every major source of funding, including business, the US is more heavily invested in basic and applied research than China.

Table 1 paints a broader global picture based on information available for the top ten countries in R&D expenditure according to OECD data. The table shows the total scale of the U.S. R&D budget assures that its expenditures for basic and applied far exceed the budgets of countries devoting a larger percentage of their total effort to basic and applied.

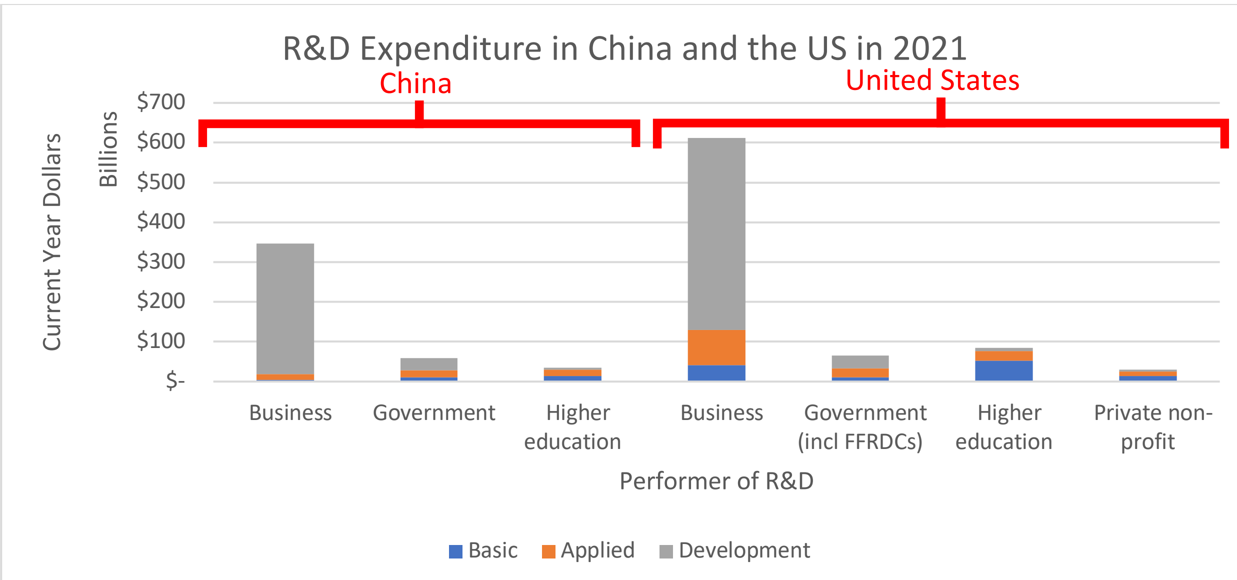

Fig. 1. Research and development expenditures of the US and China in 2021, with each column showing the various performers of R&D. Each bar shows in blue the portion categorized as basic or fundamental research, in orange the portion of applied or use-inspired research, and in gray the portion of development funding. US Data from the National Science Foundation, National Patterns of R&D Resources: 2020-21 Data Update Tables 3, 4, & 5. See https://ncses.nsf.gov/pubs/nsf23321. The Chinese Data is from the National Bureau of Statistics, China Statistical Yearbook 2022, http://www.stats.gov.cn/sj/ndsj/2022/indexeh.htm, with amounts converted to Current Year US Dollars using the Dec. 31, 2021 US Treasury exchange rate.

Table 1

Country	Data as of	Total R&D in Constant 2015 USD millions with PPP correction	% Basic Research	% Applied Research
United States	2021	$ 709,713	14.8%	18.1%
China (People's Republic of)	2018	$ 464,705	5.5%	11.1%
Japan	2021	$ 172,062	12.7%	18.8%
Germany	2020	$ 125,567	not reported	not reported
Korea	2021	$ 110,148	14.8%	21.0%
United Kingdom	2020	$ 78,153	not reported	not reported
France	2019	$ 63,923	22.7%	41.4%
Taiwan	2021	$ 51,304	7.4%	20.2%
Russia	2020	$ 40,322	17.5%	18.6%
Italy	2020	$ 32,098	22.2%	40.1%

Table 1. A list of the top ten countries based on expenditures for R&D across their entire economies. Since not all countries report their data to the OECD every year, the most recent year that data is available for each country is shown. The OECD normalizes the data through a constant 2015 US Dollar Purchasing Power Parity (PPP) conversion, but the percentage expended on basic or applied research will be unchanged by this conversion. Some countries do not report their basic and applied research data across their entire economies on a regular basis to the OECD, and hence these are shown as "not reported." Data is drawn from OECD Stats database, "R&D expenditure by sector of performance and type of R&D." See, https://stats.oecd.org/Index.aspx?DataSetCode=RD_ACTIVITY

A fundamental turning point for the US research mix came with the emergence of the federal government as a major driver of research, especially basic and applied. Following the advice of Vannevar Bush in his famous 1945 report, "Science, The Endless Frontier"[12], the US Government became the major funder of research and provided their funds mainly to the nation's universities and non-profit research institutions. Interestingly, Bush himself did not call for funding by government of non-profit research institutions, largely because he was focused on the nation's need not only for science but the need to educate a scientific and engineering workforce. Nonetheless, private, non-profit research institutions are a

[12] Vannevar Bush, Science, The Endless Frontier, US Government Printing Office. (1945)

key part of the US STEMI ecosystem, as discussed by Gage and Isaacs[13]. Fig. 2 shows how the US Government distributed those R&D funds as of 2021.

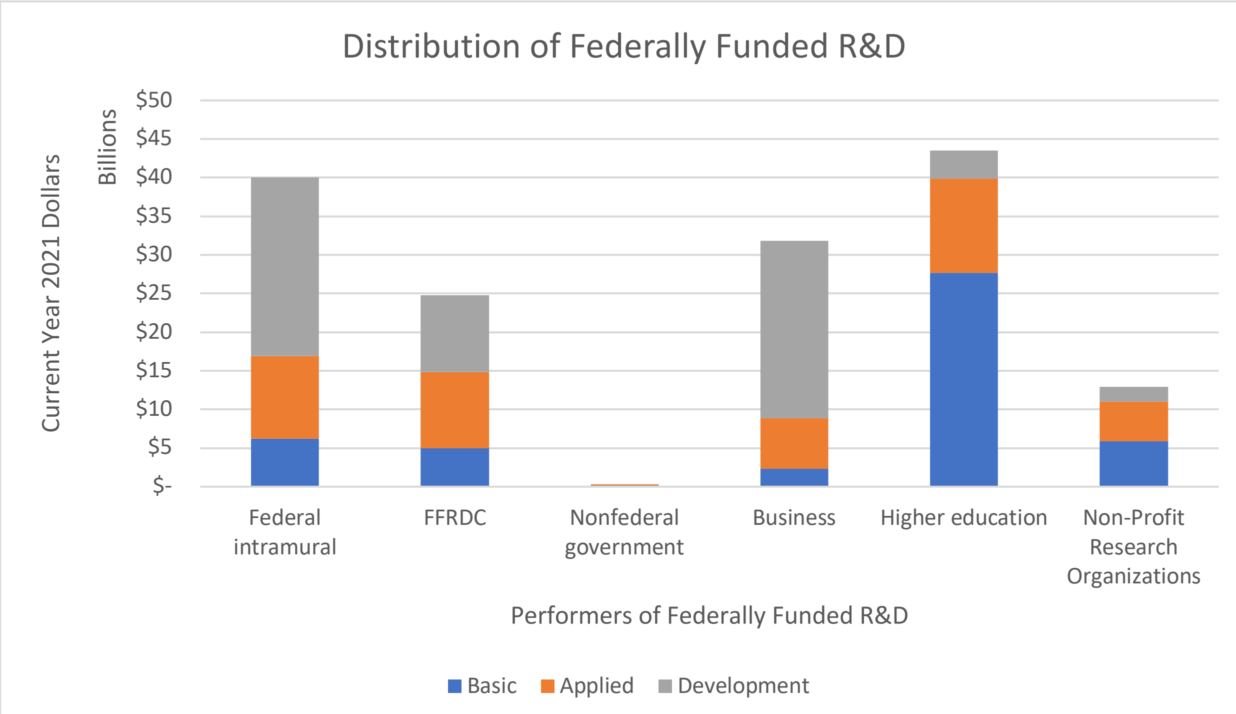

Fig. 2. FY2021 US Federal funding of research and development with each column showing the various performers of federally funded R&D. Each bar shows in blue the portion categorized as basic or fundamental research, in orange the portion of applied or use-inspired research, and in gray the portion of development funding. It is notable that not only are higher education institutions the largest recipient of all federal R&D funding, but that funding is also predominantly for basic and applied research, unlike any other recipient of funding. From left to right the columns represent: 1) Federal intramural: funding at facilities run by the federal government, 2) FFRDC: Federally Funded Research and Development Centers which are public-private partnerships to conduct research operated by universities or corporations, 3) Nonfederal government: facilities run by states and other local government entities, 4) Business: for-profit corporations, 5) Higher education: universities and colleges, and 6) Non-Profit Research Organizations other than universities. Data from National Science Foundation, National Patterns of R&D Resources: 2020-21 Data Update. See, https://ncses.nsf.gov/pubs/nsf23321 Tables 7, 8, and 9.

There is major funding for government intramural projects and Federally Funded R&D Centers (again, FFRDCs), both of which do basic and applied work and play a special role in very large-scale research projects (hereafter, VLSR) that play out over many years. This role complements one played by business in very selective fields of research today such as artificial intelligence, quantum

[13] Fred H. Gage and Eric D. Isaacs, "Independent Science for a Daunting Future", in The Next 75 Years of Science Policy (National Academies and Arizona State University. 2022)

computing, and vaccine and certain drug developments. But the largest collective share of federal funds for basic and applied research goes to higher education and NPOs. Those funds (in 2021, about $51 billion[9]) for basic and applied research mean that these institutions conduct the overwhelming majority of basic and applied research within the broader US science ecosystem. Significantly, based on the data in Table 1, the $51 billion in federal funds to these institutions roughly equals the total national expenditures on basic and applied research in Japan, the world's third largest R&D country. And as we shall show, US universities and NPOs strongly supplement the federal funding with their own resources, significantly fueled by philanthropy.

It is helpful to have a clear understanding of the distinctions that underlie the different types of research as defined by the NSF and OECD[5]. As noted earlier, basic research, sometimes called fundamental research, can be thought of as research driven by our need to understand, our curiosity about how nature works across all its realms. Einstein's research into general relativity is an example. The results of basic research can be crucial to further advances in applied research or development, but the original motivation for the research does not require any particular use in mind.

Applied research, sometimes called outcome-oriented or use-inspired research, is research done to develop the new knowledge and understanding needed to solve a specific, practical aim or objective. Pasteur's research into killing microbes to prevent the spoilage of milk and beer, or Bell Laboratories invention of the transistor, are examples of applied research, using the NSF definitions[14].

Finally, the definition of experimental development by the NSF and OECD is the work that needs to be done in order to take research and turn it into a product or a drug. Experimental development is predominantly conducted by businesses using their own funds, which are spent internally on their own development needs. (This spending was approximately $404B in FY2021[15].) Crucially, this development pipeline heavily relies upon the basic and applied research that is generally performed outside of the business sector. For the remainder of this paper, we will focus primarily on basic and applied funding performed at universities and NPO's.

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[14] Donald Stokes, *Pasteur's Quadrant, Basic Science and Innovation.* (Brookings Institution Press, 1999).

[15] Ref. 6: Table 5: Development performed by domestic businesses within their own facilities.

Since World War II, a large and constantly growing flow of federal research funds enabled university expansion and the growth in the number of science and engineering students and professionals across the country. This growth in funding since 1953 is illustrated in Fig. 3.

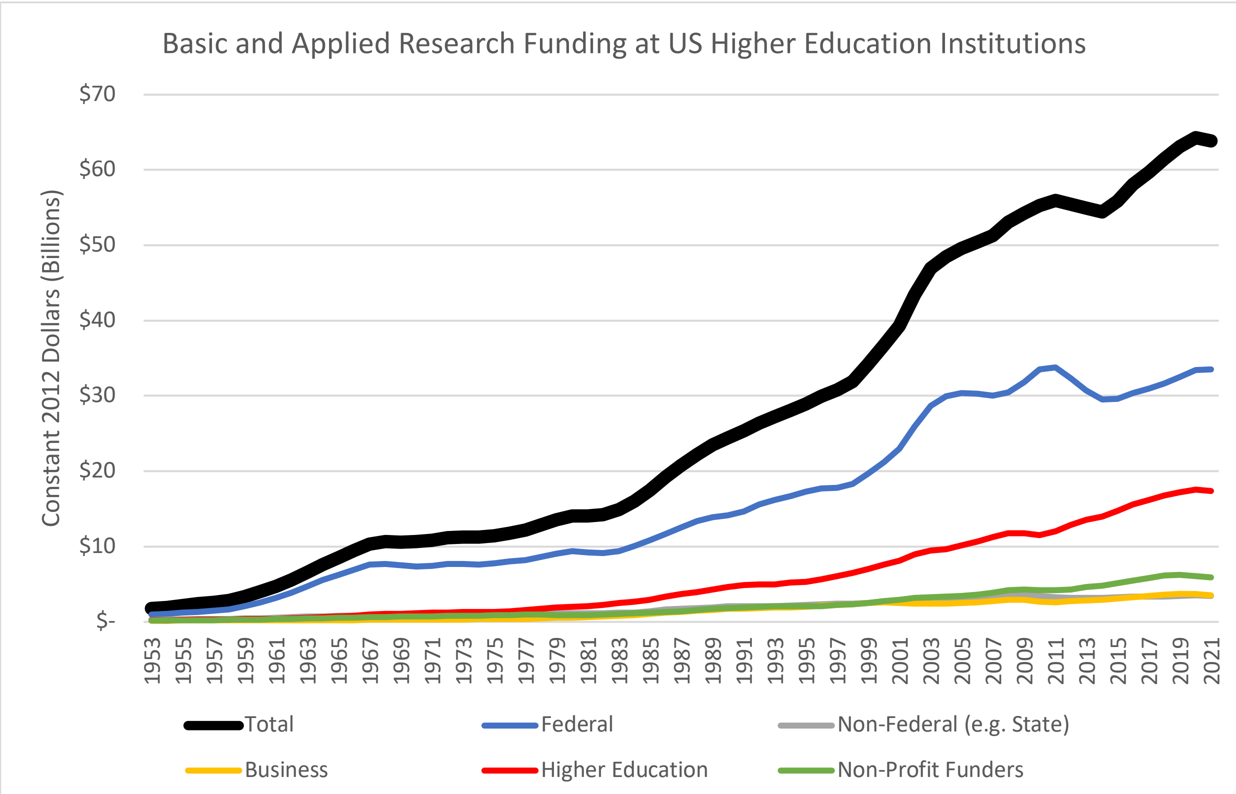

Fig. 3. Funding of basic and applied research and development at US higher education institutions (black line), broken down into the portions provided by the federal government (blue line), higher education institutions themselves (red line), by non-profit funders (green line), by businesses (yellow line), and non-federal (e.g. state and local) governments (gray line) in constant 2012 US Dollars in order to provide a consistent year to year comparison. This funding has increased greatly in constant inflation-adjusted dollars since the early 1950s. (Source: National Science Foundation, National Patterns of R&D Resources: 2020-21 Data Update. See https://ncses.nsf.gov/pubs/nsf23321 Tables 3 and 4).

Federal support for R&D grew quickly in the 1960's and then, after a pause of roughly eight years, it continued to rise at a similar rate into the 1980's. Also in the 1980's, universities grew their own expenditures on STEMI at an increasing rate due largely to the growth in their endowments (the legacy of earlier philanthropic giving), and their annual payouts. As of 2021, university spending from its own resources on basic and applied research represents 27% (or $20.6B) of the total basic and applied research at universities ($75.9B)[16]. Remarkably, this is more than half (52%) of what the federal government itself provides for basic and applied research at universities ($39.9B as of 2021). (See Fig. 4[17]). So again, the payout of legacy philanthropy and annual philanthropic giving are one of the important sources of higher education funding of basic and applied research within itself.

Universities raise internal resources in a variety of ways, not just from legacy and current philanthropy. Other key sources include such sources as licensing, tuition, and indirect cost recovery (which we will discuss later. As Section II shows, the philanthropic contribution from endowment payouts (the result of legacy philanthropy) is estimated to be at least $4.8B, or about 25% of the total internal university support of $20.6B. When combined with annual philanthropic giving of approximately $7.0B, we find that total philanthropic support at universities for basic and applied research is about $11.8B, or more than 50% of their internal spending in support of basic and applied research. This is remarkable and surprising.

In practice, during the post-war period of budget largesse, the federal government also implicitly subsidized the non-federal institutions (universities and non-profit research institutions) by providing markups for overhead costs (called Indirect Cost Recovery, or IDC) on federal research projects. The IDC contributes to the indirect costs of operating buildings and labs, and to supporting personnel needed for a research project. The IDC monies made it easier for universities and non-profits to expand, especially when the funding formulas were realistic. Today, however, the consensus is that government IDC is inadequate to cover the costs of doing the work at universities, and philanthropies provide even less in IDC than government.

In order to fill this gap in IDC funding, universities apply some of their own funds to support unrecovered indirect costs, and importantly this is one major component of the institutional support reflected in Fig. 4. We address this issue later.

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[16] Ref. 6: Tables 3 and 4: Basic and Applied research at Higher Education Institutions in FY2021 Current Year Dollars.

[17] Conn (2020) was the pioneer of this insight. See reference 4.

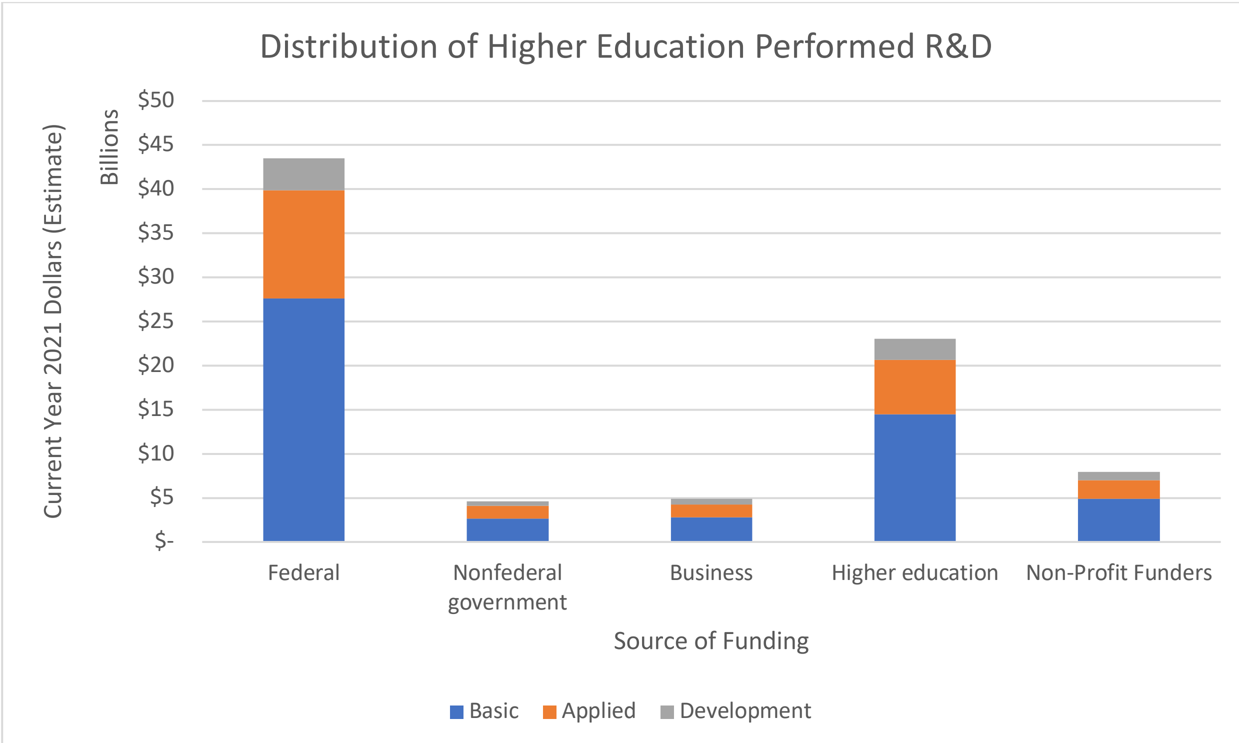

Fig. 4. The source of funds for R&D performed at US Higher Education institutions in FY2021 with each column showing the various funders of R&D. Each bar shows in blue the portion categorized as basic or fundamental research, in orange the portion of applied research, and finally in gray the portion of development funding. The federal government is the largest supporter of R&D at universities, but surprisingly universities themselves provide a sizable contribution. The sources of these university funds vary but include the annual payouts from their endowments (legacy philanthropy) and current philanthropy. Philanthropy is also represented in the column labeled Non-Profit Funders which includes both private foundations and public charities supporting university R&D. (Data: National Science Foundation, National Patterns of R&D Resources: 2020-21 Data Update. See, https://ncses.nsf.gov/pubs/nsf23321 and Tables 3, 4, and 5 therein.)

Meanwhile, the role of corporations in basic and applied research increased from 1945 until the 1980's when it shifted to a more selective engagement and to less emphasis on basic research[18]. We sketch out this change shortly. For now, the key point is that America's corporate giants did not become major contributors to the funding of universities or to private non-profit research institutions.

Philanthropy, which had been dominant in supporting basic research until 1940, became less prominent after World War II, when federal funding surged from 1950 through about 1980. (See Fig. 3.) Some foundations, such as the Rockefeller

[18] Ashish Arora, Sharon Belenzon and Andrea Patacconi. "The Decline of Science in Corporate R&D", Strategic Management Journal (John Wiley Press. November 2017).

Foundation, deliberately retreated from their previously leading roles in supporting science. However, beginning in the early 1980's and in parallel with the growth in endowment at universities, university self-spending on their own programs in STEMI began growing considerably. (The red line in Fig. 3.)

Also beginning in the early 1980's, the post-1945 STEMI ecosystem began to change for reasons described in detail in reference 4. For one, the government's funding of research in science and engineering has remained large but its growth moderated considerably in real terms beginning in the early 2000's. The exception around 2008 is the result of the ARRA Stimulus Act.

A second major source of STEMI efforts after World War II came with the growth in the number of America's universities characterized as "research universities". This is illustrated by the growth in membership in the Association of American Universities (AAU), shown in Fig. 5. The number of universities qualifying as research universities grew at an accelerated rate after 1950, plateaued after 2000, and only recently ticked up again.

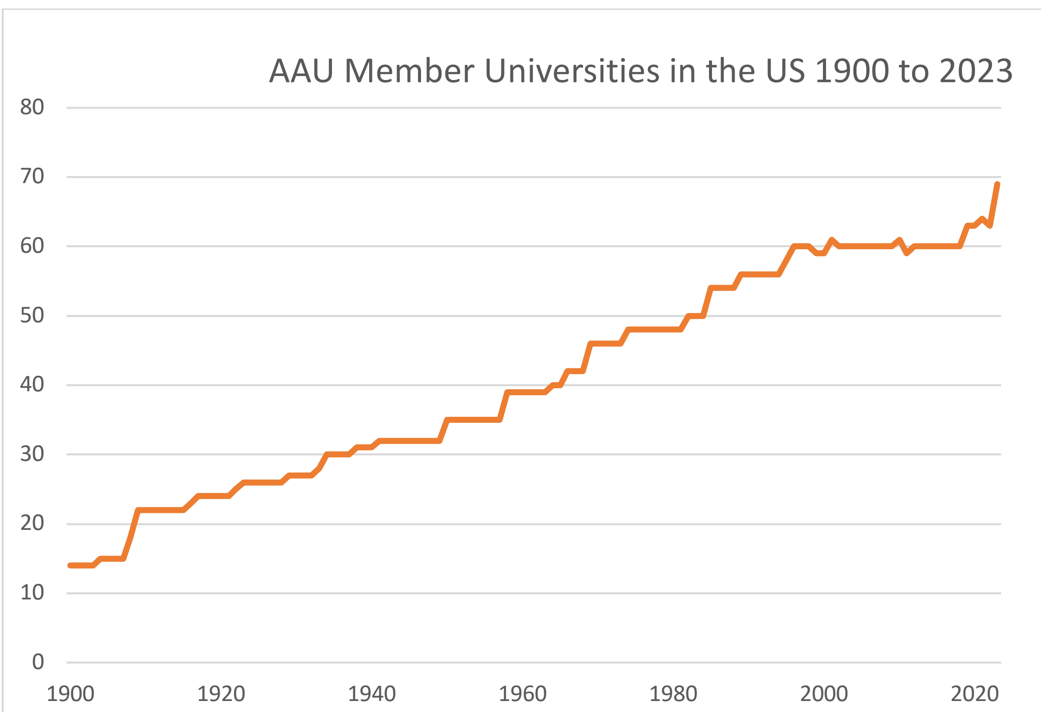

Fig. 5. Membership in the Association of American Universities over time. Growth in the number of AAU members has slowed since 2000 and as of 2023 stands at sixty-nine US Universities and two Canadian universities (not included here or in other figures).

In addition, the endowments at the AAU research universities (and at private non-profit research institutions, not shown) continued to grow, especially after the introduction in the 1980's of the endowment style of investing pioneered by David Swenson at Yale[19]. (See Fig. 6 for the endowments themselves.) This amplified greatly the endowments from past giving (again, "legacy philanthropy") and explains in part the continuing growth of spending by universities and non-profit research institutions shown in Fig. 3. University endowments typically pay out about 4-5% of the endowment corpus annually. While there are restrictions associated with many past gifts, a reasonable fraction of this payout is either unrestricted or lightly restricted (our best estimate is that this is about 10-30%). For example, Jim and Marylin Simons recently made an endowment gift of $500 million to Stony Brook University and placed no restrictions on the use of the annual payout from these funds[20].

As shown in Fig. 6, in 2022, fully 67% of the total value of all university endowments were held by the 69 American AAU universities. These 69 universities represent about 10% of the 689 universities that report their endowments to NACUBO. As a result, the AAU universities represent a disproportionate share of the basic and applied research shared in the university and private laboratory ecosystem.

In addition, the 33 private universities that are AAU members hold roughly twice as much total endowment as that held by public university AAU members. This is not unexpected, as public universities will typically have up to 20% of their operating budgets provided by State funds. These State funds generally pay for faculty salaries (which supports both research and teaching) and cover the difference between in-state tuition as discounted relative to out-of-state tuition. Crucially, as a result of state funding, the AAU public universities end up supporting STEMI research from their own institutional funds at roughly the same ratio (approximately 25% of the total research expended) as at private universities.

[19] David F. Swensen, Pioneering Portfolio Management, (Simon and Shuster, Revised, Updated Edition, 2009).
[20] See https://news.stonybrook.edu/university/simons-foundation-announces-historic-500m-gift-to-stony-brook-university-endowment/

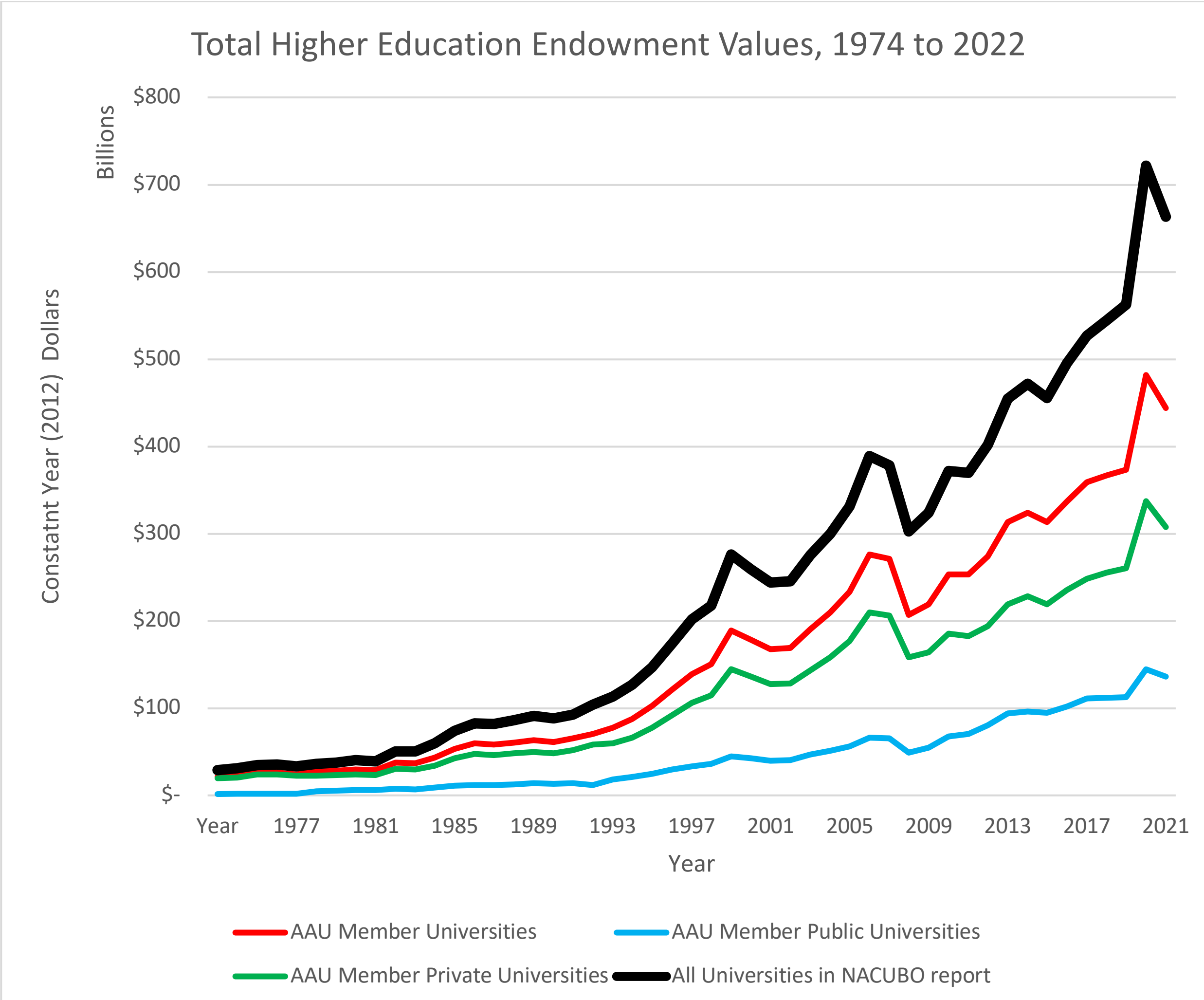

Fig. 6. The total value of university endowments reported by the National Association of College and University Business Officers (NACUBO) in constant 2012 dollars (black line) separated into the fraction of endowments held by the 69 US member universities of the AAU (red line) has skyrocketed since the 1970s. Also shown are the total endowments held by just the AAU member private universities (green line) and AAU member public universities (blue line). Data are from the NACUBO Historic Endowment Study Data[21].

Stagnating government budgets after about 2003 reflected several factors such as the end of the Cold War and the shrinking percentage of discretionary spending as a slice of total federal spending. While government agencies still took risks on big science infrastructure projects, risk taking was ring-fenced by stringent budgets and increased Congressional scrutiny, which in turn induced bureaucratic caution about risks. As such, much of federal research is for worthy but cautious

[21] NACUBO -TIAA Study of Endowments (2022). https://www.nacubo.org/Research/2022/Historic-Endowment-Study-Data

projects where a great deal of the risk associated with the underlying science has already been resolved[22]. Furthermore, a significant percentage of NSF and NIH dollars are targeted to specific disciplines, and for NIH, to specific diseases that have well organized constituencies to support them. This poses an overall challenge for the American enterprise of basic research and big discovery bets.

As the US research system evolved, universities and NPOs became the heart of the more basic styles of research. However, there is an implicit division of labor between the university/NPO complex and the roles of internal federal funding and that of business for basic and applied research. Internal federal projects and very selective areas of corporate activity take the major leadership role in basic and applied research that is risky, very large scale, and requires many years of commitment. Universities and NPOs are not usually at the forefront in such challenges, though this may change somewhat as philanthropy shifts. We remark in later sections on this possible shift.

Our interviews were striking in the common theme that government was sometimes willing to undertake large risk for more basic discovery. The examples focused on very large projects, ones that only the federal government could do. Examples include the NSF's support over more than 30 years to construct and operate LIGO to measure gravity waves[23]. NASA spent more than $10 billion over 17 years before launching the James Webb Space Telescope[24]. And the NIH and DOE spent north of $3 Billion over 13 years on the Human Genome Project[25]. In short, building and operating larger scale science and technology infrastructure (VLSR projects) is particularly the domain of government and its priorities because there were no other feasible funders.

This implicit division of labor regarding large projects also clarifies the role of business in the implicit division of labor concerning basic and applied research leadership. As noted earlier, US business still has a larger share of its research budget devoted to basic and applied research than our main competitor, China. This is largely a reflection of the comparative advantages of large US firms in high value-added products and services. Data shows that corporate spending on research

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[22] For a further discussion of how federal funding has become more conservative, see e.g. ARISE (Advancing Research in Science and Engineering). American Academy of Arts and Sciences (2008). https://www.amacad.org/sites/default/files/publication/downloads/ariseReport.pdf

[23] LIGO, National Science Foundation. See https://www.nsf.gov/news/special_reports/ligoevent/

[24] The James Webb Space Telescope, NASA. See https://www.nasa.gov/mission_pages/webb/main/index.html

[25] NIH and DOE Funding of Human Genome Project. See Biomedical Politics, Institute of Medicine (The National Academies Press, 1991) and NIH fact sheet at https://www.genome.gov/about-genomics/educational-resources/fact-sheets/human-genome-project

has expanded as a share of total national research expenditures[26]. Therefore, it is important to understand the characteristics of business R&D in order to better understand its impact on the national system of discovery.

On the one hand, business spending focuses primarily on late-stage product development work, with 79% of all business spending on R&D in 2021 categorized as development, not basic or applied[27]. (See Fig. 7.) A similar phenomenon occurred with Big Pharma as we will discuss in Section VII.

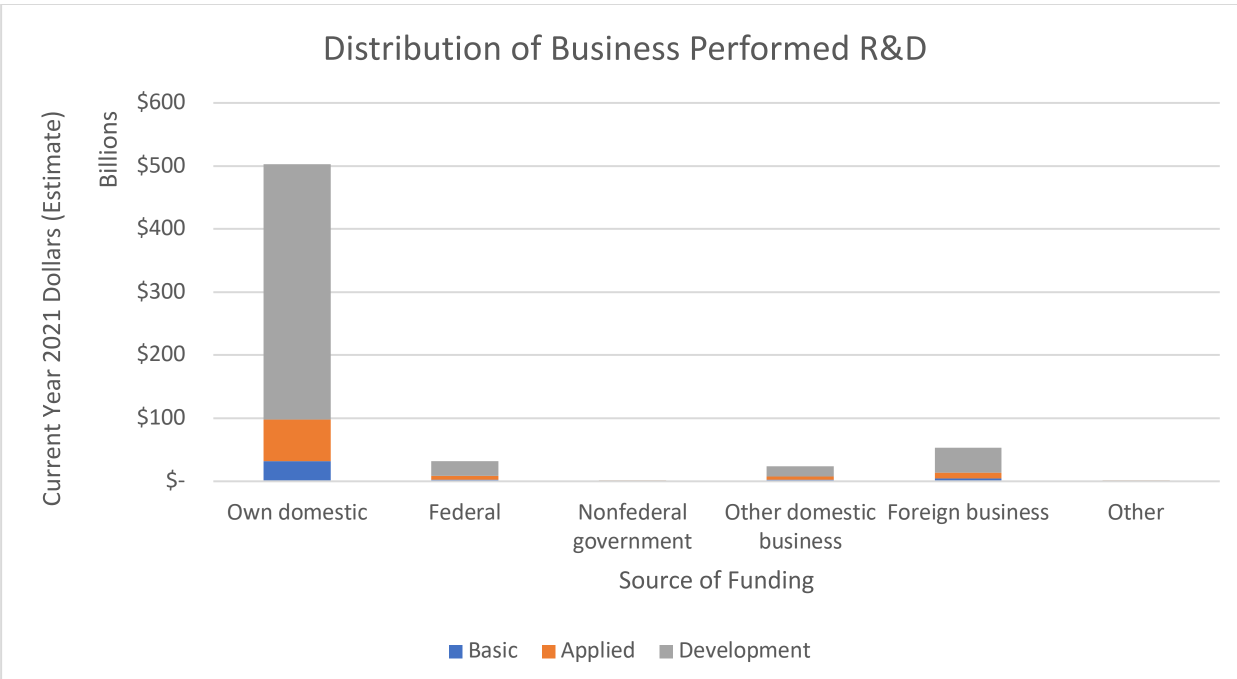

Fig. 7. The source of funds for R&D performed at US businesses in FY2021 with each column showing the various funders of R&D. Each bar shows in blue the portion categorized as basic or fundamental research, in orange the portion of applied research, and finally in gray the portion of development funding. Businesses are their own largest supporter of R&D (column labeled "Own domestic",) but even though this column contains some basic and applied research, it is almost certainly oriented on research that will enhance the profitability of the business in the long run. (Data Source: National Science Foundation, National Patterns of R&D Resources: 2020-21 Data Update. https://ncses.nsf.gov/pubs/nsf23321 Tables 3, 4, and 5.)

On the other hand, some basic and complex applied research requires very large-scale spending (annual spending of at least $50M a year, and often more) on

[26] Ref. 6: Table 2: Total R&D performed by Business was 77% of US Total R&D in FY2021 compared to 76% in FY2020 and 75% in FY2019.
[27] Ref. 6: Tables 3, 4, and 5: Basic research, applied research, and development performed by Business in FY2021 Current Year Dollars

big, "bet the company" payoffs in ten to fifteen-years. Semiconductors at the cutting edge, artificial intelligence, quantum computing, and some biomedical work exemplify undertakings where business is at the leading edge of the national effort in basic and applied discovery. In an interview, the chief scientist of one major digital firm estimated that the minimum buy-in to be a leader in quantum computing was a commitment of $200 to $300 million annually for meaningful results to arrive in ten or so years.

Even as shifts in endowments, government budgets, and business efforts altered the research landscape, another fundamental change occurred in the 1980's when new federal investment rules enabled the growth of venture capital and private equity[4]. The explosion of venture capital and private equity began a new epoch by providing higher levels of risk capital for innovation at early-stage start-up companies and for corporate buyouts. Yet despite taking more risk at earlier stages than private equity, venture capital did not fundamentally alter its reliance on universities and non-profit research institutions for the basic discoveries[28]. In short, philanthropy's boost for basic research is a crucial complement to venture capital investing.

In biotech, one senior executive with long experience in big pharmaceutical companies whom we interviewed estimated that since the great rise of venture capital in the 1980's, "big pharma" has shifted its spending from roughly 60% on sales and marketing and 40% on research and regulatory compliance (e.g., clinical trials), to 60% on sales and marketing, 20% in R&D and regulatory compliance, and 20% on mergers and acquisitions (M&A). The M&A in turn is focused on biotech startups and private companies supported by venture capital to supplement big pharma's reduced internal spending on basic research. The biotechs in turn do much of the difficult applied development work, while their big ideas largely come from universities and non-profit research institutions.

At the same time, the scale of the new investing approach in venture capital enabled founders to retain a large percentage ownership in their companies. The scale of wealth, and the number of wealthy individuals, especially in digital technology, began to expand greatly[4]. Think here of entrepreneur founders such as Bill Gates, Paul Allen, Jeff Bezos, Sergei Brin, Larry Page, and Mark Zuckerberg. These founders have become new philanthropists with great resources and has led them, as in the first Gilded Age, to focus significant portions of their wealth on

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[28] On the evolution, successes, and limits of this funding system see: Sebastian Mallaby, The Power: Law-Venture Capital and the Making of the New Future (Penguin Books, 2022); Josh Lerner (*The Architecture of Innovation: The Economics of Creative Organizations*. (Harvard Business Review Press, 2012); https://dealroom.co/guides/global.

philanthropic giving, including for basic and applied science as well as education. As a result, the magnitude of giving has boomed in a Second Gilded Age of philanthropy.

In the following sections, we argue that this new wave of philanthropy has significantly influenced the dynamics of the US STEMI ecosystem and added to its flexibility. It has injected new elements of dynamism in an institutional landscape whose decentralized nature of private and state control makes institutions more amenable to experimentation and risk taking.

II. The Scale of Philanthropic Investments in the US Portfolio Mix

The scale of philanthropic funding of basic and applied science is much larger than most people realize, at roughly $21.5 billion in total in 2021. We will show that this large sum's true significance plays out in the larger pool of overall research resources at major universities. How they interact with other resources constitutes one of the key consequences of philanthropy.

The breakdown of about $84.0 billion of financial support in FY2021 for R&D at universities, by funding source, was shown in Fig. 4. (Note that the bulk of these funds are for basic and applied research, but for the purposes of this section, we also include development wherever we use "R&D" rather than just research. The reason is that the breakdowns by discipline do not distinguish between research and development.) In addition to universities, non-profit research institutions spent an additional $29.5 billion on R&D as of FY2021. This brings the total of these performers, namely universities and NPO's, to an astonishing $114 billion.

For the purposes of understanding the role of philanthropically funded research, let us focus solely on the universities. As noted earlier, we find that the sixty-nine US AAU member universities hold 67% of the endowments at the nation's universities. It is also notable that these same universities also represent 61% of all annual higher education expenditures on R&D from all sources in the United States[29].

Further analyzing Fig. 4, one sees that the funding distribution from various sources is as follows: $43 billion is federal funding; $4.6 billion is state and local government funding; $4.9 billion is business funding; and $8 billion is current giving from philanthropy. The $23 billion of university institutional self-funding is the wild card, as this includes monies from a variety of sources. Part of this is the annual payout from their endowments (legacy philanthropy) but the $23 billion also includes royalty income, tuition dollars, unrecovered indirect costs and for public universities, state funding, to name just a few of the other sources.

[29] National Center for Science and Engineering Statistics (NCSES). 2022. Higher Education Research and Development: Fiscal Year 2021. NSF 23-304 (Table 22). Alexandria, VA: National Science Foundation. Available at https://ncses.nsf.gov/pubs/nsf23304/.

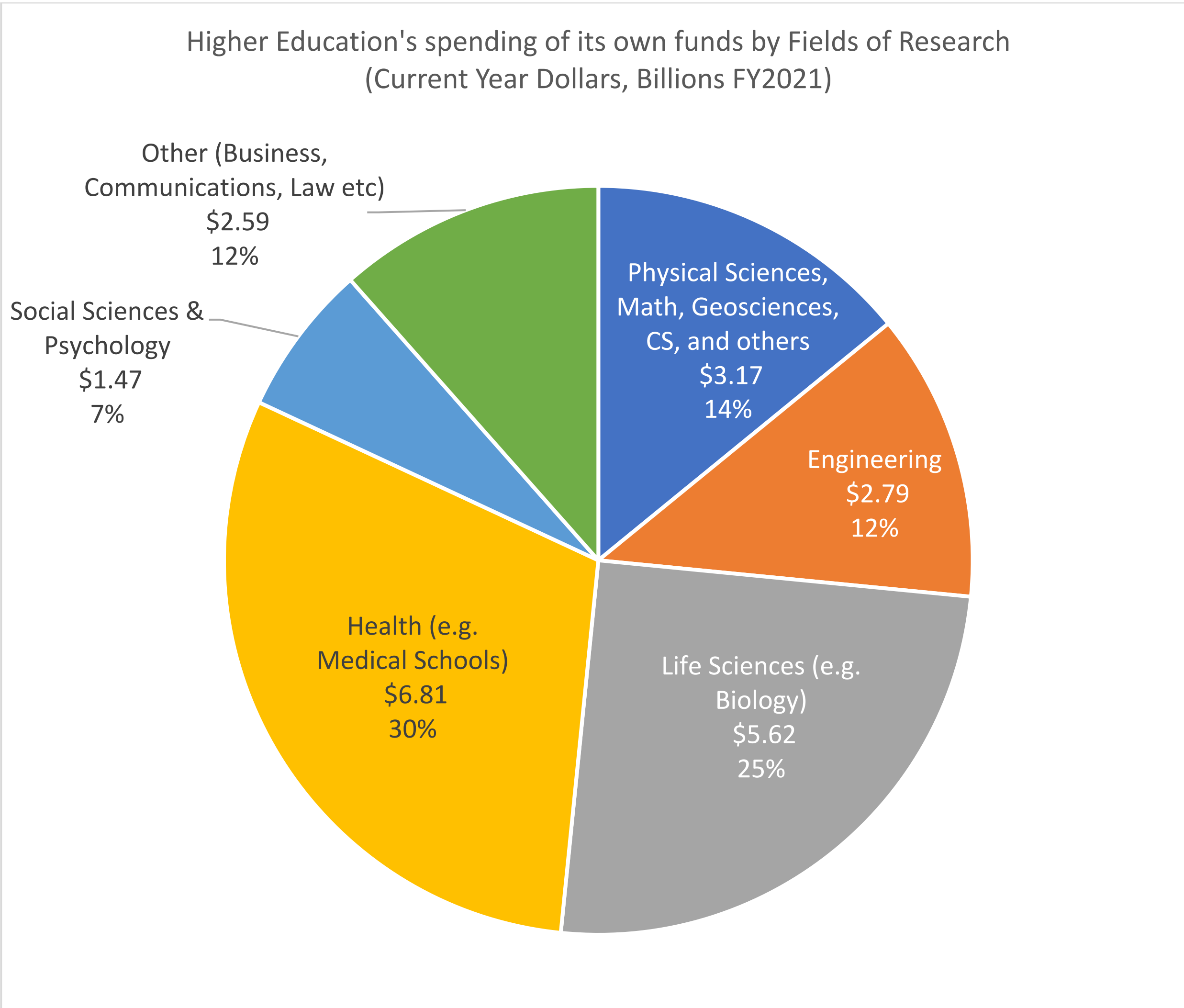

Fig. 8. Of the $23B that higher education institutions in the United States spent of their own funds on research in 2021, this figure shows that roughly 30% went to health (e.g. medical research), 25% went to research in the life sciences, 14% to research in the physical sciences (including math and geosciences), 12% to research in engineering, 7% to the social sciences, and 12% to all other non-science and non-engineering research fields. In other words, of higher education spending for its own research programs, slightly more than 88% is focused on STEMI activities. (Data source https://ncses.nsf.gov/pubs/nsf23304 Table 13)

Irrespective of source, universities have significant flexibility in how they deploy their institutional funds. If a university has a medical school and operates a hospital, then clinical revenue adds to these other sources. And while the sources of institutional funds are not reported, the research fields on which the funds are expended is reported annually by the institutions.

Analyzing Fig. 8, we see that of the $23B that higher education institutions spent of their own funds on R&D in 2021[30], fully 88% went to STEM fields. More specifically, 30% was spent on health (i.e. medical research), 25% was spent on R&D in the life sciences (e.g. biology), 14% on R&D in the physical sciences (including math and geosciences), 12% on engineering R&D, 7% on R&D in the social sciences, and 12% on all other non-science and non-engineering R&D.

Perhaps unsurprisingly, and as shown in Fig. 9, this mirrors the distribution of funding provided by the federal government broken down by discipline, though an even higher percentage (94%) of federal funding goes to STEM fields. This is understandable because universities are responsible for funding a full university education for students, and funding the humanities, the arts, and professional schools such as law and business, are part of their mission.

[30] While this breakdown by discipline also includes development funding, at universities, this is a minimal amount and other sources show that $20.6B of this $23B can be categorized as basic or applied research.

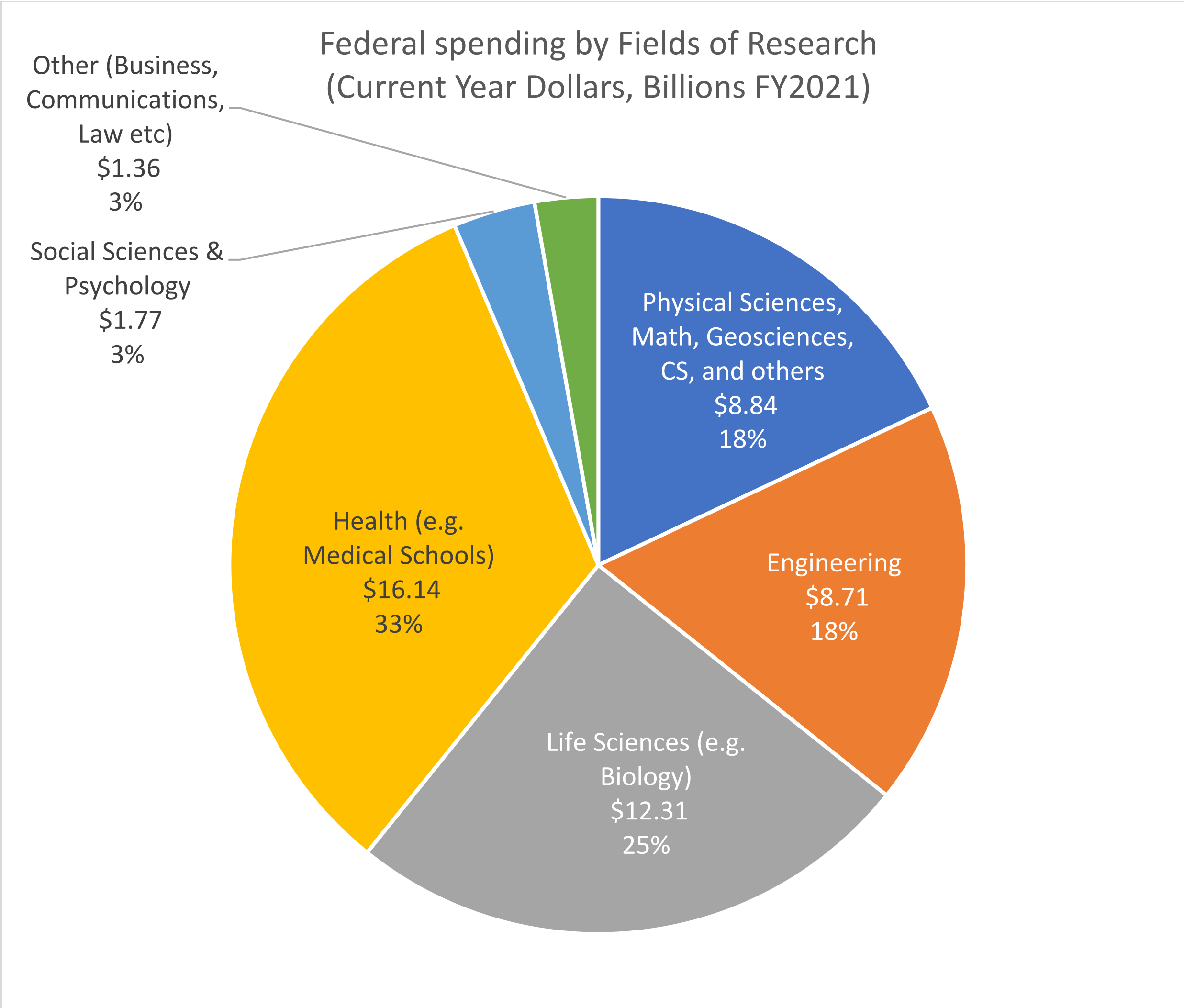

Fig. 9. By comparison with Fig. 8, this figure shows federal spending on R&D at universities by discipline. Unlike at universities, federal spending is much more focused on STEMI, fully 97%. This is understandable as universities are responsible for funding a university education and the funding of the social sciences, the humanities and the arts are central to providing a full education for students. (Data source https://ncses.nsf.gov/pubs/nsf23304 Table 14)

Beyond breaking down spending by discipline, no further breakdown of these figures is reported. Even public research universities with open financial statements do not reveal the innards of the financial engineering that mixes a variety of funding sources to fuel the research enterprise. To parse the philanthropic portion of these institutional funds further, we worked with public data on aggregate university and foundation endowments and conducted deep financial dives at several research-intensive universities drawn from the membership of the Association of American Universities.[31]

We began with two sets of public numbers about endowments. Recent figures suggest that the total of endowments at America's universities, both private and public, exceeds $800 billion (see Fig. 6), a significant fraction of which is spent on STEM fields. Similarly, foundations supporting science and technology as represented by the members of the Science Philanthropy Alliance have endowments in aggregate of at least $170 billion[32].

With the assistance of interviews and confidential data, we estimate that these university endowments together generate approximately $4.8B in annual support for basic and applied STEM work. While there is considerable heterogeneity across institutions in both the overall mix of sources and their magnitudes, it appears that, on average, legacy philanthropy accounts for roughly one-quarter of the institutional total of $20.6 billion given earlier[16]. This is consistent with data from the NACUBO-TIAA Study of Endowments[21], which shows that institutions with endowments over $1B spend on average 22% of their annual payout on academic programs and research and another 18% on endowed faculty positions (of which some fraction is used for research).

When coupled with the $7.0B in annual non-profit giving to universities[33], total philanthropic support for basic and applied STEMI at universities comes to at least $11.8B per year. Adding the $9.7B in funding at private non-profit research institutions as well yields a total figure of $21.5B in philanthropic support annually for science research each year. This estimate is equivalent to roughly 42% of the federal outlay to these institutions, and approximately 23% of *all* federal government support for basic and applied research both inside and outside universities ($91.9B in 2021). This is a surprisingly large percentage to many.

Overall, and even after including business spending on basic and applied research, philanthropy constitutes about 8.2% of the spending on all basic and applied research nation-wide by all funders, making it an important and distinctive feature of the American research ecosystem. No other country comes close to matching the US level of philanthropic funding for science, technology,

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[31] We emphasize that the following is a preliminary analysis while we wait for data from more universities.
[32] Drawn from 2019 IRS 990 filings submitted by members of the Science Philanthropy Alliance, publicly accessible from guidestar.org
[33] Ref. 6: Tables 3 and 4: Basic and Applied research at higher education institutions funded by non-profit funders ($7.0B) and non-profit research institutions funded by non-profit funds ($9.7B) in FY2021 Current Year Dollars.

engineering, and innovation, either at absolute scale or as a share of their total national investment.

We emphasize that the numbers reported here represent best estimates. As our interviews demonstrated, estimating totals even within one institution is more an art form than a precise science. Typically, there are overall budgetary limits and detailed decision rules to keep individual projects within guidelines set by government and donors. Frequently, no single person knows the precise answer as to how research dollars are mixed. This happens for good reasons. For example, many costs are joint costs shared between the teaching and research enterprise. A professor teaches and does research. The total cost for the professor must be allocated across multiple domains.

In the end, no matter how one precisely adds the numbers, the remarkably large investment by philanthropy in science, engineering, technology, and medicine is crucial to the country's overall research enterprise. This begs the question "Does it change the mix in our national investment portfolio?" We address this question in the next section.

III. The Macro Influence of Philanthropy on the US Portfolio Mix

In this section and the next four, we analyze the impact of philanthropy on the behavior of the American discovery ecosystem. The size of philanthropic investments is large enough in itself to alter the overall mix of US scientific research. In addition, our interviewees noted that research institutions develop strategies to pair early-stage risk funded by philanthropy with scaling-up strategies that later rely on federal dollars.

This section explores how philanthropy may alter the portfolio of science, technology, engineering, and innovation investments. As noted, we will focus on the impact of philanthropy primarily on basic and applied stages of research, as defined by NSF[5]. As a result, we will not delve into the large undertakings of philanthropy in later stage development work, such as the Gates Foundation work on technology and development[34]. We will also not delve into the growing interest in promoting enduring outcomes by partnering with business. For example, the Schmidt Maritime Technology Partners program of the Schmidt Family Foundation is creating tools to help commercial fisheries retain profitability while being sustainable[35].

To explore the impact of philanthropy on the basic and applied end of the research spectrum, we examine three dimensions of the portfolio:

- The first dimension is the distribution by field of research.

- The second dimension is the spectrum ranging from curiosity-driven basic research to use-inspired applied research, another way some use to describe basic and applied research. On this spectrum one could dispute whether any particular individual piece of research is basic or applied, but in aggregate, the types of research funded by different types of entities is clear. For instance, at the far end of the spectrum, much of business research investment is on near-term commercialization work as one would expect.

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[34] See, Gates Foundation, https://www.gatesfoundation.org/our-work/programs/global-health/integrated-development and https://www.gatesfoundation.org/our-work/programs/global-health/innovative-technology-solutions

[35] See, Schmidt Marine Initiative, https://www.schmidtmarine.org/

- The third dimension is the scale of the research. By scale, we mean the range from classical theoretical and experimental science, generally at a moderate scale of no larger than $5 million annually, to very large-scale research (VLSR) defined as projects costing $50-100 million per year for many years. VLSR funding is necessary to create and operate a complex piece of infrastructure either at a university, a separate national facility, or at a national laboratory.

Examples of VLSR projects along this third dimension include next generation particle colliders and light sources, major ground-based or space-based astronomy facilities, projects related to the human genome and protein structure, and VLSR in fields such as quantum computing and artificial intelligence.

Our summary judgment on the three dimensions is simple: Philanthropy does not change the distribution by field of research, but directly and indirectly bolsters the basic and applied side of the research spectrum significantly.

In regard to the first dimension, since the late 1990s, federal research dollars have skewed heavily toward biomedical and life science research, while investments in other fields such as the physical sciences have flattened in real terms. Based on data from the National Center for Science and Engineering Statistics, Higher Education Research and Development Survey, FY 2021[29], we find that about two-thirds of the total of both federal and philanthropic funding are skewed toward the biotechnology, biomedical, and health care fields. As such, philanthropy does not appear to correct this skew.

Regarding the second dimension, philanthropy's impact on the *spectrum* of basic and applied research is very significant, as is its impact on cross-disciplinary work. The dollar totals are large, and our interviews[31] suggest that the broad priorities of philanthropic funders for more basic research remains relatively constant. This steady commitment makes planning to sustain basic work over time easier. Our interviews underscored that the diversity of agendas manifests itself in features such as a greater openness to projects with longer time horizons, more tolerance for risk, and an interest in frameworks for interdisciplinary collaborations or other new ways of organizing research. The impact of these funds often plays out in combination with federal dollars. However, the impacts of philanthropy play out somewhat differently between research universities and private non-profit research institutions.

Our work described in sections I and II suggest that philanthropy provides on average roughly one-quarter of total institutional self-funding of science and technology at research universities. Self-funding combines the payout from an endowment, the indirect cost recovery on federal grants, tuition, and for public universities, support from state governments. Overall, this is a major boost to the traditional STEM fields, excluding biomed. Moreover, it appears that the mix of philanthropic funding, especially outside of the biological areas, has a tilt toward basic and early-stage applied research.

Private non-profit research institutions have a less diverse mix of funding sources than universities. They rely primarily on federal funding and current and legacy philanthropic funds. Their strategies balance their sources to emphasize more basic research. For example, one major biology institute reports that philanthropy, both legacy and current, fuels 40% of its annual budget. In this case, except for early-stage researchers, the salaries of its research faculty are paid from grants. Another renowned research institution, focused mainly on the physical sciences, reports that its legacy endowment payout covers all the salaries of its researchers. In this case, annual philanthropic giving and federal dollars are used to cover research project costs. These two examples illustrate how very different financial models can be used successfully, and philanthropy is central to both approaches.

Foundations and philanthropists, with a few exceptions, have generally been skittish about tackling projects of large scale, especially VLSR projects. While philanthropy helped to launch the early stages of medium scale research infrastructures, as has happened in ocean monitoring, the bigger, long-haul efforts were still largely left to government and business. As we argued in Section II, an implicit division of labor has evolved in the US effort in more basic research. Government and business dominate VLSR projects for basic and applied research.

The main exception to philanthropic funding that avoids VLSR projects is astronomy, where foundations have provided the primary support for construction of new facilities. For example, the Keck Foundation provided funds for the largest of our current telescopes Keck I & II in Hawaii. The personal interests of wealthy founders of large science-focused foundations, such as the Gordon and Betty Moore Foundation and the James and Marilyn Simons Foundation, led the founders to decide separately to fund new observatories. Gordon Moore personally funded the early design stages for the proposed Thirty Meter Telescope (TMT) at the level of hundreds of millions of dollars[36]. The Simons Foundation provided $40

[36] Gordon Moore used the foundation's scientific staff to organize oversight of the project. The Gordon and Betty Moore Foundation. See https://www.moore.org/initiative-strategy-detail?initiativeId=thirty-meter-telescope

million to build the Simons Observatory in the Atacama Desert of Northern Chile, which aims to measure the universe's cosmic microwave background[37].

A significant shift in the research division of labor for large research infrastructures, whether for basic or applied research, may be emerging. The Allen Institutes[38], the Howard Hughes Medical Institute's Janelia Research Campus[39], and the Chan Zuckerberg Initiative[40], are three examples of philanthropic funding explicitly seeking to create large-scale infrastructure for complex basic and applied biological research problems. Also, the Schmidt Futures initiative has been formed to address gaps and to serve as an accelerator of innovation[41]. If this becomes a broader movement, the agenda of philanthropy for large infrastructure efforts could alter the dynamics of large infrastructure in ways that mimic the behavior patterns of other fields of philanthropic funding.

We turn now to examine another important feature of the US STEMI enterprise – how philanthropy interacts with other sources of funding for research to impact the overall system in a major and perhaps unique way.

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[37] The James and Marilyn Simons Foundation. See https://www.simonsfoundation.org/flatiron/center-for-computational-astrophysics/simons-observatory/

[38] The Paul Allen Institutes. See https://paulallen.com/Science/Allen-Institutes.aspx

[39] The Howard Hughes Medical Institute, Janelia Research Campus. See https://www.hhmi.org/programs/biomedical-research/janelia-research-campus

[40] The Priscilla Chan and Mark Zuckerberg Initiative. See https://chanzuckerberg.com/

[41] The Schmidt Family Foundation. See https://www.schmidtfutures.com/schmidt-futures-launches-schmidt-futures-network-with-first-initiative-convergent-research/

IV. How Philanthropic Dollars Influence the Behavior of the US STEMI Ecosystem

This section examines how philanthropy has influenced and incentivized the structure and behavior of the STEMI ecosystem. We emphasize structure because both in the formative years of the American research systems from the 1870s through 1920, and now in recent years, philanthropy has influenced the structure and organization of our scientific enterprises[4]. Compared to many other countries, our research institutions are under much more decentralized control, whether private or state government. The federal government looms large but there is a huge pool of resources controlled from the "bottom up" in a wide variety of institutions. Philanthropic spending, including investments in people, has incentivized behaviors within these institutions that change the productivity of the system. Our propositions are informed, as noted earlier, by our interviews[31] and the literature in the field.[4,42,43,44,45]

To begin, as argued by Conn[4], we note that the contemporary era of philanthropy operates within a structure of American research institutions defined by an earlier era of philanthropy. Philanthropy established a large imprint on the American science and discovery ecosystem (including education) in the "First Gilded Age" of philanthropic giving by the financial titans of the 1870's to the 1920's. This set the model of American universities. Unlike those of many wealthy countries, the US has a large number of private institutions, all of which are outside of direct federal government control.

Examples abound and include the founding in 1871 of Johns Hopkins University with an endowment gift from Johns Hopkins; Leland Stanford's gift in 1885 to establish Stanford University; Andrew Carnegie and Andrew Mellon, separately providing megagifts to found the Carnegie Institute of Technology and Mellon University, now Carnegie Mellon University; Cornelius Vanderbilt in 1872 providing the gift to found Vanderbilt University; and John D. Rockefeller's

[42] Evan S. Michelson *Philanthropy and the Future of Science and Technology* (Routledge Publishing, June 2020)
[43] France Cordova "Envisioning Science for an Uncertain Future", https://issues.org/envisioning-science-unknown-future-philanthropy-cordova/ Also, *The Next 75 Years of Science Policy,* Issues in Science and Technology, Special Collection. (NASEM and ASU, Sept, 2022) pp. 345-350.
[44] Evan S, Michelson and Adam F. Falk, "A Vision for the Future of Science Philanthropy", https://issues.org/future-science-philanthropy-sloan-michelson-falk/ and ibid. pp. 351-360.
[45] Harvey V. Fineberg, "Stark, High, and Urgent", https://issues.org/stark-high-urgent-stakes-science-during-pandemic-fineberg/ and ibid., pp 361-368.

megagifts to found both the University of Chicago in 1890 and Rockefeller University in 1906. This class of donors established endowments and operating funds for these universities while also seeding the growth of many of the great private research institutions that we now call Non-Profit Research Institutions, or NPO's. These new institutions were secular, based more on the German model created in the early eighteen hundreds, were geographically decentralized and most importantly, not institutions run by the federal government.

In parallel, and catalyzed by the Morrill Act of 1862, State (not federal) universities entered the ranks of elite research institutions. The growth of State universities helped to democratize access to leading edge research and education. The result today is that the US has a highly diverse and decentralized mix of public and private research universities, unique in the world.

The giving of philanthropists in the first gilded age significantly defined the basic and applied science ecosystem at universities because government spending was relatively small and funding universities was not a corporate priority. Companies at the time had industrial research labs focused on applied, invention-oriented work of the Edison or Bell type.

As an era of larger scale scientific institutions emerged, philanthropic giving meant that the US could advance its scientific enterprise without having to overcome political obstacles that can be associated with national universities, such as in Europe and Asia. Importantly, this institutional path is partly a consequence of a constitutional design that enshrined federalism combined with divided powers in making national policy. The framers of the Constitution preferred substantial authority for state and local government and a more complicated (and hence more constrained) path to an expansion of federal powers[46]. As noted, the US federal government has less control over its research institutions than is commonly found today in other wealthy countries[47].

This same political landscape left the United States with more lightly regulated capital markets where stock market financing played a more central role than in countries such as Germany, Sweden, and Japan. In the latter countries, large banks (often deeply linked to the central government) loomed larger. Students of comparative government and capitalism argue that lighter regulation and more

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[46] For an examination of the impact of these factors in a comparative perspective, see: Peter F Cowhey and Matthew McCubbins, eds., Structure and Policy in Japan and the United States—An Institutionalist Approach (Cambridge University Press, 1995)

[47] We acknowledge the roles of the federal government in fields ranging from public health to aviation in this era.

reliance on non-bank financing created a liberal market economy that was particularly attuned to taking gambles on big technology shifts[48]. Philanthropy has complemented this risk-taking bent by boosting its precursor, more basic research in universities.

Our interviewees agreed that current philanthropy incentivizes some strategies and behaviors in this decentralized system that would not happen as readily if we were relying solely on government and business dollars. There is an underlying logic about why behavior is different, namely the management of flexible dollars versus restricted dollars. This logic prevails even though its specifics vary among private and public research universities, and between universities and research NPO's. Philanthropic funding introduces more flexibility in choices that can be made by research institutions even though universities do have to fill in the unrecovered IDC. In turn, this enables a larger element of "bottoms up" discretion in steering the future of the STEMI enterprise. To make this claim, we first demonstrate how flexibility comes about.

Much of the money coming to research institutions, including philanthropic dollars, is earmarked for the current costs of specific research projects. Frequently, the philanthropic grants do not cover the full cost of the projects, that is, the full overhead which is referred to as Indirect Cost Recovery (or IDC). Yet, if the research project is vital to the mission of the institution, it generally accepts the funding. So how does the deficit get paid for? The answer varies.

One element of the answer is "other revenue" that we discussed previously. It includes, for example, tuition, patent revenue, and State dollars. Tuition dollars at wealthy private schools may provide unrestricted funds when necessary[49]. At public universities, state funds can play the same role to some degree. And at all institutions, debt financing can play a key role.

A second element is the institution's pool of federal IDC dollars. The US government allows institutions to charge overhead to support the infrastructure of research (such as laboratories) as part of the project cost. This overhead for shared infrastructure may indirectly support projects that do not have enough funding to cover their full costs. Even though the present return of IDC does not fully cover costs, administrators and faculty often pursue grant synergy to cluster research

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[48] Peter Hall and David Soskice, eds, Varieties of Capitalism—Institutional Foundations of Comparative Advantage (Oxford University Press, 2001)

[49] To be clear, the ultimate use of tuition dollars is solely for education. However, they are a flexible pool of cash in the short-term.

projects in overlapping spaces (physical and intellectual) in order to achieve larger pools of money for new infrastructure, equipment, and support services.

A third element is the crucial role of less restricted philanthropic dollars. Although unrestricted or modestly restricted funds are the hardest money to raise, such unrestricted philanthropic gifts provide vital flexibility for any institution. We learned for example that one prominent private non-profit research institution (not a university) has about 10-12% of its endowment as unrestricted, and it uses a portion of its annual payout to fund project deficits.

Endowment payouts that are in part only loosely restricted often supplement unrestricted gifts. Money to endow a chemistry department must support that department, but the department has discretion on how precisely those funds are used. Endowed professorships may include annual payouts for the salary of the professor holding the chair (a restriction) but the chair holder can exercise discretion to use these unrestricted funds to help cover lab equipment or to fund graduate students, post-doctoral researchers, or professional research staff.

Frequently, the institution's pursuit of large government or business grants requires it to show it will provide a counterpart investment from its own funds. The mixing of other revenues, unrestricted gifts, and some prioritized uses of loosely restricted funds typically are the sources of this institutional "earnest money".

At the largest research universities, the magnitude of the funds illustrates the inherent opportunities. Currently, the very largest research budgets at universities exceed $1.5 billion annually. One private university reported that about 60% of its dollars were federal, both direct and IDC, while more than 30% came from a mix of endowment payouts and tuition, with the endowment payout constituting about 80% of this latter mix.

The advantages of flexibility enabled by philanthropy are somewhat handicapped by the current proclivities of philanthropy to offer a low level of IDC on its gifts and grants. Philanthropists face a financial tradeoff between their immediate project goal and tending to the long-term health of the institutions that deliver the science. This has led many philanthropists to have parsimonious IDC rates, even lower than the federal IDC rate.

The philanthropic priority maximizes the dollars for the specific research goal. It is understandably frustrating to learn that a third or more of a $5 million gift is going to IDC. Yet this unpaid overhead effectively “taxes” the earnings from legacy philanthropy and other revenue sources that must be used to fill the gap.

The IDC issue often shapes institutional strategies. Some institutions limit the volume of current philanthropic giving because they cannot cover the gap caused by the low IDC associated with such grants. In response, a small number of philanthropic organizations are cooperating on the Full Cost Project, which advocates for new practices to raise IDC rates[50]. As an example, the Sloan Foundation recently boosted its IDC rate on grants from 15% to 20% and takes an expansive view of allowable direct costs against which the IDC is calculated.

It is equally important to note that philanthropy’s successes in introducing flexibility is in part synergistic with larger federal dollars and agendas. We turn next to evaluating the specific consequences of flexibility.

[50] The Full Cost Project. See https://www.philanthropyca.org/full-cost-project

V. The Impact of Flexibility of Philanthropic Funds on the Dynamics of the STEMI Ecosystem

The greater flexibility for research introduced by philanthropic dollars has two important sets of consequences. First, flexibility adds an important fillip of risk taking, of innovation in project development and strategies, and thereby creates incentives for new ways of organizing research. Second, flexibility permits innovation in developing the vital input of human capital.

The impact of flexibility follows from the effects of the nature and scale of philanthropic funding. Individuals or groups with diverse philosophies about change and subject priorities are often the ones who establish and/or lead philanthropies. They can have distinctive theories of change and strategies that differ from those of the federal government or business. This diversity of agendas manifests itself in a greater openness to projects with longer time horizons, more tolerance for risk, and an interest in frameworks for interdisciplinary collaborations or other new ways of organizing research.

When we argue that philanthropy is open to a higher level of risk taking in research, we note a distinction between two elements of risk. By saying that philanthropy adds an additional element of willingness to take risk in the system, we mean that philanthropy (within its usual boundaries of not being VLSR projects) has more willingness to undertake projects with a lower ex ante expectation of success, usually because the underlying knowledge base is still early and preliminary. Think of risk in science as akin to the riskier bets in a venture capital portfolio. We have heard consistently in interviews that philanthropy is more open to these riskier bets than government.

Separate from the degree of risk of the "bets" is the way in which philanthropists try to manage that higher risk. Philanthropists, if doing risk management at all, tend to do it by selecting high quality researchers to take the risk. The project itself is risky but by selecting higher quality researchers to undertake the project, the risk is somewhat mitigated.

Perhaps as fundamental as risk taking, the diversity of philanthropic donors yields a sprawling agenda of research and support. To be sure, some of this is not dramatically different from federal dollars. Yet the recurring theme of comments from foundations, interviewees, and researchers is that philanthropy tries to drive the framing of new problems, along with new approaches for tackling them.

As an example, one foundation runs experiments comparing different decision rules for evaluating grant applications in order to uncover those most likely to yield bets with higher returns. If researchers want to do something novel, philanthropy can be a faster source of first stage funding. A virtue of philanthropy is indeed its speed and efficiency in decision making. Exploring a possibly good idea at its earliest stage is often not expensive. Universities, with their annual endowment payouts, and foundations have flexible funds, and both have quicker decision cycles and less bureaucratic red tape. Success at this earliest stage often helps make the case for larger federal sums.

Our interviewees also noted that research institutions develop strategies to pair early-stage risk funded by philanthropy with scaling-up strategies that later rely on federal dollars. For example, the Monterey Bay Aquarium Research Institute (MBARI) defined a strategy to chart a new approach to instrumenting the oceans. It relied on philanthropy, with its higher risk-tolerance and patience, to fund the foundational work. That proved so successful and provided valued flexibility that the institution formally decided in other new initiatives to limit federal dollars to 25% of its total revenue overall, just so it would keep its attention focused on riskier big initiatives.

Philanthropy can also be catalytic as a partner in a synergistic dance with federal agencies. After hearing persistent worries from federal officials that too little was known about the microbiology of indoor environments, one foundation simply decided to advance this field with its own funding[51].

Philanthropy is more open to funding advanced use-cases or newer fields of science beyond traditional disciplinary inquiries. Indeed, some foundations see their charters as precisely to advance new lines of inquiry or younger scientific fields. As an example, the Heising-Simons Foundation[52] makes grants in the sciences that are typically on the order of $5 million for projects. The foundation staff select very specific topics for inquiry based on their analysis of significant problems requiring new thinking. The foundation then invites participants to a brainstorming roundtable to define specific lines of attack. This exercise begins to define who the best researchers might be for the studies. The roundtable also seeds

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[51] The Alfred P. Sloan Foundation. Project on the Chemistry of Indoor Environments. See https://sloan.org/programs/completed-programs/chemistry-of-indoor-environments
[52] The Heising-Simons Foundation. See https://www.hsfoundation.org

what the foundation hopes will be an emergent network of researchers whose bonds will propel further efforts around the topic. Catalyzing new networks across institutions is one way of incentivizing further innovation.

The Kavli Foundation strategy exemplifies a different approach to philanthropy, namely, the use of endowment gifts that favor both higher risk and longer-term commitments to basic science[53]. This foundation makes large endowment gifts (up to $15 million total), often matched by the receiving university that brings in other donors, to establish Kavli Institutes focused on three broad basic science fields – astrophysics/cosmology; nanoscience; and neuroscience.

The institutes often undertake deeply interdisciplinary inquiries. The payout each year from the institute's endowment (generally 5% of the corpus) may be used without restriction by the institute for what its members determine to be its best ideas and highest needs. And they can take high risk with these funds since the Kavli Foundation places no restrictions on the use within a field. In Kavli's experience, these unrestricted funds allow the institutes to support budding ideas not yet ready to be the basis for a proposal to a federal government agency. But once the fundamental (and sometimes radical) idea is validated to a sufficient degree, the institutes find that their success rate in submitting federal grant proposals is significantly higher. The scientific idea has been de-risked.

Finally, large science foundations may have a complementary creative element imparted by their founders while they are still alive [36-41]. The foundations simply do not exhaust their founders' range of interests and financial commitments. In these cases the founders undertake separate gifts that complement the foundations' primary agenda. Good examples are the gifts of Gordon Moore for the design of the Thirty Meter Telescope and of James Simons for the Simons Observatory.

Wealthy donors and founders may also create multiple, sometimes overlapping, foundations in a manner somewhat like a portfolio investment strategy. This institutional tinkering allows experimenting with different funding and tactical strategies. An example is again The Simons Foundation and its associated research centers within its Flatiron Institutes[37]. The core foundation operates as most others. It has a wide range of interests and makes grants approaching $300M each year. But because of Jim Simons's keen interest in

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[53] The Kavli Foundation. See https://kavlifoundation.org

mathematics and the basic physical sciences, the Simons Foundation has within its five research centers, its Flatiron Institutes. Each focuses on a different scientific field, each has its own permanent scientific staff, and each has computational science at its core.

The late Paul Allen had a somewhat different strategy for the Paul Allen Science Research Institutes, each funded separately [38]. The Allen Institutes are funded to support work in four specific scientific areas each at $100M, spent as $10M per year for 10 years. These Allen institutes hire their own research staff and conduct basic research as private non-profit research institutions. In this case, the Allen Institutes are separate and independent of the Paul Allen Foundation, which has its own process for selecting areas of focus and determining grantees.

Finally, although one hears much about the notion that newer donors in this epoch are emphasizing social enterprise models for philanthropy, to date, we have found little evidence that such models are playing a visible role in STEMI research. We do see early investments in “venture philanthropy” in the realm of very applied research, such as with the Schmidt Futures and Dalio Foundation funding oceanography research.

VI. Philanthropy Changes the Ecosystem by Promoting Freedom in Choices about Institutional Direction and Human Capital Development.

Economists believe that human capital development is a critical driver of innovation and economic growth. Similarly, any leader of a successful technology enterprise is likely to say that the single most important factor for success is the quality of its people. As such, it is important to ask if philanthropy influences how the STEMI ecosystem develops talent. Our answer is affirmative – philanthropy has a major influence on talent development and human capital.

Flexibility created by philanthropy through its unrestricted and lightly restricted endowment elements is a key to allowing research institutions to have greater freedom in making strategic choices about human capital development. Philanthropic resources allow greater latitude in how any institution makes bets on which people and skills can best advance new research agendas. To be sure, universities' curricular demands restrict their degrees of freedom in choosing research specialists. And, at research institutions, the major reliance on federal funding means they cannot easily skip or de-emphasize the hiring of people able to win significant federal dollars. Nonetheless, decentralized private sources of funding give institutions greater freedom in their vision for human capital.

To illustrate, consider endowed chair professorships. The general purpose of an endowed chair is to signal that a faculty member is extraordinary, and at private universities in particular, to use the payout from the endowment of the chair to cover a good portion of the faculty member's salary. An endowed chair may, for example, be restricted to a field of study, but there is frequently significant latitude within these limits. Many fields such as biology, physics, or chemistry, have many subfields and it is at the department or dean's discretion as to which particular subfield to emphasize. In addition, endowed chairs can be used as an enticement when recruiting new faculty, especially at the senior level. The chair endowment payout funds are often augmented by the payout of endowment funds at the university level to provide a significant fraction of "startup packages" for newly hired faculty, whether junior or senior. The term "startup package" refers to the funding provided by a university to allow a newly hired faculty member to set up his or her research program. Startup packages in the sciences are frequently in the low to mid seven figures. Such funds are essential to the recruitment of both junior and senior talent for new research and teaching thrusts. They are sometimes also essential in retaining outstanding faculty members who are being recruited away by another institution.

The support for young faculty is critical. Many philanthropists and foundations now provide junior faculty endowed chairs so that a young faculty member has an annual payout to supplement the funding for their early work. Endowment payout funds also support investments that universities make in the development of their junior researchers, frequently by super-charging the cluster hiring of post-doctoral students around new undertakings or subfields. In addition, a number of foundations (such as the Packard Foundation) fund early career scientists. [54]

Universities also use current and legacy philanthropic funds to initiate and support the formation of new disciplinary departments such as was the case with bioengineering and cognitive science in the 1980's and 1990's. Such funds are also used to initiate new schools within a university, including those being formed now in the areas of artificial intelligence and environmental sustainability. These large, multi-disciplinary schools and research institutes are focused on new research directions chosen by the university. We describe some other examples shortly.

Organizing people into new clusters and mixing different types of talent into these ventures does not depend on plans by government or business. They are at the discretion of institutions competing to burnish their reputations for path breaking research and teaching. As just one example, Carnegie Mellon University believes that its prominence in robotics occurred in good part because it decided to rely more heavily on project scientists with advanced degrees and working experience than did its competitors, who spent mainly on hiring traditional faculty.

In like manner of experimentation, the breakthrough success of the University of Maryland, Baltimore County (UMBC) in preparing under-represented populations for graduate STEM careers came from a fresh approach imagined by a single university and funded by one major philanthropy, the Meyerhoff Foundation[55]. In this case both the money and the reputational endorsement in the regional community by the foundation enabled a venture that is now being successfully transplanted to other universities. At the same time, it catalyzed like-minded ventures by others, such as HHMI's commitment at UMBC and elsewhere, and by the Simons Foundation gifts to Spelman College.

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[54] Packard Fellowships for Science and Engineering. The David and Lucile Packard Foundation. See https://www.packard.org/what-we-fund/science/packard-fellowships-for-science-and-engineering/
[55] The Meyerhoff Foundation. See https://meyerhoff.umbc.edu/giving/meyerhoff-giving-fund-descriptions/

VII. The Role of Megagifts in Today's Second "Gilded" Age

A focus on human capital is crucial to understanding the importance of the new wave of "megagifts" for STEM fields. We define a megagift as a philanthropic gift greater than $50 million[4]. Such gifts are somewhat analogous to the megagifts made by donors to create universities in the first Gilded Age. In today's second such Age, megagifts are given to universities to establish new schools and colleges within existing institutional structures.

The recent surge of philanthropic megagifts for creating new schools and institutes amplifies the human capital effect. They draw together new combinations of talent and fresh forms of human capital training along with needed university infrastructure. The scale of funding may also encourage an engagement with problems that are deeply rooted in training and education (often in new interdisciplinary models) and are at the more basic research end of the scale.

As an example, Stephen Schwartzman committed $350M as the catalytic gift to the $1 billion effort at the Massachusetts Institute of Technology to create the new MIT Stephen A. Schwarzman College of Computing[56]. Aside from research, the funds will support fifty (50) new faculty members at MIT. Funds will also help construct a new building to provide the appropriate infrastructure. Here, this megagift is allowing MIT to drive forward a new activity, artificial intelligence, that it sees as central to its future global leadership. As with this MIT megagift, philanthropy's support for education in fields where corporations may dominate research is vital to developing younger talent with a diversity of agendas that extend beyond corporate needs.

Two other recent megagifts explicitly embraced a societal mission while enabling basic and applied research, novel interdisciplinary blends of research, and infrastructure. A 2022 megagift from John and Ann Doerr of $1.1 billion to Stanford University established the Stanford Doerr School of Sustainability[57]. This gift will allow Stanford to hire faculty in clusters in an area, global sustainability, that Stanford deems central to its future.

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[56] The Stephen A. Schwarzman Gift to MIT. See https://news.mit.edu/2018/mit-reshapes-itself-stephen-schwarzman-college-of-computing-1015

[57] The John and Ann Doerr Gift to Stanford University. See https://sustainability.stanford.edu/giving/foundational-launch-partners . Also see https://www.washingtonpost.com/education/2022/05/04/john-doerr-stanford-climate-school/

Similarly, Stewart and Lynda Resnick provided a megagift of $750 million in 2019 to the California Institute of Technology (Caltech) to establish the Resnick Institute of Science, Energy, and Sustainability[58]. Again, cluster-hiring of faculty and new infrastructure are enabling an educational and research direction that Caltech has deemed central to its future leadership.

Importantly, megagifts are not confined to private universities. An example close to home for the authors is the philanthropy of Irwin and Joan Jacobs. In 1998, the Jacobs provided an initial endowment gift of $15 million to name the Irwin and Joan Jacobs School of Engineering at the University of California, San Diego. In 2002, they added a megagift of $110 million which, even today, gives the Jacobs School at UC San Diego the largest endowment of any engineering school at a public university in the country[59]. These funds are essential for hiring and supporting faculty, undergraduate and graduate students, and startup packages for new faculty.

Megagifts are likewise going to private, non-profit research institutions. As an example, the Jacobs recently pledged $100 million to the Salk Institute for Biological Sciences to establish the Joan and Irwin Jacobs Science and Technology Center[60]. This is a challenge gift in which the Jacobs add $1 for every $2 pledged as either a naming or endowment gift by others, up to $100M. Their gift is catalyzing up to $300M in giving and has launched the Salk Institute's five-year, $500M capital campaign.

Finally, megagifts can enable collaborations amongst universities and amongst donors. Megagifts from Eli and Edythe Broad[61] and from Ted Stanley[62] established The Eli and Edythe L. Broad Institute of MIT and Harvard. The Broads provided $200 million in 2004 as a "venture philanthropy" gift to establish the Broad Institute and see how it would develop. When it developed well, the Broads added another $400 million. Ted Stanley then gifted $650 million in 2016 to

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[58] The Steward and Lynda Resnick Gift to the California Institute of Technology. See https://www.caltech.edu/about/news/stewart-and-lynda-resnick-pledge-750-million-caltech-support-environmental-sustainability-research and https://www.nytimes.com/2019/09/26/us/caltech-resnick-climate-change.html

[59] The Irwin and Joan Jacobs Gifts to the UC San Diego Jacobs School of Engineering. See https://www.eetimes.com/qualcomm-chief-pledges-110m-to-former-university/

[60] The Irwin and Joan Jacobs Gift to The Salk Institute for Biological Science. See https://www.salk.edu/news-release/salk-institute-announces-historic-100m-challenge-gift-from-irwin-and-joan-jacobs/

[61] The Eli and Edyth Broad Gift to establish the Broad Institute of Harvard and MIT. See https://www.broadinstitute.org/news/philanthropists-eli-and-edythe-l-broad-make-unprecedented-gift-endow-broad-institute-harvard

[62] The Ted Stanley Gift to the Broad Institute. See https://www.broadinstitute.org/news/650-million-commitment-stanley-center-broad-institute-aims-galvanize-mental-illness-research

establish the Stanley Center within the Broad Institute to support psychiatric and mental illness research. Overall, the Broad Institute is a cross-disciplinary, cross institutional, independent research institution focused on biomedical, genomics, and psychiatric research. It brings together people from across many disciplines and has as partner institutions Harvard, MIT, and the Harvard-affiliated hospitals.

We close this section by noting that some fear megagifts could imbalance the American research structure in a way that favors private universities with wealthier alumni bases. We agree that this is an important question deserving careful attention. Nonetheless, there are many counter examples such as those at the University of Maryland, Baltimore County, at Stony Brook University, at UC San Diego, and at the Salk Institute. Such gifts firmly fit into the tradition of philanthropy creating new models for developing human capital, and novel ways of defining fields of inquiry.

VIII. The Biomedical and Life Sciences Behave Differently

The biological and life sciences receive the largest share of US government and philanthropic research dollars. Importantly, the organizational and incentive structure for much of the biomedical research complex – which mingles clinical and research activities and where faculty compensation is driven by external sources – is different from the rest of science, technology, engineering, and mathematics (the so-called STEM fields). Scholars of management and the social sciences believe that significant variations in incentives and organization influence how inputs translate into behavior[63]. If so, the question is whether this large level of government funding and distinctive organizational system has created behaviors that differ from other fields. Our answer is, yes and no.

To begin, parts of this biomedical research establishment resemble the organization and research reward systems of classic STEM fields. This similarity is strongest in large swaths of traditional biology and chemistry departments in universities and non-profit research institutes that focus on basic biological and biochemistry research. Examples include The Scripps Research Institute, the Broad Institute, and the Salk Institute. Interviewees also noted that some segments of medical school faculty have the type of financial stability and organization structure that resembles those in classic STEM fields.

It is difficult to quantify the share of life science/biomed dollars flowing through a system closely resembling other STEM fields. We ballpark this figure based on data from the National Center for Science and Engineering Statistics, Higher Education Research and Development Survey[29]. This source provides separate figures for spending on biological and biomedical sciences and health sciences in FY2021. Under the imperfect assumptions that health sciences spending mostly occurs in the medical school and its affiliated hospitals, and that biological and biomedical funding is more likely to take place in 'main' campus departments of biology and chemistry (perhaps with a subset of medical school faculty), we estimate that roughly 40% of this research is conducted in ways and with incentive systems similar to those in other STEM fields.

The larger share of funds, roughly 60%, lands in the academic departments of medical schools and their affiliated hospitals. These schools and hospitals have

[63] Oliver E. Williamson won the Nobel Prize for showing how institutions solve incentive issues in The Economic Institutions of Capitalism - Firms, Markets, Relational Contracting, The Free Press, New York (1985).

two distinctively different features, as their leaders acknowledge. First, medical school faculty and hospital researchers are substantially self-funded. Even if affiliated with a research university, the institution pays either zero or a small fraction of a medical school faculty member's total salary. Their clinical practice and research funds generate the predominant amount of a medical school faculty member's financial support. Indeed, clinical practice revenues often also cover shortfalls in IDC.

As one leader in translational medicine remarked to us, every faculty member is necessarily running a small business fiefdom. The system must value this "fiefdom" metric in its hiring and promotions decisions. All this tilts the system toward over valuing successful fiefdoms for financial reasons. And, as another interviewee noted, the requirement to cover one's own salary creates a greater incentive for pursuing current-use gifts, rather than endowment gifts, from philanthropy.

Second, to state the obvious, a great deal of philanthropic donor support comes to medical schools because of the school's engagement in improving treatments and finding cures for disease. This means that a significant share of dollars go to projects that advance treatment, with a tendency to cluster more toward the highly applied end of the research spectrum. The major conclusion is that these two forces together mean that the biomedical and life sciences part of philanthropy is more likely to be focused on incremental, applied research than on the risk level taken in science philanthropy more generally[64].

And within medical schools and hospitals, there is an even more varied set of micro-agendas for research, such as being tied to a specific illness, than is the case with the rest of STEM giving. Most importantly, while our interviewees suggest the next waves of big breakthroughs in research in this arena may require big team science efforts around platform technologies, the fiefdom and incremental/applied model works against the optimal organization of such research and its human capital development in the biomedical area.

The combination of NIH grant practices and the disposition of many philanthropies along the lines we have described has produced a distinctive pattern of human capital development in the biomedical area. At the NIH, funding decisions emerge from an elaborate peer review process that focuses on the

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[64] P.J. Azoulay, J. Graff Zivin, and G Manso, "Incentives and Creativity: Evidence from the Howard Hughes Medical Investigator Program" The RAND Journal of Economics, 42 (2011) 527-554.

research team and its institution as part of its evaluation. The process tends to favor projects with strong preliminary evidence. Moreover, NIH grants encumber institutions over several years. This makes institutions reluctant to have post-docs lead new grants. All these factors lead to a system that is oriented around more senior researchers who have the reputation and financial resources to generate the preliminary evidence in advance of grant submissions, and thus be able to sustain projects over several years[65].

Philanthropic support has historically been more open to the funding of young investigators and cohorts of investigators, and the NIH itself has undertaken some initiatives in recent years to do the same. Nonetheless, the quite limited amount of early career funding in support of health research scientists has led to the gestation period from receiving an M.D. or Ph.D. degree (or both) to becoming a regular research scientist or faculty member to become unreasonably long. A typical post-doctoral fellow in the biomedical area often holds this title for six to eight years, much longer than the at most two years in the rest of the STEM fields.[66]

Significantly, the mix of incentives in life science and biomedical research may be changing because of the wave of recent megagifts. One leader in the field pointed out that many of these megagifts prioritize basic science and foundational technologies that underpin research in an area. The recent philanthropy of Priscilla Chan and Mark Zuckerberg, and their Chan-Zuckerberg Initiative (CZI)[40] created in 2015, has had as its primary focus the development of foundational technologies and data science to advance biomedical research, especially in neuroscience. This undertaking and others like it (e.g., the Paul Allen Institutes[38]) lean toward the more basic end of the research agenda and have more flexibility in project selection to advance their missions. They operate with longer time horizons that are more conducive to speculative projects of a more fundamental nature.

Philanthropy as an agenda-setter can help to reorganize the biomedical enterprise. One major example is in neuroscience and the use by philanthropy of its convening powers. In 2011, the Kavli Foundation, the Allen Institutes, and the Gatsby Foundation organized a meeting to examine the opportunities at the intersection of the fields of nanoscience and neuroscience. The meeting included

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[65] For a more extensive discussion of the NIH peer review process and its implicit incentives, see P. Azoulay, J. Graff Zivin, and G. Manso, "NIH Peer Review: Challenges and Avenues for Reform," in Innovation Policy and the Economy, Volume 13, J Lerner and S Stern (Eds.) University of Chicago Press (2013).

[66] Denton, M., M. Borrego, and D. Knight, "US Postdoctoral Careers in Life Sciences, Physical Sciences, and Engineering: Government, Industry, and Academia," PLoS One 17(2): e0263185, 2022.

about forty participants in an open-ended format and was held at the Kavli Royal Society International Center in the UK. Two seminal papers resulted from the meeting[67,68] that showed it might be feasible in the coming few decades to map the neuronal structure of the active functioning brain. This insight became the catalyst for a group of nanoscientists and neuroscientists to propose a bold new idea to the NIH and NSF. It resulted two years later in the US BRAIN Initiative, announced by President Obama in 2013[69]. The BRAIN Initiative is the first science grand challenge problem funded by the US government in the 21st Century. It was front ended by philanthropy and continues today with annual government funding of $680 million[70].

[67] P. Alivisatos, M. Chun, G.M. Church, R.J. Greenspan, M.L. Roukes, and R. Yuste, "The Brain Activity Map Project and the Challenge of Functional Connectomics". Neuron 74 , 970-974 (June 2012).
[68] P. Alivisatos, M. Chung, G.M. Church, K. Deisseroth, J.P. Donoghue, R.J. Greenspan, P. McEuen, M.L. Roukes, T.J. Sejnowski, P. S. Weiss, and R. Yuste "The Brain Activity Map", Science 338(6125); 1284-1285 (March 2013)
[69] The BRAIN Initiative Announcement. See https://obamawhitehouse.archives.gov/the-press-office/2013/04/02/fact-sheet-brain-initiative and https://obamawhitehouse.archives.gov/BRAIN
[70] https://brainblog.nih.gov/brain-blog/congress-passes-budget-bill-nih-brain-initiative-receives-60m-additional-funds-fiscal-1

IX. Philanthropy and the Future of US Leadership in Global Science, Technology, Engineering, Medicine, and Innovation

We began this study by broadly characterizing the national ecosystem ranging from pure scientific discovery into the final refinements in knowledge to yield products and services as an "innovation system."[3] It has two broad bundles of activity. The first stage is basic and applied research, as defined by the NSF, that opens up the frontiers of possibility both by investigation for its own sake and by tackling the deepest problems of application before practical development of a technology can proceed. The second stage is incremental process innovation, such as learning-by-doing to upgrade products and systems, and experimental development research (which characterizes the bulk of commercial research). Success in both stages of innovation is necessary to achieve national leadership for the overall STEMI ecosystem.

The fragmented decision-making system of the US federal government impedes the forging of a comprehensive R&D strategy. However, given the uncertainties of pursuing the more basic end of the research range, this may be a virtue[71]. Master plans at grand scale and vaulting ambition typically suffer from gaps in knowledge and information, difficulties in coordination, and clashing motives.

Instead of a master plan, the United States' political and economic structures have incrementally moved toward a national innovation system that has placed a very large bet, even in business, on the advantages bestowed by the first stages of basic and applied research. We have argued that a decentralized set of major private and public research institutions has further improved the success of the system because of their diverse strategies for bottom-up initiatives. In this system, philanthropic dollars (both current and legacy) are a large reinforcement for bolder creative strategies. Moreover, the insights and skilled research groups working in the first stage of innovation are strong advantages for responding quickly to shifting opportunities created by new knowledge, and to translating them into successful commercialization of the highest value-added products and services.

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[71] See, for example, Charles E. Lindblom, The Science of Muddling Through (Oxford University Press). Charles F Sabel and David G Victor, Fixing the Climate: Strategies for an Uncertain World (Princeton 2022). Hall and Soskice, op cit.

By way of comparison, China's strategy to achieve world leadership in key technologies (backed by a massively funded industrial policy and adept commercial firms) has a much stronger element of centralized control. This is not to say that Beijing dictates rigid plans for all key R&D, but its control and influence over all of the research institutions and companies looms much larger. This raises the perennial issues of the vulnerabilities of central planning to make errors in conception or implementation. For example, a recent study of the strategic and administrative reforms of the Chinese science effort concludes that it too often tries to do everything at once, basic science breakthroughs and incremental improvements, in a single plan. This muddles the focus and ignores the tradeoffs of different approaches.[72]

Inefficiencies in planning aside, China does have the virtue of being to make massive investments toward big goals. As a result, China has recently elevated the importance of basic and applied research in its strategic technology goals. China has doubled its spending in the past five years on basic research, growing it to 6.3% of its total research budget in 2021, and it seeks to enhance that share to 8% by 2025[73]. Visiting U.S. researchers report that China's efforts bristle with state-of-the-art research facilities.

Despite its upgraded effort, China will still spend less than half of what the US spends on basic and applied research (see Fig. 1), and also less than half of its Asian neighbor, Japan. In Japan, R&D expenditures in 2021 were composed of 13% basic and 20% applied research[74]. Even as China continues to lag in the scale of basic and applied research, it also suffers from not having the benefit of the leavening effects that philanthropy has brought to the research effort in the United States.

Our argument is that philanthropy has shaped the American STEMI ecosystem, particularly in basic and applied research, in four important ways that bolster its effectiveness over the long-term. Any assessment of China's potential for world leadership in STEMI should consider the absence of these factors in the first stage of its innovation system, the basic and applied research component.

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[72] Barry Naughton, Tai Ming Cheung, Siwan Xiao, Yaoshang Xu, and Yujing Yang, Reorganization of China's Science and Technology System, U.C. Institute on Global Conflict and Cooperation Working Paper, July 2023.
[73] Dennis Normille, "China rolls out 'radical' change to its research enterprise", Science, March 15, 2023.
[74] OECD Stats database, "R&D expenditure by sector of performance and type of R&D." https://stats.oecd.org/Index.aspx?DataSetCode=RD_ACTIVITY

First, in its early days, philanthropy helped the US develop its decentralized institutional structure of private and public universities and private scientific institutions that were largely independent of federal control. After World War II and the start of the Cold War, this system was not replaced but strongly enhanced by deliberate federal policies[12]. The diversity of institutions empowered to set their individual strategies helped to incent competing strategies for research successes. Even our concepts of what were key fields in basic and applied research changed due to initiatives of individual institutions, such as happened with the growth of bioengineering and cognitive science.

Second, within this decentralized institutional environment, an informal but effective division of labor among the federal, commercial, and philanthropic funding of basic and applied research has evolved. The scale, scope, and diversity of federal programs makes them the indispensable bedrock of the country's innovation ecosystem. Our review of federal science budgets for basic and applied research (with complementary development) had two distinct features.

On one hand, the federal agenda featured management projects for risky, very large-scale, and multi-year basic and applied research that it is uniquely advantaged to pursue. These VLSR (very large-scale research projects) are selectively complemented in a few fields by companies who "bet the business" on attaining technological capabilities at very large scale. On the other hand, the largest share of federal funding for basic and applied research (about $51 billion) goes to universities and non-profit research laboratories. These institutions are the main organizations for advancing investigator led work in basic and applied research. Yet it is precisely in these institutions that the impact of philanthropy is so large, measured by dollars and behavioral consequences.

We have shown in sections I and II that as of 2021, the combination of current giving and the yield from endowments (which we have termed "legacy philanthropy") at universities and NPO's equals about $21.5 billion on STEMI. This is roughly 42% of the federal outlay to these institutions, and 23% of the federal outlay in basic and applied research to *all* institutions, including business and federal labs. And this large sum's true significance plays out in the larger pool of overall research resources at major universities, e.g. the AAU Universities.

Philanthropy provides on average roughly one-quarter (25%) of total institutional self-funding of science and technology at American research universities. The sources of this self-funding are the payout from institutional endowments, indirect cost recovery on federal grants that the university controls but which must be used in proscribed ways, tuition, and for public universities, support from state governments. In fact, state funding at the AAU public universities ends up supporting STEMI R&D spending from institutional funds at roughly the same ratio (approximately 25% of the total R&D expended) as at private universities, an important insight.

The interaction of philanthropy with other institutional funds allows for flexibility in the bottoms-up strategies set by our research institutions. Outside of biomedical funding, philanthropy boosts research because it combines with, and adds to, flexibility in the use of funds at these decentralized research institutions to amplify agendas around basic and applied research. Researchers can leverage these funds to explore new ideas and apply for additional funds from other sources, e.g. the federal government. Although the lower IDC rates by philanthropy often do not fully cover the costs of individual projects, philanthropic funds in aggregate also make it easier for institutional leadership to experiment with the best way to invest in the crucial area of human capital agglomeration and development.

Third, philanthropy has permitted more risk taking (and often quicker and simpler decision making) about pursuing important new ideas, different strategies of investigation, and new forms of research organization. It also greatly expanded the agenda for investigation because donors vary so widely. Precisely because the US Government does not have a powerful central plan for basic R&D (even though it can be very good at individual priorities), it is advantageous to have a mechanism attuned to rapid exploratory probes of new possibilities. Philanthropy accelerates a path from risky fundamental discovery to the scalable working out of downstream investigations and infrastructure using federal funds.

It should be noted that the stronger emphasis on a more investigator-driven agendas for basic and applied research in the universities and non-profit research institutions supplies the fuel for American firms who are especially rewarded by its capital markets for strategies focused on major product breakthroughs.

These virtues of philanthropy emerge in interaction with the properties of federal funding. And precisely because philanthropy can be a significant agenda setter in the earlier stages of basic research, government has more options to focus its biggest dollars, political effort, and risk-taking on VLSR projects that philanthropy shies away from, and that business only selectively pursues.

Fourth and finally, philanthropy permits competitive research institutions to explore different ways of combining and developing their human capital. People are perhaps the most important asset of basic and applied research discovery. This in turn is fundamental to the evolution of novel paths for the discovery enterprise.

Even as this summary emphasizes the benefits of philanthropy, we again emphasize that every system has risks. For example, issues of social responsibility confront our nation's decentralized research institutions of public and private universities and its private, non-profit research institutions[75]. Philanthropy has done some important innovative work in preparing under-represented populations for graduate STEM careers. Yet, philanthropic leaders agree that the collective effort on social responsibility should have been greater.

On a different dimension of equity, the tendency for institutions with very large endowments to grow those endowments still further raises questions about the resource imbalances that may result from a system so reliant on private funding. While public universities are getting better at attracting philanthropic funds, this is an issue worth watching carefully. And, as we noted at the outset, our focus on how the current system of research investment operates does not lend itself to analyzing such larger societal debates as the one over the appropriate tax regime (including charitable deductions) for the very wealthy.

For all the strengths that philanthropy adds to the first stage of innovation through its support of basic and applied research, it cannot correct concerns about the lagging growth in federal expenditures on R&D. The recent CHIPS and Science Act authorized such an increase, but the final budget appropriation did not reflect the authorized increases.

A second concern focuses on the second stage, the translation of basic and applied research discoveries to innovation. Critics argue that the US is lagging on this challenge, especially when compared to the massive resources being invested by China in its innovation system[76]. Some critics of the US system note that, aside from the now stagnant federal funding in real terms, the fragmentation at the top of the US government is a detriment in pursuing big, cross-cutting innovations like AI, new pharmaceutical platforms based on AI and CRISPR tools, or next generation innovations in weapons systems. Furthermore, they argue that the

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[75] Evan S, Michelson and Adam F. Falk, "A Vision for the Future of Science Philanthropy", https://issues.org/future-science-philanthropy-sloan-michelson-falk/ and ibid. pp. 351-360.

[76] Dan Wang, China's Hidden Tech Revolution—How Beijing Threatens U.S. Dominance, Foreign Affairs, March/April 2023. For more comprehensive analyses of Chinese innovation strategy, see Tai Ming Cheung, Ed., Forging China's Military Might: A New Framework for Assessing Innovation, Johns Hopkins University Press, 2014; and Barry Naughton, The Rise of China's Industrial Policy, 1976 to 2020

American emphasis on stage one of innovation (i.e., on basic and applied research) has led the US to neglect necessary reforms to its stage two system. In this view America performs inadequately in translating basic and applied research into cutting edge commercial technologies. It also neglects the potential for regional innovation clusters that would bolster more traditional industries and benefit a broader geographic swath of the country.

Like the first stage of innovation, the federal government's funding is indispensable to programs that are necessary to shore up the second stage, the incremental innovation and development research system. For example, the CHIPS and Science Act[2] explicitly addresses these critiques by supporting advanced semiconductor manufacturing and its key implementing technologies. The R&D emphasis is especially on applied research to meet the needs of revitalizing semiconductor production in the US. This research is translated into innovation through subsidies for expensive production fabs and final product development efforts. Its scope also includes measures for workforce training and other measures critical to incremental innovation. Moreover, the Act explicitly seeks to bolster regional innovation clusters that would work on applied, or use-inspired, research.

The Inflation Reduction Act[77] similarly devotes its largest funds to bolstering technologies and their production to address climate change via a sweeping change in our energy and transport infrastructures. It aims to reinvigorate government and business investment in newer public infrastructure systems, such as smart roads or modernizing the electric grid using new technologies.

All this said, philanthropy already plays a strong role in translation and innovation in one field, biomedicine. As explained in Section VIII, biomedical philanthropy is both a large share of all philanthropy, and probably about 60% of this biomedical philanthropy goes to incremental innovation and development research. This is a big help for American biomedical leadership even if it may discourage more fundamental research and increase the time younger researchers spend in post-doctoral positions.

Even more fundamentally for the future, the emergence of a large crop of megagifts to universities and non-profit research organizations could alter the role of philanthropy in linking stage one research to stage two innovations. While the biggest dollars of these enormous megagifts are for stage one research and human capital development, their sheer magnitude has allowed several of them to allow

[77] The Inflation Reduction Act of 2022. Pub. L. 117-169. Signed into Law, August 16, 2022.

universities and NPO's to set goals for creating new research platforms at a scale resembling the VLSR projects that were traditionally dominated by government and business. They also incent institutional mechanisms that could expedite crossovers between the two stages of innovation.

Like the entire saga of philanthropy's impact on the American research and discovery system, this will be a tale written in bottom-up experiments by a diverse set of research institutions who both compete and cooperate in the advancement of our most basic understanding of the universe, and our most ambitious efforts to reshape the way that our civilization progresses. Particularly in a time of rising political pressures to fracture the world's cooperative undertakings of such challenges as climate change and public health, philanthropy could be a moderating influence that may help us steer away from political extremes. Meanwhile, philanthropy will continue to be a singular American advantage in the field of basic and applied research over the long term.