World War II and the 20th-Century Transformation of Biomedicine*

Daniel P. Gross†
Duke University and NBER

Bhaven N. Sampat‡
Johns Hopkins University and NBER

July 2026

Abstract:

During World War II, the U.S. Committee on Medical Research (CMR) coordinated and funded an integrated, cross-sectoral effort to develop medical science and technology for war, representing the U.S. government's first substantial investment in medical research. Using data on all CMR research contracts, we show that despite mixed results during the war, this effort laid the foundation for the postwar growth of U.S. biomedical innovation, including the expansion of biomedical science, new drug development, advances in clinical knowledge, and the postwar extramural research funding at the National Institutes of Health. Though the impacts on science diffused globally, the acceleration of drug development concentrated in U.S. firms, which subsequently adopted new methods of drug discovery and development and the systematic application of science. The episode provides evidence on the systemic effects of innovation policy and highlights an integrated approach to biomedical innovation policy distinct from modern funding models.

JEL Classification: H51, H56, N42, N72, O14, O31, O32, O38

Keywords: Public R&D; Innovation policy; Innovation systems; Institutional development; Biomedicine

*We thank the editor and two anonymous referees for comments which significantly improved this paper. We also thank Ashish Arora, Tim Bresnahan, Wes Cohen, Bob Cook-Deegan, and Paolo Surico, discussants Pierre Azoulay, Tamri Matiashvili, Kyle Myers, and Gary Pisano, and numerous seminar and conference audiences for helpful feedback. We also thank Hayley Pallan, Senan Hogan-Hennessy, and Oum Lahade for research assistance during this project's early stages and Eric Gilliam for helpful discussions and related background research. Duke University's Fuqua School of Business, the Harvard Business School Division of Research and Faculty Development, and the National Bureau of Economic Research provided financial support. This material is based upon work supported by the National Science Foundation under Grant No. 1951470. All errors are our own.
†Address: Duke University Fuqua School of Business, Durham, NC 27708, USA; email: daniel.gross@duke.edu.
‡Address: Johns Hopkins University, School of Government and Policy & Carey Business School; Washington DC 20001, USA; email: sampat@jhu.edu.

Improvements in human health rank among the most transformative developments of the twentieth century: Nordhaus (2003) estimates that the 30-year increase in U.S. life expectancy over the century was as valuable as measured economic growth in all other sectors combined. Although the reasons for these gains have been debated, a crucial contributor is widely thought to be advances in medical science, technology, and practice (e.g., Murphy and Topel 2003, Cutler and Kadiyala 2003, Cutler et al. 2006). Many observers attribute these advances to the productivity of a highly developed U.S. biomedical R&D ecosystem (e.g., Laitner et al. 2024).

This ecosystem, however, is a post-World War II phenomenon. A century ago, U.S. universities were far less research intensive than they are today and had limited resources for research, medical or otherwise (Geiger 1986).[1] The pharmaceutical industry was small and concentrated, spent a smaller share of sales on R&D, and undertook little formal testing (Cockburn et al. 1999). The National Institutes of Health (NIH) was also small and intramural, interfacing little with the university or commercial sector. As Figure 1 shows, U.S. biomedicine grew slowly prior to the 1940s. World War II then placed new demands on the country's relatively immature biomedical research system, and between 1941 and 1945, the newly-created U.S. Office of Scientific Research and Development's (OSRD) Committee on Medical Research (CMR) enlisted universities, firms, and hospitals around the country in a large, collaborative effort to develop medical science and technology for war—an undertaking which was not only the federal government's first extramural investment in biomedical research but also one of its few pursuits (ever) of an actively-managed biomedical research policy. The end of the war in 1945 marked a turning point in annual scientific publications and drug-related patents (Panels A and B), which have been growing rapidly ever since.

[Figure 1 about here]

This evidence motivates the central question of this paper: what relation did World War II have to postwar U.S. biomedical innovation, and why? Using newly-collected archival data on all CMR research contracts, we argue that the war effort triggered long-lasting growth in scientific research and drug development in subjects it supported, with effects persisting into the 1960s and beyond. Firms engaged in CMR-led drug development projects entered a two-decade period of prolific drug innovation, which was increasingly characterized by systematic approaches to drug discovery and a stronger basis in science—features which persisted even after this surge in new drugs tied to CMR research subsided. CMR also provided a foundation for the postwar NIH, which absorbed CMR's portfolio and much of its apparatus after it demobilized. With academic science, the pharmaceutical

[1] As Geiger (1986), Urquiola (2020), and others have observed, U.S. universities began growing their research capacity in the 1920s and 1930s, but had limited capabilities by modern standards (and nearly none outside of a small number of universities) and limited research funding (even from leading foundations).

industry, and NIH being the three pillars of U.S. biomedical innovation today, World War II is now recognizable as the key turning point in its institutional development, with large implications for public health and economic growth over the remainder of the century.

Our first set of analyses examines science. To do so, we collect data on the universe of biomedical research publications between 1930 and 1970 and map both these and CMR contracts to Medical Subject Headings (the National Library of Medicine's controlled vocabulary for indexing research in the life sciences), as a measure of research space. Comparing the long-run growth trajectories of research subjects that were targets of CMR investment against those that were not, we find that underdeveloped subjects that were a focus of CMR research grew significantly during and after the war, relative to others, despite not being on differential prewar trends.

Our second set of analyses examines CMR's impacts on drug development in the postwar pharmaceutical industry. Using a list of new drugs introduced to the U.S. market between 1940 and 1975, we show that drug categories where CMR was active yielded significantly more new drugs in the 1950s and 1960s. Firms involved in the war effort—some of whom, like Pfizer, were not previously in the drug business—became particularly prolific drug developers for the next two decades. Many of these drugs developed as a result of new discoveries, processes, and capabilities which CMR directly supported—from semi-synthetic antibiotics to natural drugs which could be produced using techniques for industrial-scale fermentation borne of the war effort.

One practical effect of this investment was a reduction in military morbidity and mortality, particularly from infectious disease. But CMR-led wartime innovation also had the potential to influence civilian health. Though specific links to civilian disease burdens are difficult to establish econometrically, in our third set of analyses, we examine the diffusion of CMR-funded research into medical training and practice. To do so, we draw on a leading medical textbook (Cecil's *Textbook of Medicine*) and popular clinical reference manual (the *Merck Manual of Diagnosis and Therapy*).[2] Using successive editions of these texts, we show that CMR-funded subjects were more likely to be added to postwar editions of these textbooks, reflecting the practical value of new medical knowledge which emerged from the war effort—albeit with a several-year lag, reflecting the time it takes for this medical knowledge to standardize and diffuse into practice.

Individually, these results document the impacts of public R&D on biomedicine and its application in technology—subjects of perennial scholarly interest (e.g., Cockburn and Henderson 1996, Jacob

[2]Our choice to probe diffusion of medical information into textbooks is motivated by research arguing that textbooks were until recently a main source of information for clinicians which "reflect the level of knowledge of the average medical practitioner and [can be used as] a consistent sampling device for measuring changing practice patterns" based on their periodic revisions (Greene 2007, p. 294; also see Catillon 2017).

and Lefgren 2011, Toole 2012, Azoulay et al. 2019b, Myers 2020).[3] However, additional evidence suggests that the CMR effort engendered a broader structural transformation, of a type which has been less of a focus in research on the effects of public R&D. The persistent growth of biological approaches to drug development and increasing use of science are both indicative of a more fundamental change in the pharmaceutical sector's innovation process itself, and coincided with the emergence of the U.S. pharmaceutical industry as the global leader. That these changes are present for U.S. firms but not foreign firms, and for the U.S.-based patenting of U.S. firms but not their foreign patenting, seemingly reinforces a structural interpretation.

An old literature on industrial development, and an emerging literature on the macroeconomic impacts of innovation policy, together provide a framework through which these findings can be interpreted. Existing theories describe how a coordinated investment across complementary activities can move an economy from a low- to a high-investment equilibrium (Rosenstein-Rodan 1943, Murphy et al. 1989)—a logic that, transposed to innovation, describes how CMR's simultaneous investment in science, technology, and the institutions linking them could have set U.S. biomedicine down this path. A recent macroeconomic literature, meanwhile, finds that public R&D of broadly this kind—extramural, science-oriented, and often health-related—generates large and persistent returns to productivity and growth (e.g., Antolin-Diaz and Surico 2025, Fieldhouse and Mertens 2026a, Gazzani et al. 2026). One contribution of this paper is to connect that literature's aggregate findings to microeconomic evidence on mechanisms behind them.

Another contribution of this paper is in understanding innovation processes and institutions. In particular, the interconnectedness of innovation under CMR and in postwar biomedicine is different from the popular "linear" view of innovation in which science flows unidirectionally to technology, production, and implementation (Godin 2006, Balconi et al. 2010). Despite frequent critiques, the linear model remains the subject of a large and interdisciplinary scholarship on innovation and a significant share of innovation policy (including much of NIH).[4] This paper offers a reminder that innovation processes involve substantial interdependence across different actors and institutions and across the R&D value chain (Rosenberg 1982). Our emphasis on this feature of innovation and its implications brings a complementary "systems" perspective to empirical research on the effects

[3] To these outcomes, we add a measure of incorporation into practice. Our research also differs from prior work in studying not "bottom-up", investigator-initiated funding for fundamental research, but the effects of a more "top-down", use-oriented biomedical R&D policy bordering on technology policy—an approach which draws recurring interest in biomedicine (Cook-Deegan 1996, Sampat 2012, D'Souza et al. 2024) and other fields (Branscomb 1992, Nelson 1997) and which has a recognized evidentiary gap (Bloom et al. 2019).

[4] Though long declared "dead" (e.g., Rosenberg 1991, p. 335), the linear model is implicit in the voluminous literature examining the impact of science on technology (see Rosenberg 1974 or Brooks 1994), efforts to measure direct linkages from science to technology (e.g., Marx and Fuegi 2020, Bryan et al. 2020), and policies designed to encourage commercialization of university science (Mowery et al. 2001, 2004), among others.

of R&D policy, which otherwise often focuses on discrete outcomes.

More generally, this paper contributes to a wider literature on the effects of biomedical research funding. Although the NIH has been the subject of most previous empirical studies assessing the returns to medical research, its emphasis on funding undirected, investigator-initiated science at universities is specific and distinct from CMR's integrated research model in World War II, which set application-oriented priorities, coordinated the activity it funded, spanned sectors and disciplines, and linked science to technology, manufacturing, and diffusion. While scholarly interest in R&D policies with these features is growing (e.g., Mowery 2009, Foray et al. 2012, Mazzucato 2018, 2021, Kattel and Mazzucato 2018, Azoulay et al. 2019a, Agarwal et al. 2021), there is limited systematic empirical evidence on what effects such approaches might have and why.[5] This paper brings new evidence to this literature, complementing our prior writing on the effects of World War II research on the non-biomedical U.S. innovation system (Gross and Sampat 2023a), where we found that the broader OSRD effort set in motion postwar growth and regional agglomeration of U.S. electronics and communications innovation. Beyond the shift in domain (to biomedicine), this paper provides empirical perspective into the structure of innovation systems and the ways in which R&D policy can catalyze structural transformation and long-run growth.

The paper is organized as follows. Section 1 provides institutional background, including on the importance of medicine to warfare, World War II medical research, and CMR's imprint on postwar research policy. Section 2 introduces our data and characterizes the CMR shock. Section 3 presents our empirical approach and examines the case for causal interpretations. Section 4 evaluates CMR's relationship to postwar biomedical science; Section 5, to pharmaceutical innovation; and Section 6, to broader changes in U.S. biomedicine, including the growth of science-based innovation and the diffusion of research to clinical practice. Section 7 considers the potential aggregate implications of these changes and explores how the evidence relates to modern and recurring innovation policy questions. Section 8 synthesizes the evidence and concludes.

[5] Though this growing body of scholarship on "mission-oriented" R&D considers the impacts of actively-managed R&D policy, we find that the "mission" label is too ambiguous for our purposes and can be difficult to generalize. For this reason we largely eschew it in this paper. For example, though NIH is a mission-oriented agency (whose mission is to seek and apply fundamental knowledge to improve human health; Sampat 2012), it functions mainly as an arms-length financier, delegating both grant review and the performance of the research it funds to a decentralized scientific community, and leaving it to the private sector to decide how to use it. Most academic writing on "mission-oriented" R&D has a more interventionist approach in mind, where the state makes or shapes the market (e.g., Mazzucato 2018, 2021)—a feature which is more characteristic of defense R&D (Mowery 2012) or crisis innovation policy (Gross and Sampat 2022) specifically than of mission-oriented policy generically.

1 World War II and Biomedicine

1.1 Military medicine: The battle against disease

Although nearly 70 countries participated in World War II, the U.S. military's greatest adversary was arguably disease: for most of history, infectious disease has killed more soldiers than battlefield wounds and incapacitated an even greater number (Hoyt 2006).[6] World War II also introduced a wider range of medical problems than the U.S. military had previously encountered—not only new diseases, but also new environmental conditions and traumatic injuries. In the early 1940s, there was thus an urgent need for knowledge and technologies that could address medical problems Allied soldiers faced, including prevention and treatment of bacterial and viral infections, malaria, wound and shock treatment, blood substitutes, mental health, and issues relating to aviation physiology, motion sickness, temperature, and nutrition, among many others.

When World War II began, there was no obvious office in the U.S. federal government to assign to this charge. Though the National Institute of Health (singular) was created in 1930, and was expanded by Congress to include a National Cancer Institute in 1937, it was small and had no serious extramural research funding capacity of the type that the war required (e.g., Swain 1962). Private foundations had previously funded medical research through grants to individual researchers, but these too were insufficient for the demands the war presented, due to their relatively small scale and their focus on fundamental research rather than applications.

In 1941, the U.S. government's Committee on Medical Research (CMR) was created as a subsidiary to the Office of Scientific Research and Development (OSRD)—an agency established to coordinate and fund civilian R&D for war—to fill this void. At the time, this was an unprecedented choice: before 1940, there was very little federal funding of research outside of agriculture, nor precedent or mechanism for funding extramural research. In the executive order creating OSRD, CMR was to support "the mobilization of medical and scientific personnel of the Nation" and advise and oversee contracts "with universities, hospitals, and other agencies conducting medical research activities ... related to the national defense" (Andrus 1948, p. xlii).

The R&D-funding apparatus that CMR ultimately developed to fulfill this charge was broad and multifaceted (Gross and Sampat 2023b). General research priorities were determined in partnership with the military, which brought military medical problems to its attention. CMR then shared these priorities and solicited proposals widely, including from university scientists, firms, hospitals, and independent research institutes. Rather than reviewing these proposals directly, CMR forwarded

[6] See Online Supplement A for further discussion, where Table A.1 compares mortality from disease versus injury in eight prior conflicts, based on reporting from the U.S. Army's Medical Department.

proposals to the National Research Council's (NRC) Division of Medical Sciences (DMS), where over thirty committees—comprised of hundreds of elite medical researchers and officers from the Army and Navy—provided peer evaluations, in an early use of peer review. Based on these reviews, DMS gave each application a letter grade and returned a recommendation for funding, which CMR typically followed. Once funded, CMR provided active project management, including organizing meetings of investigators to promote information flows, collecting and circulating progress reports, and supplementing or terminating projects as their results, and CMR's priorities, evolved. For research directed at new treatments for diseases, CMR was also active in development, evaluation, and implementation, with many of its contracts supporting experimental interventions and/or clinical trials. Like OSRD in general, it was primarily a "results-oriented" program, and prioritized relevance and speed over fundamental, scientific value.

Beyond funding: coordination and brokerage

Beyond funding, CMR played an important role in creating connective tissue in the nascent U.S. biomedical innovation system. This connective role was particularly pronounced in specific projects, such as in the effort to mass produce penicillin. At the beginning of the war, the technology did not exist to produce enough penicillin to treat a single patient, let alone for clinical testing—yet by the end of the war, there was enough for all Allied troops and civilian use (Keefer 1969). Early in the war, CMR reportedly was crucial in persuading private firms to get involved, brokering information flows between these firms and the U.S. Department of Agriculture's Northern Regional Research Laboratory (NRRL), organizing meetings, and refereeing conflicts among participants (Swann 1983, Neushul 1993). Once firms were able to produce enough penicillin for testing, CMR coordinated and funded clinical trials. After trials were complete, CMR worked with the Office of Production R&D of the War Production Board (WPB) to scale up production to the needed levels. The WPB provided needed material and equipment to firms, shared technical expertise, and provided some funding. WPB corresponded with 175 potential producers, and eventually worked with 20 in the program, chosen based on experience with penicillin, fermentation, and biological production in general, as well as the quality of staff (Neushul 1993). Although CMR's primary role in the scale-up of natural penicillin was coordination and clinical testing rather than more upstream R&D funding for biochemistry or drug discovery, CMR did invest considerable research funds in a parallel synthetic penicillin development program—which, at the beginning of the war, it viewed as a more likely path to large-scale production (Swann 1983).

1.2 Results of CMR research

Between 1941 and 1945, CMR engaged researchers in roughly 570 contracts totaling around $400 million (2024 dollars). Though it comprised only 5% of OSRD's total spending, and is less than 1% of NIH's modern budget, CMR research funding was an order of magnitude larger than previous federal spending on medical research, much of it going into subjects that had not been a major focus of research prior to the war. As Stewart (1948, p. 102) describes:

> The shift in emphasis and even in direction was enormous. Many subjects of minor importance in peacetime become of controlling importance in war. Some subjects are born of war. Tropical medicine had been considered of rather academic interest to the health of the United States. Even the machine age had not adapted our younger generation to flying at 40,000 feet or diving at 400 miles an hour.

Though the performance of individual research programs it supported was mixed, CMR was successful enough during the war to impact its conduct. The mass production of penicillin is its most celebrated accomplishment: by 1944 the U.S. was able to produce enough natural penicillin to meet military demand, and so much by 1945 that it was made available for civilian use. In contrast, CMR's parallel effort to chemically synthesize penicillin—initially seen as more promising—was unsuccessful. Its research also extended to malaria. Though malaria had long been treatable with quinine, the Japanese invasion of Java and war in the South Pacific cut off supply routes. CMR's malaria program focused on finding quinine substitutes. It identified and synthesized over 14,000 compounds and tested promising candidates against animal models, in clinical trials, and on soldiers in the field (Keefer 1969). This effort struggled to find substitutes during the war, and when CMR established that an existing molecule, atarabine, could be used safely and effectively, it was adopted as the military's preferred preventative and treatment.[7]

There were numerous other successes and failures, most of which are detailed in Baxter (1946) and Andrus (1948). Hoyt (2006) finds that between CMR and other government agencies, wartime research helped develop new or improved vaccines for 10 of the 28 vaccine-preventable diseases identified in the 20th century. CMR had a crucial role in funding research and development on blood substitutes used to treat battlefield casualties (Creager 1999). CMR research also deepened understanding of human physiology under environmental hardships such as nutrient deficiencies, sleep or oxygen deprivation, and temperature exposure, as well as of stress disorders and mental health—all in response to the demands the war presented.

The medical impacts of this work can be seen in military statistics (Online Supplement A). In short, World War II R&D essentially solved the military's problem of infectious disease. The ratio

[7] Chloroquine was also a subject of CMR research, though it came into focus too late to be useful during the war—and instead became a revolutionary malaria treatment in the years immediately after.

of U.S. military deaths from disease vs. injury fell from 1.02 in World War I to 0.07 in World War II (0.01 in the European theater). Hospital admission and death rates for many common infectious diseases—such as pneumonia, influenza, and typhoid fever—declined nearly 100% between the two conflicts. Figure C.1 in the supplement extends this comparison by plotting the time series of U.S. Army hospital admissions and death rates per capita between 1895 and 1955, which have significant spikes in prior wars, but no such deviations in World War II.

1.3 CMR and postwar research policy

When CMR was disbanded in 1945, the Public Health Service took over its forty-odd open contracts, which became the kernel of NIH's extramural research program (Swain 1962, Fox 1987). Beyond providing a general model for using grants and contracts to fund research, NIH adapted specific contracting approaches developed by CMR and OSRD during the war, including indirect cost recovery policies and elements of patent policy (Rosenzweig 1998, Sampat 2020, Azoulay et al. 2025). NIH's peer review approach was also based on CMR: "study sections" of external scientists providing initial scientific/technical review were modeled on the wartime NRC/DMS review system. In 1946, the NRC Penicillin Panel transitioned into the Syphilis Study Section, marking the inception of what has grown to encompass over 250 similar study sections within the NIH. The NIH budget has increased 1000-fold in real terms since the end of the war, and the agency is sometimes known as the "crown jewel" of the federal government (Sampat 2023).

Despite these continuities, NIH also made major and explicit departures from CMR, including by emphasizing fundamental research and providing flexibility for scientists to take their research in unplanned directions when opportunities emerged (Van Slyke 1946). In addition to this freedom of exploration, topic choice in the NIH program was also primarily investigator-initiated or "bottom up" rather than the "top down" priority setting of the wartime model. In a 1962 interview, Van Slyke recounted that the targeting of biomedical research ("[T]hou shalt concern yourself with the making of anti-malarial. Thou shalt concern yourself with the survivor's suits.") was "justified by war time needs and exigencies" but was not the focus of the NIH.

Over time, and especially after Congressional investigations in the 1960s, NIH's original emphasis on scientific freedom eroded, with the growth of bureaucracy and reporting requirements (Sampat 2023). However, the NIH model continues to focus on "bottom up" investigator-initiated research with little of the explicit top-down project selection, active project management, and focus on application and diffusion that were core elements of the CMR model. NIH's approach has come under scrutiny, including during debates surrounding the War on Cancer in the 1970s, the Artificial Heart Program, concerns about NIH priority setting (Sampat 2012) and more recently in the initiative

that led to ARPA-H (Sampat and Cook-Deegan 2021). Though nominally a mission agency, NIH (and its parent Department of Health and Human Services) also does not link up different aspects of its health mission (research, development, testing, diffusion into practice, procurement) as CMR's "integrated research model" (Hoyt 2006) did.

2 Data and Descriptives

To systematically examine the link between CMR and postwar biomedical innovation, we collected a complete record of all 590 CMR contracts (573 extramural, 17 intramural) from OSRD archival records.[8] For nearly all (588), we have a summary report identifying the responsible CMR division and the research subject, principal investigator(s) (PI), institution(s), budget, and timing (see Appendix Figure A.1 for an example).[9] These summary reports also provide an extended abstract and list all resulting publications (e.g., journal articles, technical reports, progress updates). Collectively, this information provides the corpus we work with: titles and abstracts provide information on subject matter, publications on research output, and header data on institutions and PIs. We identify 2,438 scientific publications produced by CMR-funded research, spanning a wide range of journals in the medical sciences and related fields (e.g., public health, organic chemistry, entomology). We manually linked these publications to three external publication databases: Microsoft Academic Graph (MAG), Web of Science (WOS), and PubMed.

In parallel to information from CMR, we collect data on three categories of outcomes: science, innovation, and medical practice. We measure scientific activity via research publications, which are attractive for their transparency and observability over long horizons, including both before and after the war. Our publication sample begins with the universe of publications between 1930 and 1970 in MAG. We filter this sample to the 5.5 million publications in the *Natural Sciences* and *Medical and Health Sciences* published over this period, as indicated by MAG topic labels (OECD field codes). Though other publication datasets (e.g., WOS) have been used in prior research, MAG has two main advantages over other sources: (i) it has comprehensive historical coverage dating to the late 1800s, and (ii) it is open access. MAG provides additional information about individual publications that are useful for our purposes, including titles, journals, authors, and cross-paper citation linkages, and enables us to use secondary data products produced from the MAG sample,

[8] See Appendix A for a detailed description of our data sources and data collection. We cross-validate CMR contract and publication data against additional OSRD records, including separately-maintained CMR contract lists and publication lists (details in Appendix A). This cross-validation led to occasional minor corrections, usually attributable to minor typos in the source records. The 17 intramural contracts were entered into with other government agencies (primarily with the USDA, NIH, and FDA), which participated in a handful of CMR research programs (e.g., USDA's Bureau of Entomology in malaria transmission research).

[9] Extended abstracts are available for 441 (75%) of summary reports. The two contracts for which we do not have summary reports are CMR's first and last extramural contracts.

such as patent citations to science (Marx and Fuegi 2020, 2022).

Measuring pharmaceutical innovation is harder: though drug development is often measured via FDA drug approvals, there are no electronic data on drug approvals from this era, and the FDA Orange Book begins only in 1985 (Durvasula et al. 2023). We fill this gap by locating and digitizing de Haen (1976)'s "Compilation of New Drugs, 1940-1975", which lists "new chemical entities or synthesized drugs not previously available in the United States" first marketed between 1940 and 1975 and serves as the basis for the FDA History Office's historical drug approval statistics.[10] The De Haen data document 1,010 drugs developed by 126 distinct firms over this period, along with their trademark name, generic name, and year introduced. Each drug is categorized into one of 42 therapeutic classes and over 150 subclasses, which we will use in our analyses below. In parts of the paper, we will also analyze drug-producing firms, for which we take two further steps. First, we link firms in de Haen (1976) to patent assignees and measure these firms' drug patents (which we define as those in NBER patent category 31, "Drugs"; Hall et al. 2001) and their characteristics.[11] Second, because some firms in our sample merged during the study period, we collect merger data from historical Federal Trade Commission tables (FTC 1980, covering 1947-1978) and dynamically assign firms to their contemporary parents after known mergers.

Our next set of outcomes measure science-based innovation in the pharmaceutical sector, broader technological innovation in the U.S. economy, and population health—channels through which CMR may have had aggregate impacts. We use data on pharmaceutical firms' patent citations to science (Marx and Fuegi 2020, 2022) to measure science linkages, and we expand our patent data beyond this sector to all U.S. patents to evaluate CMR's relationship to wider trends in patenting. Although linking R&D to population health is notoriously difficult, we treat medical practice as a surrogate endpoint. Building on research which points to medical reference books as a window into evolving medical knowledge, we collect the contents of two prominent book series published both before and after the war: the *Cecil Textbook of Medicine* (henceforth CT), a staple textbook of medical training (Greene 2007), and the *Merck Manual of Diagnosis and Therapy* (MM), a popular clinical reference (Tomes 2021). For these book series, we digitize all editions with an index through approximately 1960 and recover the subjects in each edition's index.

A final resource for this paper is postwar biomedical research funding. As Section 1 explains, CMR inspired and funded the creation of NIH extramural research funding, which increased sharply over the first two postwar decades. Postwar NIH funding in specific subjects may be another effect of the CMR shock. We digitize annual editions of the U.S. Public Health Service's *Research Grants and*

[10] See https://www.fda.gov/about-fda/histories-product-regulation/summary-nda-approvals-receipts-1938-present.
[11] Patent data obtained from Google Patents and the Reliance on Science project (Marx and Fuegi 2020, 2022).

Fellowships Awarded by the National Institutes of Health from 1948 to 1970 to collect information on all NIH grants over this period, complementing the CMR record.

2.1 Categorizing CMR contracts, publications, and other sources

We use the National Library of Medicine's (NLM) Medical Text Indexer (MTI) to map these data to a common domain: NLM's Medical Subject Headings (MeSH) vocabulary, which gives structure to biomedical research space. The MeSH vocabulary was developed as part of MEDLINE, NLM's database of biomedical journals, and consists of descriptors used to index MEDLINE articles for searching and retrieval. There were 29,915 unique MeSH descriptors ("MeSH terms") at our time of use (2021-2022).[12] MeSH has an accompanying hierarchical structure, and the underlying "MeSH space" is organized into 16 broad classes (Appendix Figure A.4 provides a list), each with subclasses, which have further subclasses, and so on.[13] For example, the "Diseases" branch (letter C) begins with Infections (C01), which in turn contains infections at various levels of specificity; each node in this tree we will refer to as a MeSH code (e.g., C01.221.250: Blood-Borne Infections). Individual MeSH terms can exist at multiple locations in the MeSH tree (e.g., "Blood" is listed under both Body Fluids and Hemic and Immune Systems)—a feature which shapes our preference for MeSH terms (which are unique) rather than codes as our unit of analysis.

MTI is a language processing tool that maps input text to MeSH terms and is used by NLM to provide initial indexing of MEDLINE articles based on titles and abstracts. It can also be used to categorize arbitrary biomedical text (NLM 2022). It does so in several ways, including (i) taking the words in provided text and finding similar concepts in NLM's UMLS Metathesaurus, then finding the closest MeSH headings, and (ii) by finding similar PubMed articles and extracting their MeSH terms (Mork et al. 2013). It also returns scores indicating confidence in each match. Prior research has used MTI in other applications, including to measure the breadth of scientific articles (Kolev et al. 2020) or determine the gender focus of patents (Koning et al. 2021). Here we use it to identify the subjects of contracts, grants, publications, and medical texts.

In practice, MTI requires choices over what input text to use, how to map text to terms, how to use confidence scores, and how to aggregate up to MeSH subjects or subject-years. Where possible, we use all available text: we index MAG publications on their titles, CMR contracts on their titles and abstracts, NIH grants on their titles, and medical textbooks on index entries. In using these data, we normalize the returned MeSH term confidence scores for each publication to sum to one,

[12] The MeSH vocabulary is continuously revised and updated as new terms appear in the scientific literature.

[13] The MeSH tree is conceptually similar to hierarchical patent classification schemes such as the Cooperative Patent Classification (CPC), with top-level (lettered) MeSH codes conceptually analogous to top-level CPC sections, three-character MeSH codes (e.g., A01) analogous to CPC classes, and so on.

and drop all terms with a score below 10% to reduce noise.[14] Our analysis will at times make use of score-weighted totals at the MeSH term or term-year level, and at times binary indicators (e.g., of whether a particular MeSH term was a focus of CMR research).

For drugs we take a different approach, partly because we have less raw text to feed into MTI, and our preliminary probes indicated that MTI does not reliably return descriptors from drug names, active ingredients, or even drug categories as inputs. We instead create a manual crosswalk between de Haen (1976) drug categories and 12-digit MeSH codes on the *pharmacologic action* branch of the MeSH tree. We can then perform analysis at the level of these codes or their associated descriptors. We discuss this drug-MeSH linkage in more detail in Appendix A.

2.2 Characteristics of the CMR shock

Table 1 describes the shape of CMR's research investment, showing the distribution of contracts, contractors, and research funding across CMR divisions. Two patterns stand out: one is the (relatively) even distribution of contracts and funding across divisions and the myriad problems they were solving. The other is the shockingly low total cost of the program, at roughly $21 million in the 1940s—equivalent to $400 million in 2024, or less than 1% of the current NIH research budget. The table also contextualizes CMR research in MeSH space, documenting the most common MeSH terms in each division: *Syphilis* (Medicine), *Burns* (Surgery), *Oxygen* (Aviation Medicine), *Shock* (Physiology), *DDT* (Chemistry), and *Antimalarials* (Malaria). The most common MeSH term across the CMR portfolio is *Penicillins*. Figure 2 extends the last row of this table, showing the top 10 MeSH terms for each of these divisions, by term share of division contracts. The results reveal a fuller list of focal subjects of CMR research, while also providing a check on the face validity of the MTI approach to categorizing contracts and publications.

[Table 1 and Figure 2 about here]

The raw data suggest that despite the specificity of the wartime problems CMR targeted, research it funded may have been more broadly impactful. One such indication is visible in publication counts alone. Appendix Table B.1 lists the top five MeSH terms entering the publication record (based on titles in the complete MAG corpus) each year from 1939 to 1946. For each term, we also report the number of associated publications over the next 10 years and indicate whether it was a focus of CMR research. New treatments and therapies that CMR cultivated were immensely more likely to be the most heavily studied new topics of this period.

[14] We also drop check tags (MeSH descriptors that specify species, sex, or age, such as "Humans"), and supplementary concepts (terms outside of the MeSH thesaurus, many of which are chemical formulae).

Other evidence comes from comparing CMR-funded research to contemporary work in the same subjects. In Table 2 we estimate differences in the characteristics of CMR and non-CMR publications, conditional on subject-year (i.e., cohort) fixed effects.[15] Column (1) finds that CMR-funded publications are significantly more likely to introduce new MeSH term combinations (novelty), with the difference an approximate 10% increase on the mean rate. Columns (2) to (5) show that CMR publications were also impactful, roughly twice as likely to be in the top 10% cited publications in their cohort and over three times as likely to be in the top 1%.

[Table 2 about here]

3 Empirical Approach

Most of our analysis will compare outcomes over time in biomedical research subjects, drug categories, or patent classes with higher or lower CMR investment, or between firms which participated in CMR research and others. Our baseline estimating equation is as follows, where m and t index MeSH terms and years and the sample runs from 1930 to 1970:

$$Y_{mt} = \sum_t \beta_t \cdot \mathbb{1}(\text{Any CMR contracts})_m \cdot \text{Year}_t + \alpha_m + \delta_t + \varepsilon_{mt} \tag{1}$$

Elsewhere we estimate similar specifications over different units (e.g., firms instead of MeSH terms), with otherwise similar structure, and covering the same period (or as much of it as our data permit). In each case we cluster standard errors by the panel unit.

Our dependent variables vary across analyses. Where we study CMR's relationship to postwar science (Section 4), we measure publications by subject and year, as well as derivative outcomes such as unique publishing authors. Where we study its relationship to postwar drug innovation, we measure new drug development by category and by firm (Section 5), and we measure drug-related patenting by firms (Section 6.1). Where we study its relationship to clinical knowledge (Section 6.3), we measure subjects' coverage in medical reference books.

In most of this analysis, our preferred treatment measure will be an indicator of whether a MeSH term (or drug category, firm, etc.) was the subject of any CMR contracts. This choice is a product of two subsidiary choices: whether to measure inputs (CMR contracts) versus outputs (e.g., CMR-funded publications), and whether to do so on the extensive versus intensive margin. We prioritize

[15] Concretely, we estimate the following specification: $Y_i = \beta \cdot \mathbb{1}(\text{CMR-funded})_i + \delta_{st} + \varepsilon_i$, where i indexes publications, δ_{st} are subject-year fixed effects, and standard errors are clustered by subject and year. For the purposes of these tests, publications' primary subjects are measured as their top MTI-scoring subject.

inputs over outputs, mainly because some CMR research may not lend itself to specific measurable outputs (e.g., clinical testing), or may not have paid off directly during the war but may have done so in indirect ways afterwards. We prefer the extensive to intensive margin for two reasons. The first is the potentially wide variation in the cost of research across subject areas (e.g., bench science versus drug trials), which is difficult to adjust for. Second is that in a few areas (e.g., in natural penicillin), CMR primarily provided coordination rather than funding, and these contracts had only nominal legal consideration. This latter observation applies more broadly: CMR was both a research management organization and financier. For these reasons, the extensive margin will be more meaningful than the intensive margin in this setting.

Identification and interpretation

A first question is whether the results of our analysis can be interpreted as causal. Though World War II produced the first significant U.S. government funding for medical research, this fact alone does not clarify whether it is responsible for the patterns we find or what would have happened in its absence. If the CMR effort supported research in subjects which were either (i) already growing or (ii) imminently about to, or if these areas grew for other reasons, causal interpretations would likely be undermined. To what degree was CMR independent of other changes potentially driving midcentury progress in science, technology, and clinical practice?

Formally, our identifying assumption is that CMR investments were not correlated with unobserved determinants of the outcomes we study. Although we will not be able to make a fully dispositive case for this assumption, a substantial amount of evidence is consistent with it. However, we will first rule out a seemingly plausible defense: an intuitive argument for independence is that military medical needs were exogenously different than the problems research activity would have otherwise concentrated around absent the war. Contemporary accounts suggest this is true in part, but not in full: in the opening sentence to the official history of CMR, Andrus (1948, p. 3) observes that "War [both] augments certain problems already existent in civilian life and engenders new ones." Intuitively, problems like aviation medicine or traumatic injury may be particularly acute in a war, but in other areas, civilian and military medicine can coincide—most prominently in preventing and treating common infectious diseases. The potential distinctiveness of military medical problems alone is thus, in our view, not enough to claim independence.

The supportive evidence instead takes other, primarily empirical forms. The first is via pre-trends, testing whether treated units were already on differential growth trends: where our data span the prewar to postwar period, we will regularly find that CMR-supported subjects and firms were not on differential trends prior to the war. In our evaluation of CMR's relationship to postwar science,

this was the case for emerging, "embryonic" subjects, which are the focus of our analysis; for other outcomes, it is the case broadly. The absence of pre-trends thus suggests that CMR was not simply riding existing growth trajectories, ruling out one potential confound.

Although we cannot fully rule out that CMR pursued subjects which were on the precipice of new breakthroughs that might have occurred anyway—an impossible claim to prove—a few historical observations challenge this possibility. One is that CMR's pursuit of multiple, parallel approaches in many of its research programs, and its mix of successes and failures, suggests against predictability: if success were predictable, the war effort would have been much more focused and successful. Even if CMR prioritized areas where breakthroughs were conceivable in 1940, this does not imply they were imminent: penicillin was long known to have therapeutic potential, yet at the time no firm was making it, and there was no known way to produce it in large enough quantities for research, let alone clinical use. The risk that CMR is confounded by support from other funders with similar priorities also appears low: though foundations such as Rockefeller were the main source of prewar university medical research funding, they were too small and concentrated to support science at CMR's scale, let alone catalyze research ecosystems as CMR did.[16]

History conveniently offers the opportunity to test whether CMR was supporting research subjects which may have grown anyway by other means. In 1935, NIH announced plans for "a program of attack on disease along some 70 lines" of research, using a then-windfall of $1 million (5% of CMR's future budget) authorized by Congress under the umbrella of social security legislation (Science Service 1935)—funds which Congress ultimately never appropriated. NIH's press release at the time described the specific research problems which it intended to prioritize, where research had allegedly been on hold due to a lack of funds, including conditions as varied as cancer, heart disease, leprosy, and Rocky Mountain spotted fever (Minneapolis Journal 1935)—diseases for which there was ostensibly either scientific and technological opportunity or high need (or both). These problems bore extremely little overlap with CMR's research priorities a few years later. Systematic comparisons reinforce this view: when we map diseases in the 1935 NIH priority list to MeSH terms and evaluate their similarity to the disease areas CMR supported, we find that they are significantly *negatively* correlated; that is, CMR priorities were inverse to those which were considered important problems of that era and in turn priorities for public investment.

[16]The Rockefeller Foundation in particular is of singular interest, as it was the largest benefactor of natural sciences research prior to the war, and in the mid-1930s accounted for over 70% of foundation funding in the natural sciences (Geiger 1986). Though Rockefeller began supporting experimental biology in the 1930s, and much of what it funded is thought to have been impactful, Geiger reports that in 1938 (at its peak), the foundation funded only 22 project grants in the natural sciences, at a total of roughly $22 million (2024 dollars), and primarily at the most established research universities of the time (see Geiger 1986, pp. 39, 165-166). By comparison, CMR contracted with nearly 70 universities (in addition to many firms)—and funded 20x as much R&D over the war.

The identification discussion thus far has emphasized CMR's independence of trends, opportunity, and civilian need. Despite the affirming evidence, attributing effects we find to CMR alone could still be challenging for three additional reasons. First, the CMR shock (a supply shock) coincided with war-driven demand for specific types of innovation, which could produce similar effects (e.g., Clemens and Rogers 2023 show that prior U.S. wars attracted private R&D in prosthetic devices). Second, civilian demand may have concurrently attracted private investments in the same science and technology CMR supported. Third, NIH's postwar expansion may have correlated (in research space) with CMR's portfolio and influenced the same outcomes.[17]

We perform formal tests of the first possibility, evaluating research trajectories in World War I, which presented a similar military demand shock without comparable directed funding for military medical research, and do not find comparable effects. Civilian demand is also unlikely to explain our results, especially for academic science—where there is no salable product, and no price signal through which demand would pull research—but also for pharmaceutical innovation, where civilian demand for infectious disease treatments like antibiotics was already high and to our knowledge did not change in the 1940s.[18] To account for the third possibility, we control for postwar NIH funding in a subset of our analysis and find our results unchanged.

The collective evidence is thus suggestive that CMR can be interpreted causally. This is particularly the case as we explore structural changes in biomedicine: CMR's emphasis on not only research but also drug development, clinical trials, and production techniques, and its role in building more connective tissue between them, made it a more likely catalyst for the range of changes we find than any other source would. The results should nevertheless be interpreted cautiously, recognizing that the case for identification is only suggestive, not dispositive.

4 Growth of Biomedical Science

Our analysis of CMR's effects begins by examining its impacts on science. As Section 1 discussed, wartime medical research had several thrusts, including research efforts in antibiotics, antimalarials, synthetic hormones, and vaccines; new techniques and understanding for blood, blood preservation, and blood substitutes; physiological challenges the war presented (like human performance at high altitudes or in extreme temperatures); and more. Appendix Figure B.1 illustrates raw publication patterns in several related subjects from the pre- to postwar period. Consistent with Stewart (1948,

[17] Another possibility is that the 1950s Korean War extended the CMR shock. Though we lack comparable measures of 1950s military medical research investments, these were almost certainly lower and far narrower in scope than in World War II, due to the Korean War being a smaller, single-front war and to the successes in World War II, which solved the military's infectious disease problem (see Online Supplement A).

[18] Though U.S. medical insurance began to diffuse in the 1940s (Alsan and Neberai 2026), prescription drug coverage was effectively non-existent and did not become widespread until many decades later.

p. 102)'s observation that "some subjects are born of war," we find that many of these research areas had little pre-war publication activity but took off after the war ended (e.g., *Anti-bacterial Agents*, *Steroids*, and *Blood Proteins*). Other subjects had some pre-war research activity but grew significantly after the CMR shock (e.g., *Oxygen*), and yet others temporarily spiked during the war but did not sustain afterwards (e.g., *Antimalarials*). Relative to the overall scale of biomedical science, however, CMR itself was small, supporting ∼2,500 publications out of nearly 400,000 global publications in our data in the 1940s (200,000 at U.S. publishers).

Not shown in Appendix Figure B.1 are the thousands of other subjects outside of CMR's scope. In this section, we systematically compare publications over time in subjects with and without CMR investment, estimating Equation (1) at the MeSH term x year level. The focal parameter (β_t in Eq. 1) represents annual differences between CMR-supported subjects versus others, which in figures will be estimated relative to 1940 (the omitted category); tables will present parameters in 5-year intervals (for parsimony), estimated relative to the 1930-1934 period.

Our main dependent variable will measure the inverse hyperbolic sine (IHS) of *MTI score-weighted* publications in a given MeSH term, which due to the MTI weights is continuous rather than discrete. In robustness tests we estimate log outcomes and count models, which return directionally similar results.[19] Although author affiliations and locations are not consistently available for our period, to try to isolate the analysis to U.S. science specifically, we limit our measurement to articles in U.S. journals.[20] Additional analysis evaluates the number of unique authors publishing in a given MeSH term (using MAG identifiers) and the number of new combinations created with other MeSH terms, as a measure of recombinant science. Whereas publications reflect the level of research activity in a subject, new combinations measure an expansion in its scope.

4.1 Baseline effects

Figure 3 presents our initial results, displaying the β_t estimates from Equation (1) for publication output, with 95% confidence intervals. Panel (A) estimates effects across established subjects (with above-median pre-war publications), finding that CMR-supported subjects in this set were growing modestly before the war and continued growing during it, peaking in the 1950s before contracting. Panel (B) reproduces this analysis for embryonic subjects (with below-median pre-war publications), which were stagnant prior to the war, grew quickly during it, and remained high

[19] IHS-transformed outcomes approximate logged values but are defined at zero, and in many settings support interpreting parameters as semi-elasticities. We present IHS-based results in the paper in part for their flexibility and ease of interpretation (where each parameter can be interpreted without applying an exponential transformation), and in part because count model estimators (like PPML) can be sensitive to large-valued units (i.e., large subjects), where the variation is closer to continuous than discrete—variation which is common in our data. Results are also quantitatively similar when estimated for unweighted publication counts.

[20] Publications in U.S. journals comprise 35-55% of the sample in any given year.

thereafter: these emerging subjects were by 1950 generating roughly 50% more publications per year by 1950 than before the war, and these effects largely sustain through 1970. This initial set of results adds to Figure 1 in suggesting that World War II marked an inflection point in biomedical science, as not only did total research volume take off (Appendix Figure 1), but new, CMR-borne subjects grew rapidly whereas old subjects stalled or declined.

[Figure 3 about here]

The finding we especially wish to emphasize is that for embryonic subjects (Panel B), where postwar changes were largest, and where the absence of pre-trends is particularly evocative of a seemingly causal CMR effect. Appendices B.2 to B.6 provide a battery of robustness checks on this result. Appendix B.2 re-estimates Equation (1) for log publications and counts; results for log publications are nearly identical to those for IHS publications (with slightly wider confidence bands, but remaining significant at conventional levels), and more accentuated for count model, with a larger 1940s spike and greater post-1960 attenuation, but presenting qualitatively similar patterns. In Appendix B.3, we estimate a variant of Equation (1) using intensive treatment measures—grouping subjects into quantiles of CMR funding—and find that effects concentrate in the most heavily-funded subjects. In Appendix B.4 we re-estimate Equation (1) against a propensity-matched control group, which conditions the comparisons to subjects on the same branch of the MeSH tree, with a similar number of pre-1940 publications, and on similar pre-1940 growth trends; we continue to find similar patterns. Appendix B.5 re-estimates Equation (1) controlling for whether a given subject was funded by the postwar NIH (between 1948 and 1970), and we find these results unchanged—suggesting the CMR effect is distinct from any effect of the postwar NIH.

Finally, in Appendix B.6 we probe the possibility that the "CMR shock" may represent a more general war shock. Though absent a research funder, there is no price signal for public science that would attract new scientific investments directly, war might nevertheless have a demand-pull effect if it brings scientific attention and activity to new subjects (even without CMR-style funding or coordination). As a placebo test, we collected analogous data around World War I (WWI), including digitizing contemporary lists of WWI medical problems, and estimate Equation (1) around WWI in relation to these subjects. We find little evidence of a generic effect of war on science. Finally, in additional tests we reproduce our analysis on a sample 12-digit MeSH codes (rather than MeSH terms), with quantitatively and statistically similar results. MeSH code-based results also remain similar when we cluster standard errors at higher levels of the MeSH tree to account for potential interdependence in error structures across related subjects.

4.2 Expansion of the field

A corollary question to the results in Figure 3 is to what degree this increased scientific output is attributable to entry versus enhanced productivity. We explore these questions in Table 3. As a reference point, Column (1) of the table reproduces Figure 3's result with these periodic parameters. In Column (2), we evaluate differences in the number of unique authors who published in a given subject and year (conditional on $\geq$1 publication in the subject-year). The results indicate substantial postwar entry into CMR-treated subjects. Columns (3) to (5) probe this result further, evaluating to what degree publication growth is driven by old or new authors: Column (3) examines the growth of publications which had only prewar authors (defined as authors with at least one prewar publication); Column (4), publications with any prewar author; and Column (5), publications with any postwar author.[21] The evidence indicates that the growth seen in Figure 3 (and Column 1) is heavily driven by an expansion of the field, in the form of new authors, and publications with at least one author who entered post-1940.

[Table 3 about here]

Column (6) of the table provides one further perspective on this growth, re-estimating Equation (1) for introduction of new MeSH combinations, defined as MeSH term pairs observed for the first time in our data in a given year. This outcome does not mechanically rise as publications do, as research will often study the same subjects (or bundles of subjects) as prior literature. It instead captures the tendency for researchers to expand the scope of inquiry around a given subject. Column (6) indicates that during and for the first decade after the war, research in CMR subjects differentially expanded in new combinatoric directions.[22] That the estimates are statistically insignificant in later years should be read as evidence of a short-lived increase in the rate of introduction of new combinations, but not a short-lived increase in the stock, as previously-introduced combinations are by this time established and by definition no longer new.

5 The Postwar Pharmaceutical Industry

Given the relatively primitive condition of the pre-war pharmaceutical industry, the possibility that the war would have any impacts on pharmaceutical innovation—let alone that CMR's efforts might succeed during the war itself—is far from straightforward.[23] Despite this, the first two post-

[21] In doing so we extend the omitted category to 1939, as there is no pre-1940 variation in the outcome.

[22] Appendix C.2 provides specific examples of this type of expansion, from narrative historical accounts.

[23] The U.S. pharmaceutical industry in the early 20th century was primitive and disorganized by modern standards: most drug manufacturers were chemical companies with incidental or subsidiary pharmaceutical businesses, and drug discovery was driven more by serendipity or trial-and-error empiricism than by science. Perhaps as a result, as Figure 1 shows, annual drug-related patenting grew only meagerly pre-1940.

war decades produced an immediate and sustained take-off in U.S. pharmaceutical innovation, in what is now seen as a "golden age" of drug discovery. Postwar progress was powered by growing use of synthetic chemistry, rational drug design, and systematic drug screens, and by the 1960s the U.S. pharmaceutical industry already looked much more similar to its current state than its pre-war condition. Several scholars have attributed these changes to wartime research in historical analysis: Landau et al. (1999, p. 63), for example, claims that "To a great extent the U.S. government's wartime policies led to the emergence of the American pharmaceutical industry as the undisputed worldwide leader," observing that "the federal war effort encouraged corporate research and development, widened and deepened the companies' cooperation with academic institutions, and catalyzed the diffusion of new technologies across the industry."[24]

Perhaps no single firm exemplifies these changes better than Pfizer. Founded in 1849 by two German emigres, Pfizer was for most of its first 100 years a fine chemical manufacturer and commodity chemical supplier whose keystone product by the 1930s was citric acid, which it produced at scale through fermentation. Despite its lack of experience in drug development, Pfizer was brought into the wartime penicillin project for its expertise in fermentation, which was needed to produce natural penicillin from the *Penicillium notatum* mold at scale. Its success led it to become the U.S. Army's biggest penicillin supplier, and after the war ended, Pfizer pivoted around this experience and new R&D capability and entered the pharmaceutical industry, focusing first on developing a wider range of antibiotics and later expanding its R&D portfolio to other drug categories. As it did so, it grew increasingly scientifically oriented, employing a large staff of biologists, mycologists, and later organic chemists and developing consulting relationships with leading academic scientists, and soon became a leading drug developer (Daemmrich 2009).

To make systematic comparisons in relation to CMR, we harness the de Haen (1976) list of new drugs introduced between 1940 and 1975, which we manually link to 12-digit MeSH codes under the *therapeutic use* or *physiological effects* sub-branches of the *pharmacologic action* branch of the MeSH tree, and then through these links we retrieve associated MeSH terms. We use this crosswalk to produce a count of annual new drugs associated with individual MeSH terms. Our analysis will examine changes in the rate of aggregate drug development across MeSH terms, comparing those which were a target of CMR-funded research vs. others. We then extend this analysis to the firm level, comparing the rate of new drug introductions by pharmaceutical firms (defined as firms in the De Haen sample) which were CMR contractors against those that were not. Here we will expand our treated set to include firms which were engaged in penicillin production under contract with WPB, most (but not all) of which were CMR contractors as well.

[24] Also see, e.g., Temin (1979), Cockburn et al. (1999), and Pisano (2002).

We continue using the same specification as in our analysis of CMR's effects on science, estimating time-varying differences across subjects or firms with vs. without CMR suport (Equation 1). Table 4 presents the results, estimating five-year (rather than annual) parameters, following the format of Table 3. Our estimation sample in this case runs from 1940 (when the De Haen drug statistics begin) to 1970, with 1940-1945 the omitted category. That the sample begins during the war is a constraint of the data, but insofar as there may be a CMR effect, defining the early 1940s as the reference period will generally only attenuate postwar differences.

[Table 4 about here]

We first report estimates from our term-level analysis in Panel (A), where the unit of observation is a term-year. We estimate the impact of CMR on (i) the likelihood of any new drug introductions related to a given MeSH term in a given year, (ii) the number of new drugs, and (iii) the IHS number of new drugs. Even-numbered columns exclude anti-infectives, as a test of whether antibiotic drugs were responsible for any overall effects. We do not find an effect of CMR on the extensive margin (Columns 1 and 2), in part because many of the areas CMR emphasized already had relatively high propensity to produce at least one related drug per year in the aggregate. However, we find large effects on the intensive margin (Columns 3 to 6), with CMR-supported areas producing on average 1-2 more new drugs per year in the 1950s than others, and with similar-magnitude effects across both anti-infective drugs and other drug categories.[25]

Table 4, Panel (B) reproduces this analysis at the firm level, with similar (if not stronger) patterns. Relative to other drug-producing firms, CMR contractors produced a differentially-large surge of new drugs over the next two decades. At its peak, these firms were an extra 25 p.p. more likely to introduce at least one new drug per year than other firms, and on average introduced one more new drug per year—in both cases doubling or tripling mean rates. As with total drug innovation (Panel A), these differences are largest during the pharmaceutical industry's golden age in the 1950s and early 1960s, and cannot be attributed solely to antibiotics.[26]

[25] These differences are visible in the raw data (e.g., in binned scatterplots). We estimate count outcomes (Columns 3 and 4) by OLS in part to simplify interpretation of average cross-firm differences in drug counts, and in part because count models (including Poisson models) suffer from an incidental parameters problem with two-way fixed effects, due to the limited number of subjects in the sample: Table 4(A) includes 46 MeSH terms, only 25 of which have at least one associated drug in our data and would thus enter a PPML estimation sample.

[26] That the magnitudes of the effects in Panel (A) are larger than those of Panel (B) on the intensive margin (# of new drugs), and smaller on the extensive margin (1(Any new drugs)), reflects the different level of aggregation, where MeSH terms are generally more aggregated than firms are, and therefore likely to produce larger magnitudes on the intensive margin and exhibit lower variation on the extensive margin.

Product and process innovation in biologic drugs

Beyond developing new drugs, the war effort also supported R&D in new ways of producing them—especially natural drugs and vaccines manufactured through industrial-scale fermentation—which according to some narrative accounts became a sustained new approach to drug innovation. To evaluate such changes in drug development itself, we shift our analysis to drug-related patents, focusing on patents filed between 1930 and 1970 by firms in the De Haen sample (see Section 2). We particularly direct our attention to fermentation process patents, identified as patents in CPC subclass C12P ("Fermentation or enzyme-using processes to synthesize a desired chemical compound"), and patents related to biologically-produced drugs, identified using CPC subgroup Y10S 435/82 and its subsidiaries ("Subcellular parts of microorganisms", which encompasses bacterial and fungal cultures from which these drugs are produced). We estimate a similar regression to that in Table 3, evaluating differential growth over time in fermentation patenting and biologically-manufactured drug patenting by CMR/WPB contractors versus other firms.

[Table 5 about here]

The table estimates three variants of each outcome at the firm-year level, measuring an indicator for (i) any patent (Columns 1 and 2), (ii) the number of patents (Columns 3 and 4), and (iii) IHS patents (Columns 5 and 6), in all cases estimated by OLS to evaluate average differences between CMR firms and others. Results for fermentation process patenting are provided in the odd-numbered columns, and for biological drug patents in the even numbered columns. The evidence indicates that in the 1950s and 1960s, firms which participated in the war effort disproportionately increased biological and fermentation-related drug patenting, filing patents in these classes at a roughly 60% higher rate by 1960, with no evidence of differential pretrends.

6 The Scientific Roots of Accelerated Progress

6.1 The high-tech economy: Growth of science-based innovation

A different, distinguishing feature of CMR-led drug development was its use of science. Penicillin production, for example, used science in identifying productive mold strains and their optimal growing conditions, and linked science with both engineering and manufacturing in designing and running industrial-scale fermentation systems. The effort to synthesize and test thousands of potential antimalarial drugs was shaped by basic understanding (and fundamental studies) of Plasmodium parasites and quinoline biochemistry, in an early application of rational drug design, which was pursued in tandem with conventional empirical trial-and-error.

Whether this pattern continued after the war is a testable, empirical question. The De Haen list of new drugs does not provide information on the underlying discovery process and its connections to science. We instead return to drug-related patents by firms in the De Haen sample, assessing their use of science via in-text citations to scientific literature.[27] Figure 4(A) suggests that very little pre-war drug innovation was linked to science, but World War II marked a structural change in the industry's use of science, which subsequently grew rapidly.

[Figure 4 about here]

These patterns are consistent with known changes in R&D practices, such as the growing application of rational drug design anchored in physical, chemical, and biological understanding. Our question is to what degree these changes could be causally connected to the CMR effort in World War II. To evaluate this question we disaggregate the sample into CMR/WPB contractors vs. other firms and compare across them. Figure 4, Panel (B) shows the average, annual likelihood of filing any non-science versus science-citing drug patents—an indicator that a firm is engaged in science-based drug development—in five-year bins, first for non-CMR firms (left half) and then for CMR firms (right half). The raw data suggest these changes were driven by CMR/WPB firms. We formalize these comparisons in Panel (B), which estimates a triple-difference regression, comparing (i) science vs. non-science based patenting by (ii) CMR/WPB-contracted firms vs. other firms (iii) before vs. after the war. The estimating equation takes the following form:

$$Y_{ist} = \sum_{t=1931}^{1970} \beta_t \cdot \mathbb{1}(\text{CMR/WPB firm})_i \cdot \mathbb{1}(\text{Science-based})_s + \alpha_{is} + \delta_t + \varepsilon_{it} \tag{2}$$

where i, s, and t index firms, science- vs. non-science based innovation, and years, and the sample runs from 1930 to 1970, with standard errors clustered by firm. The unit of analysis is a firm-year-invention type, and the outcome (Y_{ist}) measures patenting by firm i in year t that is or is not based in science ($s \in \{0, 1\}$). Because patenting was a low frequency event (the firms in our sample have an average of 1.3 drug-related patents per year, and 0.3 science-citing drug patents),

[27] "In-text" citations are references which appear in the patent disclosure. Bryan et al. (2020) argue that in-text citations may be a better measure of an invention's knowledge inputs than "front-page" citations to non-patent literature (NPL), whose legal purpose is identifying prior art against which claims are evaluated. More pragmatically, NPL citations only began to be included in patents beginning in February 1947, which coincides with the end of the war. In-text citations, on the other hand, date to the establishment of the modern Patent Office in 1836 and can thus be observed both before and after World War II. However, classifying citations as in-text or NPL is difficult for historical patents, where citations have to be extracted from unstructured, digitized text (in contrast to modern patents with structured files), and on manual review we have noticed several miscategorized examples. We therefore refine the Marx-Fuegi PCS data for use in this paper by removing likely false-positive in-text citations, which we identify by their location in the patent. See Appendix A for details.

our preferred specification evaluates whether a firm had any science-based patents in a given year; in Appendix B.7 we also examine patent intensity. In short, Figure 4(C) shows CMR/WPB firms were significantly more likely to generate science-based inventions after World War II, relative to non-science based invention, with no differential pre-war trends.

A striking difference between this result and those seen in Table 4 is how long they persist: whereas differences in new drug introductions in CMR-supported areas dissipated by the late 1960s (Table 4), differences in the use of science and new production methods persisted (Table 5 and Figure 4). This evidence is consistent with a structural, long-run change in the U.S. pharmaceutical industry with respect to how drugs were discovered, developed, and made, which continued even after the antibiotic revolution (and broader "golden age" of drug discovery) subsided. It is partly through these mechanisms that CMR may have had long-run aggregate impacts—through what Griliches (1957, p. 502) termed "the invention of a method of inventing."

Broader impacts on U.S. technological innovation

The impacts of CMR research may have extended beyond the pharmaceutical sector specifically to U.S. technological innovation more broadly. To evaluate this possibility, in Appendix B.9 we study changes in U.S. patenting over time across technology areas (CPC subclasses) with differential exposure to CMR research, which we measure based on the (MTI-indexed) research subjects of cited biomedical publications and their relation to CMR research. As constructed, CPCs whose patents cite CMR-supported subjects as a higher share of all cited subjects are measured as more CMR-exposed. For parsimonious comparisons, we divide the sample into above- and below-median exposure CPCs and estimate differential changes in patenting across them.

Appendix Table B.5 evaluates differences in more vs. less exposed CPCs over time in total associated patents by U.S. inventors, firm patents, and non-firm patents, first across all CPCs in the sample, and then for those in the Chemistry (C) branch of the CPC classification. We find evidence of a long-run, differential ∼20% increase in patenting in CPCs which were more exposed to CMR research, specifically driven by firm patenting. Within the Chemistry branch specifically, we find much larger differences, which begin to emerge during the war years, become statistically significant at conventional levels by the late 1940s, and continue growing through the 1960s. Though the results should be interpreted cautiously, for reasons we discuss in the appendix, they are suggestive of a broader imprint of CMR-funded science on U.S. innovation.

6.2 Impacts on U.S. vs. global science and technology

Thus far, our analysis of the postwar pharmaceutical industry has evaluated the De Haen sample globally—where roughly one third of listed drugs were developed by firms in non-U.S. countries. However, CMR primarily engaged U.S. firms (or in select cases, U.S. subsidiaries of foreign firms), raising the question of whether the postwar acceleration of drug development was a U.S. or global phenomenon—i.e., whether the gains spilled over to other countries.

We probe global spillovers in Appendix B.8. As a starting point, we expand our earlier analysis of U.S. science (in Section 4) to evaluate changes in foreign science, using publisher countries as a proxy for locations, as author locations are not consistently available for our study period. As in Section 4, we compare postwar changes in research output in CMR-supported versus other subjects, focusing the analysis to embryonic research areas. Appendix Figure B.8 presents results for the five countries with the most postwar biomedical publications in our data: the U.S. (as a reference point), Germany, Japan, the Netherlands, and Switzerland. We find positive effects on scientific output in all cases, with the largest and swiftest impacts on U.S. science. Though the results must be qualified by the recognition that journal countries are not equivalent to author countries, the results suggest that CMR's effects on science spilled out broadly.

We then evaluate U.S. versus European drug innovation, where we find sharply different patterns: as Appendix Figure B.9 shows, the postwar surge in new drug discovery was specific to U.S. drug companies (and among U.S. drug companies, to CMR/WPB firms). Similarly, the increase in patent linkages to science was specific to U.S. firms, and within these firms, to their patents developed in the U.S., as Appendix Figure B.10 demonstrates—even as many of these firms had R&D in several European countries. The CMR effect on innovation thus appears to have been a distinctly American phenomenon, and the 1940s marked the beginning of a pulling away of the U.S. pharmaceutical industry from its global competition—even as science globalized.

We view this evidence as having first-order relevance to understanding the domestic returns to public R&D. A substantial literature has argued that science flows relatively freely across borders, but whether technological capabilities and science-based technologies are as mobile is not a resolved question. On the one hand, research has shown that technological innovation can diffuse through information channels, including through patent documents themselves (e.g., Furman et al. 2021); on the other, substantial research has argued that imitating or implementing innovation developed elsewhere may require substantial complementary assets (such as tacit knowledge) that are harder to acquire or reproduce (e.g., Teece 1986)—and which in the case of CMR/WPB firms appears to have been developed in the course of their wartime work. CMR's integrated R&D model, in this

case, would seem to have helped create a platform off of which biomedical science and technology could co-develop and be put into postwar practice by U.S. firms.

6.3 Advances in medical practice and health

The most significant potential impact of wartime research was improving human health. Appendix C.1 provides suggestive evidence of its short-run effects on military morbidity and mortality, with hospitalizations and deaths from many common infectious diseases declining to near zero. This progress held large potential for postwar civilian health as well.

A crucial intermediate step for the adoption of new knowledge, techniques, and therapies in health care is getting frontier research findings to medical professionals (Phelps 1992, 2000). Historically, medical textbooks were used in both training and clinical practice (Greene 2007, Catillon 2017, Tomes 2021), especially before the academic publishing industry began to grow in the late 1960s and practitioner journals became more widely available. We therefore use historical textbook series to study the diffusion of CMR research into practice. As we described in Section 2, we digitized two textbook series that were published both before and after World War II: the *Cecil Textbook of Medicine* (CT) and the *Merck Manual of Diagnosis and Therapy* (MM). We obtained copies of each edition with an index between 1930 and ca. 1960 (comprising nine editions of CT spanning 1930-1959, and four editions of MM spanning 1940-1961), digitized each index, and mapped index entries to MeSH using MTI. For each MeSH term, we measure associated pages in each edition to assess coverage. Merging these data with MeSH term-level measures of the CMR shock, we use the specification in Equation (1) to estimate the differential growth of CMR-funded subjects' coverage in medical textbooks and manuals before versus after the war.

Figure 5 presents results for CT (Panel A), where our earliest edition is in 1930, and for MM (Panel B), where our earliest edition is in 1940. We find that textbook coverage of CMR-funded subjects grew significantly in the postwar period, despite no differential pre-war growth, though it also took several years to realize these impacts. Although these subjects were slow to expand in the late 1940s, by the early 1950s their coverage had grown 20-30% more than other subjects in CT and 10-20% more in MM. To our knowledge, this is the first empirical evidence of publicly-funded medical research entering the knowledge base of medical practice—offering a lens into how information about frontier research historically diffused to practitioners and the delayed horizons over which it reaches practitioners. In the context of this paper, it also illustrates a pathway beyond the discovery of new drugs through which CMR research may have affected public health (namely, through health care)—and in turn population-level outcomes.

[Figure 5 about here]

7 Discussion

The results of the prior sections document CMR's effects on science, drugs, firms, patented inventions, and medical knowledge. A natural next question is what these effects add up to for U.S. biomedicine as a whole, or for the broader economy. The question is sharpened by the contrast between CMR's scale and its apparent reach: CMR spent roughly $400 million in 2024 dollars—less than one percent of one year of the modern NIH budget—and directly produced only around 2,500 scientific publications and few patents, yet it appears to have left a durable imprint on U.S. science, pharmaceutical innovation, and medical practice. Because our research design identifies effects in relative terms, comparing supported subjects, firms, and technologies to others, it cannot recover CMR's aggregate contribution, which would require accounting for equilibrium adjustments that our approach has set aside. Here we engage this question by relating our evidence to a developing literature evaluating the macroeconomic effects of public R&D.

This literature studies the economy-wide effects of public R&D using aggregate time-series, narrative-identification, and firm-panel designs, and increasingly finds these effects to be large, persistent, and realized over long horizons. For example, Antolin-Diaz and Surico (2025) show that government spending—especially military spending—raises long-run output because it shifts the composition of public spending toward R&D, which stimulates private innovation and investment that creates long-run productivity gains. Fieldhouse and Mertens (2026a) estimate returns to nondefense government R&D of roughly 140 to 210 percent over the postwar period, attributing on the order of one-fifth of postwar growth in U.S. business-sector productivity to government-funded research.[28] Most closely related to our setting, Gazzani et al. (2026) use U.S. government-funded patents as an agency-specific indicator of government R&D to show that government-funded innovation accounts for a disproportionate share of medium-run movements in U.S. aggregate productivity and output, with particularly strong effects generated by the NIH and NSF.

Together, this work provides systematic evidence of the economic returns to public research investment, of a kind that more anecdotal accounts (e.g, Mazzucato 2018, 2021) cannot. Yet because it is based on aggregate variation, the macroeconomic literature has had difficulty isolating the mechanisms through which these returns are produced. Moreover, its emphasis is specifically on direct economic returns—typically realized through accelerated productivity growth—whereas R&D can also improve many other outcomes at the aggregate level, including population health, national security, and more, which have indirect economic consequences.

Our evidence speaks to these gaps. Where aggregate designs recover magnitudes, the CMR episode

[28] Dyèvre (2024) similarly estimates spillovers of public R&D to firm productivity that are 2-3x larger than those of private R&D (see also Fieldhouse and Mertens 2026b on the social returns to public R&D).

offers a mechanism: a well-identified case in which the path from public funding to long-run innovation can be traced in detail, from science to technology to clinical practice. As we document in Appendix C.2, CMR did not merely raise research output in the subjects it funded; it more broadly created new inputs, capabilities, and institutional relationships around which a more integrated biomedical innovation system could grow. Put differently, CMR seemingly produced durable structural changes, rather than shorter-lived, more isolated ones.

Persistence of this kind is a precondition for the effects the macroeconomic literature measures: a shock that decays leaves little lasting trace, whereas one that reconfigures the complementary inputs and institutions of an innovation system can set in motion a self-reinforcing cycle of growth. Such complementarities are the logic of "big push" theories of economic development (e.g., Rosenstein-Rodan 1943, Murphy et al. 1989), transposed here to an innovation system (Nelson and Rosenberg 1993), and they offer one interpretation of how a modest wartime program could have effects large and lasting enough to register at horizons this literature studies.

A more specific connection to this literature concerns the form that public support took. The macroeconomic evidence increasingly points to returns to public R&D varying by the specific type or source. Read together, the evidence in Gazzani et al. (2026) and Fieldhouse and Mertens (2026a) suggests that public investments in extramural basic or applied research have the largest impacts on economic growth—arguably because research is more general-purpose than development and has greater spillover potential. That the type of research this literature associates with the largest returns is the same as that which CMR embodied (and helped pioneer) in U.S. biomedicine is, in our view, unlikely to be coincidental. But at a minimum, it reflects a theme our evidence shares: the public origins of American innovation (Gazzani et al. 2026).

8 Conclusion

The high returns to medical research for human health, coupled with market failures in R&D, have led to biomedical research becoming a major focus of innovation policy in the U.S. and around the world. In this paper, we study one of the largest shocks to biomedical research in history: World War II. Recognizing that disease and other ailments presented an even larger threat to America's military than enemy forces, in the 1940s the U.S. government created the Committee on Medical Research to fund and coordinate civilian R&D into military medical problems. The wartime effort was in effect the United States' first biomedical R&D policy, marking the U.S. government's first significant extramural funding for medical research. We show that CMR-supported research led to an expansion of postwar biomedical science, a surge of postwar drug development, longer-lasting structural changes in the pharmaceutical sector, and advances in clinical knowledge in subjects

CMR supported, while also laying the groundwork for the postwar NIH. Collectively, these are the institutions which continue to drive progress in biomedicine today.

The evidence is indicative of the broad effects that public R&D can have on science, innovation, health, and through them the economy. Interpreted through the lens of existing theories of industrial development and growth, the episode shows how an integrated, applied public R&D program may do more than expand knowledge alone: by investing jointly in science, technology, and institutions that connect them, it can reconfigure a subset of an innovation system and set in motion a self-reinforcing process of growth. This is the mechanism through which a growing macroeconomic literature finds large and persistent economic returns to public R&D (e.g., Fieldhouse and Mertens 2026a, Gazzani et al. 2026); although our evidence cannot measure CMR's impacts at the same level, it suggestively points to the process by which they can arise.

Yet CMR was also distinctive, and its research portfolio does not neatly fit into the basic/applied dichotomy that typifies academic and policy understanding of the innovation process, as it spanned sectors, disciplines, and categories of R&D, and included investments in production and implementation. The evidence of broad, systemic effects may in turn be a result of CMR's integrated research model, which distinguishes it from most research policy today—in biomedicine or otherwise—and seems to have made it possible for some hard but high-value innovation to succeed.[29] The findings, in turn, have bearing for research policy in other settings, including today: the evidence from CMR not only highlights a range of historical returns from public R&D, but also suggests that integrative R&D policy models may be particularly impactful through their potential to create or stimulate new innovation ecosystems—an idea which dovetails with the operation and storied reputation of modern R&D institutions like DARPA (Bonvillian et al. 2019).

Much as CMR did, our analyses raise new questions, fundamental and applied, including on the dynamic two-directional relationship between science and technology, and on the domestic versus global returns to national R&D investments. A natural policy question is whether a research funding organization similar to CMR would yield high social returns today, in a very different context and innovation system; although CMR is but one example, we anticipate that in the coming years, an analysis similar to ours on the post-crisis impacts of Operation Warp Speed or the broader Covid-19 pandemic response may be possible as well. For now, while we cannot definitively speak to this question, our view is that the results from this paper at least support calls for more experimentation with alternative funding approaches for biomedical research (Azoulay 2012, Myers 2023), including for late-stage research and commercialization (Ouellette 2023).

[29] It is telling that despite the large, latent civilian demand for antibiotics, it took a war to turn Fleming's discovery of penicillin into a mass-produced drug. Prior research attributes this breakthrough to a level of coordination and knowledge transfer not ordinarily achieved in other contexts (Neushul 1993).

References

Agarwal, Rajshree, Seojin Kim, and Mahka Moeen. 2021. "Leveraging private enterprise: Incubation of new industries to address the public sector's mission-oriented grand challenges." *Strategy Science* **6**(4):385-411.

Andrus, Edwin C. 1948. *Advances in military medicine*. Boston: Little, Brown, and Company.

Antolin-Diaz, Juan and Paolo Surico. 2025. "The long-run effects of government spending." *American Economic Review* **115**(7):2376-2413.

Azoulay, Pierre. 2012. "Turn the scientific method on ourselves." *Nature* **484**(7392):31-32.

Azoulay, Pierre, Erica Fuchs, Anna P. Goldstein, and Michael Kearney. 2019a. "Funding breakthrough research: Promises and challenges of the 'ARPA Model'." *Innovation Policy and the Economy* **19**(1):69-96.

Azoulay, Pierre, Joshua S. Graff Zivin, Danielle Li, and Bhaven N. Sampat. 2019b. "Public R&D investments and private-sector patenting: Evidence from NIH funding rules." *Review of Economic Studies* **86**(1):117-152.

Azoulay, Pierre, Daniel P. Gross, and Bhaven N. Sampat. 2025. *Indirect Cost Recovery in U.S. Innovation Policy: History, Evidence, and Avenues for Reform*. NBER working paper no. 33627.

Balconi, Margherita, Stefano Brusoni, and Luigi Orsenigo. 2010. "In defence of the linear model: An essay." *Research Policy* **39**(1):1-13.

Baxter, James Phinney. 1946. *Scientists against time*. Boston: Little, Brown and Company.

Bloom, Nicholas, John Van Reenen, and Heidi Williams. 2019. "A toolkit of policies to promote innovation." *Journal of Economic Perspectives* **33**(3):163-84.

Bonvillian, William B, Richard Van Atta, and Patrick Windham. 2019. *The DARPA model for transformative technologies: Perspectives on the US defense advanced research projects agency*. Open Book Publishers.

Branscomb, Lewis M. 1992. "Does America need a technology policy?" *Harvard Business Review* **70**(2):24-30.

Brooks, Harvey. 1994. "The relationship between science and technology." *Research Policy* **23**(5):477-486.

Bryan, Kevin A, Yasin Ozcan, and Bhaven Sampat. 2020. "In-text patent citations: A user's guide." *Research Policy* **49**(4):103946.

Catillon, Maryaline. 2017. *Medical knowledge synthesis: A brief overview*. Working paper.

Clemens, Jeffrey and Parker Rogers. 2023. "Demand shocks, procurement policies, and the nature of medical innovation: Evidence from wartime prosthetic device patents." *Review of Economics and Statistics* pp. 1-45.

Cockburn, Iain and Rebecca Henderson. 1996. "Public-private interaction in pharmaceutical research." *Proceedings of the National Academy of Sciences* **93**(23):12725-12730.

Cockburn, Iain, Rebecca Henderson, Luigi Orsenigo, and Gary Pisano. 1999. "Pharmaceuticals and biotechnology." In *U.S. industry in 2000: Studies in competitive performance*, edited by David C. Mowery, pp. 363-398. Washington DC: National Academies Press.

Cook-Deegan, Robert Mullan. 1996. "Does NIH need a DARPA?" *Issues in Science and Technology* **13**(2):25-28.

Creager, Angela N. H. 1999. "'What Blood Told Dr Cohn': World War II, plasma fractionation, and the growth of human blood research." *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* **30**(3):377-405.

Cutler, David, Angus Deaton, and Adriana Lleras-Muney. 2006. "The determinants of mortality." *Journal of Economic Perspectives* **20**(3):97-120.

Cutler, David M. and Srikanth Kadiyala. 2003. "The return to biomedical research: treatment and behavioral effects." In *Measuring the gains from medical research: An economic approach*, edited by Kevin M. Murphy and Robert H. Topel. Chicago: University of Chicago Press.

Daemmrich, Arthur. 2009. "Synthesis by microbes or chemists? Pharmaceutical research and manufacturing in the antibiotic era." *History and Technology* **25**(3):237-256.

de Haen, Paul. 1976. "Compilation of New Drugs: 1940 thru 1975." *Pharmacy Times* **March**:40-74.

D'Souza, Arielle, Kendall Hoyt, Christopher M Snyder, and Alec Stapp. 2024. *Can Operation Warp Speed Serve as a Model for Accelerating Innovations Beyond Covid Vaccines?* NBER Working Paper No. 32831.

Durvasula, Maya, C Scott Hemphill, Lisa Larrimore Ouellette, Bhaven Sampat, and Heidi L Williams. 2023.

"The NBER Orange Book dataset: A user's guide." *Research Policy* **52**(7):104791.

Dyèvre, Arnaud. 2024. *Public R&D spillovers and productivity growth*. Working paper.

Fieldhouse, Andrew J. and Karel Mertens. 2026a. *The returns to government R&D: Evidence from US appropriations shocks*. Federal Reserve Bank of Dallas Working Paper 2305.

Fieldhouse, Andrew J and Karel Mertens. 2026b. "The social returns to public R&D." *Entrepreneurship and Innovation Policy and the Economy* **5**(1):9-39.

Foray, Dominique, David C Mowery, and Richard R Nelson. 2012. "Public R&D and social challenges: What lessons from mission R&D programs?" *Research Policy* **41**(10):1697-1702.

Fox, Daniel M. 1987. "The politics of the NIH extramural program, 1937-1950." *Journal of the History of Medicine and Allied Sciences* **42**(4):447-466.

Furman, Jeffrey, Markus Nagler, and Martin Watzinger. 2021. "Disclosure and Subsequent Innovation: Evidence from the Patent Depository Library Program." *American Economic Journal: Economy Policy* **13**:239-270.

Gazzani, Andrea, Joseba Martinez, Filippo Natoli, and Paolo Surico. 2026. *The Public Origins of American Innovation*. CEPR working paper no. 33447.

Geiger, Roger L. 1986. *To advance knowledge: The growth of American research universities, 1900-1940*. Oxford: Oxford University Press.

Godin, Benoît. 2006. "The linear model of innovation: The historical construction of an analytical framework." *Science, Technology, & Human Values* **31**(6):639-667.

Greene, Jeremy A. 2007. "Statins: The Abnormal and the Pathological—Cholesterol, Statins, and the Threshold of Disease." In *Medicating Modern America: Prescription Drugs in History*, edited by Andrea Tone and Elizabeth Siegel Watkins, pp. 181-228.

Griliches, Zvi. 1957. "Hybrid Corn: An Exploration in the Economics of Technological Change." *Econometrica* **25**(4):501-522.

Gross, Daniel P. and Bhaven N. Sampat. 2022. "Crisis innovation policy from World War II to COVID-19." In *Entrepreneurship and Innovation Policy and the Economy*, edited by Josh Lerner and Scott Stern, volume 1, pp. 135-181.

Gross, Daniel P. and Bhaven N. Sampat. 2023a. "America, jump-started: World War II R&D and the takeoff of the US innovation system." *American Economic Review* **113**(12):3323-3356.

Gross, Daniel P. and Bhaven N. Sampat. 2023b. "The World War II crisis innovation model: What was it, and where does it apply?" *Research Policy* **52**(9):104845.

Hall, Bronwyn H, Adam B Jaffe, and Manuel Trajtenberg. 2001. *The NBER patent citation data file: Lessons, insights and methodological tools*. NBER Working Paper No. 8498.

Hoyt, Kendall. 2006. "Vaccine innovation: Lessons from World War II." *Journal of Public Health Policy* **27**(1):38-57.

Jacob, Brian A. and Lars Lefgren. 2011. "The impact of research grant funding on scientific productivity." *Journal of Public Economics* **95**(9-10):1168-1177.

Kattel, Rainer and Mariana Mazzucato. 2018. "Mission-oriented innovation policy and dynamic capabilities in the public sector."

Keefer, Chester S. 1969. "Dr. Richards as Chairman of the Committee on Medical Research." *Annals of Internal Medicine* **71**(8):61-70.

Kolev, Julian, Yuly Fuentes-Medel, and Fiona Murray. 2020. "Gender differences in scientific communication and their impact on grant funding decisions." In *AEA Papers and Proceedings*, volume 110, pp. 245-249.

Koning, Rembrand, Sampsa Samila, and John-Paul Ferguson. 2021. "Who do we invent for? Patents by women focus more on women's health, but few women get to invent." *Science* **372**(6548):1345-1348.

Laitner, Melissa H, Audry M Huang, and Shannon Takala-Harrison. 2024. "The State of the U.S. Biomedical and Health Research Enterprise: Strategies for Achieving a Healthier America." National Academies Press.

Landau, Ralph, Basil Achilladelis, and Alexander Scriabine. 1999. *Pharmaceutical innovation: Revolutionizing human health*. Philadelphia: Chemical Heritage Foundation.

Marx, Matt and Aaron Fuegi. 2020. "Reliance on science: Worldwide front-page patent citations to scientific articles." *Strategic Management Journal* **41**(9):1572-1594.

Marx, Matt and Aaron Fuegi. 2022. "Reliance on science by inventors: Hybrid extraction of in-text patent-to-article citations." *Journal of Economics & Management Strategy* **31**(2):369-392.

Mazzucato, Mariana. 2018. "Mission-oriented innovation policies: Challenges and opportunities." *Industrial and Corporate Change* **27**(5):803-815.

Mazzucato, Mariana. 2021. *Mission economy: A moonshot guide to changing capitalism*. New York: Harper Business.

Minneapolis Journal. 1935. *U.S. to War on Diseases.* Published August 30.

Mork, James G, Antonio Jimeno-Yepes, and Alan R Aronson. 2013. "The NLM Medical Text Indexer System for Indexing Biomedical Literature." In *BioASQ@ CLEF*.

Mowery, David C. 2009. "What does economic theory tell us about mission-oriented R&D?" In *The new economics of technology policy*, edited by Dominique Foray. Northampton: Edward Elgar.

Mowery, David C. 2012. "Defense-related R&D as a model for 'Grand Challenges' technology policies." *Research Policy* **41**(10):1703-1715.

Mowery, David C, Richard R Nelson, Bhaven N Sampat, and Arvids A Ziedonis. 2001. "The growth of patenting and licensing by U.S. universities: An assessment of the effects of the Bayh–Dole Act of 1980." *Research Policy* **30**(1):99-119.

Mowery, David C, Richard R Nelson, Bhaven N Sampat, and Arvids A Ziedonis. 2004. *Ivory tower and industrial innovation: University-industry technology transfer before and after the Bayh-Dole Act*. Palo Alto: Stanford University Press.

Murphy, Kevin M, Andrei Shleifer, and Robert W Vishny. 1989. "Industrialization and the big push." *Journal of Political Economy* **97**(5):1003-1026.

Murphy, Kevin M and Robert H Topel. 2003. "The economic value of medical research." In *Measuring the gains from medical research: An economic approach*, edited by Kevin M. Murphy and Robert H. Topel. Chicago: University of Chicago Press.

Myers, Kyle. 2020. "The elasticity of science." *American Economic Journal: Applied Economics* **12**(4):103-134.

Myers, Kyle R. 2023. *Experimentation at the NIH*. Building a Better NIH Project whitepaper, available at https://www.brookings.edu/collection/building-a-better-nih/.

Nelson, Richard R. 1997. "Why the Bush Report has hindered an effective civilian technology policy." In *Science for the 21st century: The Bush Report revisited*, edited by Claude E Barfield. Washington DC: American Enterprise Institute.

Nelson, Richard R and Nathan Rosenberg. 1993. "Technical innovation and national systems." In *National Innovation Systems*, edited by Richard R Nelson, pp. 3–22. New York: Oxford University Press.

Neushul, Peter. 1993. "Science, government and the mass production of penicillin." *Journal of the History of Medicine and Allied Sciences* **48**(4):371-395.

NLM. 2022. "NLM Medical Text Indexer (MTI)." https://lhncbc.nlm.nih.gov/ii/tools/MTI.html.

Nordhaus, William. 2003. "The health of nations: The contribution of improved health to living standards." In *Measuring the gains from medical research: An economic approach*, edited by Kevin M. Murphy and Robert H. Topel. Chicago: University of Chicago Press.

Ouellette, Lisa Larrimore. 2023. *Commercialization of NIH-supported research*. Building a Better NIH Project whitepaper, available at https://www.brookings.edu/collection/building-a-better-nih/.

Phelps, Charles E. 1992. "Diffusion of information in medical care." *Journal of Economic Perspectives* **6**(3):23-42.

Phelps, Charles E. 2000. "Information diffusion and best practice adoption." In *Handbook of health economics*, edited by Anthony J Culyer and Joseph P Newhouse, volume 1A, pp. 223-264.

Pisano, Gary. 2002. "Pharmaceutical biotechnology." In *Technological Innovation and Economic Performance*, edited by Benn Steil, David G Victor, and Richard R Nelson, pp. 347-365. Princeton: Princeton University Press.

Rosenberg, Nathan. 1974. "Science, invention and economic growth." *The Economic Journal* **84**(333):90-108.

Rosenberg, Nathan. 1982. *Inside the black box: Technology and economics*. Cambridge: cambridge University Press.

Rosenberg, Nathan. 1991. "Critical issues in science policy research." *Science and Public Policy* **18**(6):335-346.

Rosenstein-Rodan, Paul N. 1943. "Problems of Industrialisation of Eastern and South-Eastern Europe." *The Economic Journal* **53**(210-211):202-211.

Rosenzweig, Robert M. 1998. "The politics of indirect costs." *Council on Governmental Relations* **August**:1-12.

Sampat, Bhaven N. 2012. "Mission-oriented biomedical research at the NIH." *Research Policy* **41**(10):1729-1741.

Sampat, Bhaven N. 2020. "Whose drugs are these?" *Issues in Science and Technology* **36**(4):42-48.

Sampat, Bhaven N. 2023. *The history and political economy of NIH peer review*. Building a Better NIH Project whitepaper, available at https://www.brookings.edu/collection/building-a-better-nih/.

Sampat, Bhaven N and Robert Cook-Deegan. 2021. "An ARPA for Health Research." *Milbank Quarterly Opinion* **30**.

Science Service. 1935. *70 Lines of Research Planned by Federal Health Service*. Records of the National Institutes of Health (RG443), National Institute of Health 1930-1948, Records Relating to NIH Divisions ("Divisions File"), Box 189, folder "Miscellaneous Matters - Social Security funds", accessed 2025.

Stewart, Irvin. 1948. *Organizing scientific research for war: The administrative history of the Office of Scientific Research and Development*. Boston: Little, Brown, and Company.

Swain, Donald C. 1962. "The rise of a research empire: NIH, 1930 to 1950." *Science* **138**(3546):1233-1237.

Swann, John Patrick. 1983. "The search for synthetic penicillin during World War II." *The British Journal for the History of Science* **16**(2):154-190.

Teece, David J. 1986. "Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy." *Research Policy* **15**(6):285-305.

Temin, Peter. 1979. "Technology, regulation, and market structure in the modern pharmaceutical industry." *The Bell Journal of Economics* pp. 429-446.

Tomes, Nancy. 2021. ""Not Just for Doctors Anymore": How the Merck Manual Became a Consumer Health "Bible"." *Bulletin of the History of Medicine* **95**(1):1-23.

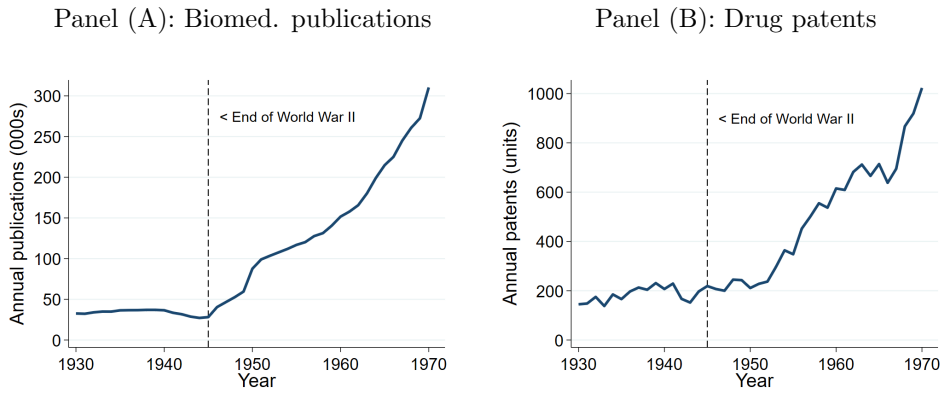
Toole, Andrew A. 2012. "The impact of public basic research on industrial innovation: Evidence from the pharmaceutical industry." *Research Policy* **41**(1):1-12.

Urquiola, Miguel. 2020. *Markets, minds, and money: Why America leads the world in university research*. Cambridge: Harvard University Press.

U.S. Federal Trade Commission. 1980. *Statistical Report on Mergers and Acquisitions*. Produced by the Federal Trade Commission (FTC) Bureau of Economics.

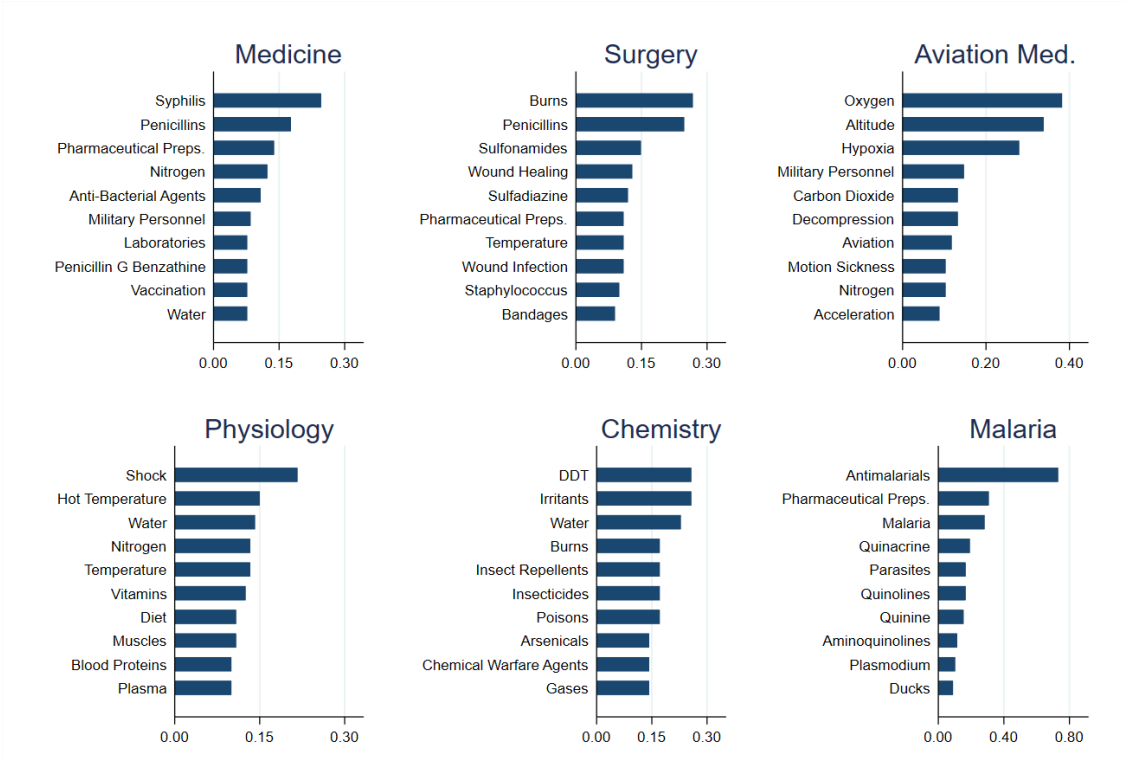
Van Slyke, Cassius J. 1946. "New horizons in medical research." *Science* **104**(2711):559-567.

Figure 1: Biomedical research publications and USPTO drug patents, 1930-1970



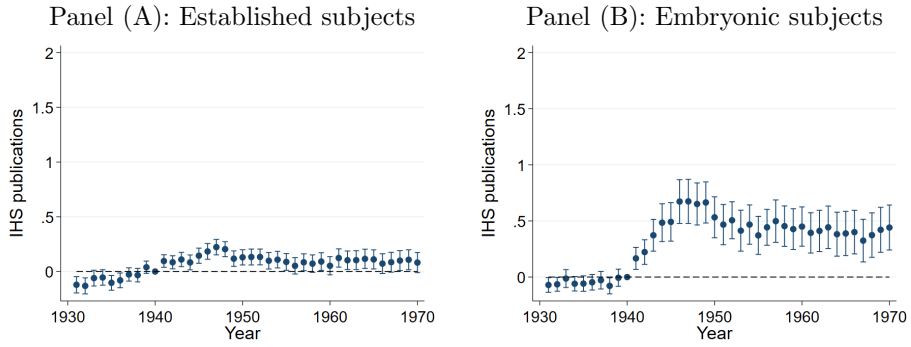
Notes: Left figure shows time series of total biomedical research publications in our core publication sample (Microsoft Academic Graph; see Appendix A). Sample consists of publications in the natural sciences and health sciences (OECD field codes 1 and 3) between 1930 and 1970. Right figure shows time series of total filings of drug patents in U.S. patent data, defined as patents in NBER category 31 ("Drugs"; Hall et al. 2001), corresponding to USPC 424 and 514. Dashed vertical line marks the end of World War II.

Figure 2: Top 10 MeSH terms by CMR division, as a fraction of division contracts



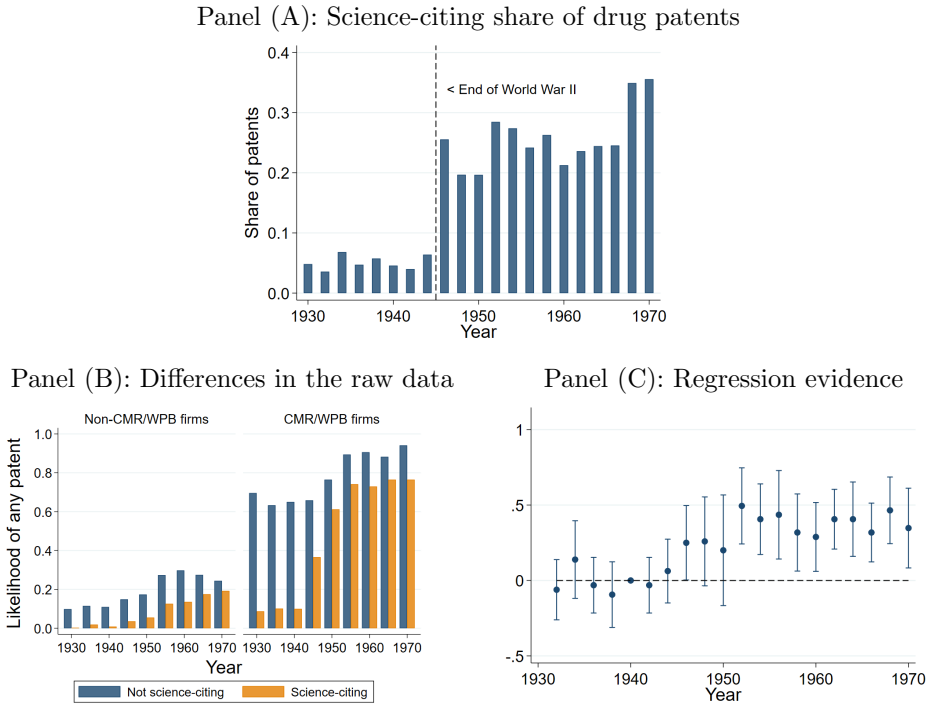
Notes: Figure lists the top 10 MeSH terms associated with CMR contracts in each of the six primary CMR divisions, showing what share of divisional contracts each term associates with. Individual contracts map to multiple MeSH terms.

Figure 3: Effects of CMR on research publications, 1930-1970



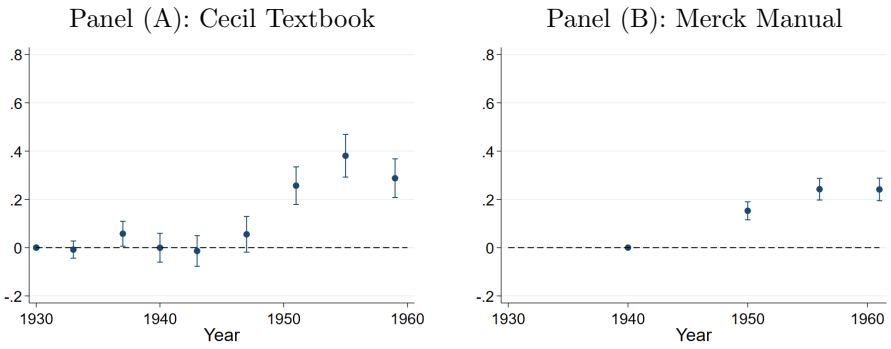
Notes: Figure shows annual estimates of the differential growth of scientific publications in MeSH terms with CMR funding, relative to others. Panels (A) and (B) divide the sample into subjects with greater than and less than the median number of pre-1940 publications, which we label "established" and "embryonic" subjects. Error bars represent 95% confidence intervals, with SEs clustered at the MeSH term level.

Figure 4: Differential growth in annual likelihood of filing science-citing vs. non-citing drug patents, by CMR/WPB-contracted firms vs. others, 1930-1970



Notes: Panel (A) shows the science-citing share of drug patents filed by firms in de Haen (1976). Drug patents defined as those associated with NBER category 31 (Hall et al. 2001), and science-citing patents as those which cite scientific literature in their text. Panel (B) shows the share of firm-years with at least one drug patent, in five-year intervals, separately reporting patent rates for CMR/WPB-contracted and other firms, and for their science-citing and non-citing patents. Panel (C) estimates the triple-difference, showing biannual estimates of the differential growth in the likelihood of filing science-citing versus non-citing patents at CMR/WPB-contracted firms versus others. Error bars represent 95% confidence intervals, with SEs clustered by firm.

Figure 5: Cecil Textbook and Merck Manual coverage of subjects with CMR funding



Notes: Figure estimates differences over time in whether the Cecil Textbook (Panel A) and Merck Manual (Panel B) cover individual MeSH terms with CMR funding, relative to others. The Cecil Textbook sample consists of consecutive editions from 1930 (2nd ed., when an index is first observed) to 1959 (nearest edition to 1960). The Merck Manual sample consists of consecutive editions from 1940 to 1961 (on the same basis). Results are estimated relative to the 1930 and 1940 editions, respectively. Error bars represent 95% confidence intervals, with SEs clustered by MeSH term.

Table 1: Extramural research contracts, contractors, and modal research subjects by CMR division

		Division						
		(1)	(2)	(3)	(4)	(5)	(6)	
	All	Medicine	Surgery	Aviat. Med.	Physiology	Chemistry	Malaria	Miscellany
CMR contracts	571	130	101	68	120	36	78	38
Percent of total	100%	23%	18%	12%	21%	6%	14%	7%
Unique contractors	128	55	39	31	56	20	49	27
Percent of total	100%	43%	31%	24%	44%	16%	38%	21%
Contract value (MMs)	$21.3	$3.4	$2.2	$2.4	$3.7	$1.2	$4.8	$3.5
Percent of total	100%	16%	11%	12%	18%	6%	22%	17%
MeSH terms per contract	11.3	11.5	13.4	10	11.8	14.9	9.1	6.5
Modal MeSH term	Penicillins	Syphilis	Burns	Oxygen	Shock	DDT	Antimalarials	Penicillins

Notes: Table provides summary statistics for CMR, overall and by division. The table lists the number of contracts, contractors, and total contract value by division, and provides the modal MeSH term from contracts in each division, weighted by value. The overall modal subject across all of CMR is *Penicillins*.

Table 2: Novelty and impact of CMR-funded publications

	Novelty	Above given f. citation pctile.			
	(1)	(2)	(3)	(4)	(5)
	New combo	75th pct.	90th pct.	95th pct.	99th pct.
CMR-funded	0.039**	0.140***	0.104***	0.065***	0.024***
	(0.018)	(0.018)	(0.014)	(0.011)	(0.007)
N	195303	119773	119773	119773	119773
R^2	0.26	0.30	0.27	0.26	0.23
Subj-Year FEs	Y	Y	Y	Y	Y
Y mean	0.309	0.239	0.098	0.049	0.010

Notes: Table estimates differences between CMR-funded and contemporary publications in novelty and impact. Column (1) estimates differences in their propensity to include a new MeSH term combination (novelty), and Columns (5) to (8) their propensity to be top 25%, 10%, 5%, or 1% cited publications (impact, based on 20-year forward citations). Sample is restricted to publications between 1940 and 1950. All specifications include fixed effects for publications' primary subject (highest-scoring MeSH term) and year. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by subject and year in parentheses.

Table 3: Effects of CMR on research publications in embryonic subjects

			Publications with authors:			
	(1)	(2)	(3)	(4)	(5)	(6)
	Pubs	Uniq. auths.	Only prewar	Any prewar	Any postwar	New combos
Any CMR * 1(1935-1939)	-0.000	0.025				-0.063
	(0.014)	(0.102)				(0.087)
Any CMR * 1(1940-1945)	0.333***	0.379***	0.096***	0.181***	0.296***	0.179**
	(0.051)	(0.107)	(0.025)	(0.038)	(0.045)	(0.088)
Any CMR * 1(1946-1950)	0.682***	0.616***	0.080***	0.277***	0.680***	0.268***
	(0.085)	(0.118)	(0.031)	(0.056)	(0.082)	(0.088)
Any CMR * 1(1951-1955)	0.488***	0.361***	0.008	0.144***	0.499***	0.149*
	(0.077)	(0.112)	(0.013)	(0.037)	(0.075)	(0.087)
Any CMR * 1(1956-1960)	0.498***	0.329***	-0.012	0.081***	0.514***	0.091
	(0.079)	(0.113)	(0.008)	(0.030)	(0.079)	(0.086)
Any CMR * 1(1961-1965)	0.447***	0.323***	-0.012	0.054**	0.466***	0.085
	(0.086)	(0.113)	(0.009)	(0.023)	(0.085)	(0.094)
Any CMR * 1(1966-1970)	0.435***	0.277**	-0.014*	0.010	0.452***	0.144
	(0.091)	(0.119)	(0.008)	(0.018)	(0.090)	(0.093)
N	269657	102489	269657	269657	269657	102489
R^2	0.44	0.55	0.10	0.14	0.47	0.34
Y mean	0.360	1.908	0.040	0.067	0.324	1.048

Notes: Table estimates differences over time in scientific activity in MeSH terms with CMR funding, relative to others. Evaluated outcomes are the number of scientific publications (Column 1); unique authors (Column 2); number of publications with only prewar authors (Column 3), any prewar authors (Column 4); and any postwar authors (Column 5); and new combinations (Column 6). Unique authors measured using author identifiers in the MAG data. Prewar authors defined as authors with at least one pre-1940 publication, and postwar authors those with no pre-1940 publications. New combinations are defined as new co-occurring MeSH terms in articles with the given MeSH term. All columns restrict the sample to "embryonic" subjects (with below-median pre-1940 publications), and Columns (2) to (6) condition to subject-years with $\geq$1 publication. Results are estimated relative to the 1930-1934 period. Note that Columns (3) to (5) omit the "Any CMR * 1935-1939" parameter due to a lack of pre-1940 variation in the outcome. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by MeSH term in parentheses.

Table 4: Effects of CMR on new drug introductions, 1940-1970

Panel A: MeSH subject-year level

	1(Any new drugs)		# of new drugs		IHS(New drugs)	
	(1)	(2)	(3)	(4)	(5)	(6)
	All drugs	Excl. A-I	All drugs	Excl. A-I	All drugs	Excl. A-I
Any CMR * 1(1946-1950)	-0.011	-0.011	0.468	0.271	0.131	0.103
	(0.069)	(0.069)	(0.393)	(0.360)	(0.145)	(0.149)
Any CMR * 1(1951-1955)	0.141	0.141	1.420***	1.178**	0.469***	0.444**
	(0.087)	(0.087)	(0.518)	(0.487)	(0.163)	(0.170)
Any CMR * 1(1956-1960)	0.105	0.105	2.359**	2.078**	0.630***	0.612***
	(0.092)	(0.092)	(0.924)	(0.939)	(0.211)	(0.223)
Any CMR * 1(1961-1965)	0.146	0.146	0.543*	0.584*	0.267**	0.289**
	(0.100)	(0.100)	(0.301)	(0.317)	(0.127)	(0.132)
Any CMR * 1(1966-1970)	0.039	0.039	0.397	0.378	0.138	0.139
	(0.081)	(0.081)	(0.376)	(0.401)	(0.152)	(0.162)
N	1426	1426	1426	1395	1426	1395
R^2	0.57	0.57	0.62	0.57	0.67	0.63
Y mean	0.264	0.264	0.795	0.680	0.413	0.371

Panel B: Firm-year sample

	1(Any new drugs)		# of new drugs		IHS(New drugs)	
	(1)	(2)	(3)	(4)	(5)	(6)
	All drugs	Excl. A-I	All drugs	Excl. A-I	All drugs	Excl. A-I
CMR/WPB firm * 1(1946-1950)	0.205**	0.144**	0.446***	0.342***	0.295***	0.227***
	(0.080)	(0.065)	(0.140)	(0.121)	(0.097)	(0.083)
CMR/WPB firm * 1(1951-1955)	0.254***	0.303***	0.930***	0.768***	0.511***	0.475***
	(0.069)	(0.069)	(0.209)	(0.164)	(0.116)	(0.099)
CMR/WPB firm * 1(1956-1960)	0.222***	0.253***	0.977***	0.747***	0.514***	0.439***
	(0.072)	(0.076)	(0.246)	(0.210)	(0.127)	(0.119)
CMR/WPB firm * 1(1961-1965)	0.140**	0.123*	0.250**	0.261*	0.172**	0.172**
	(0.058)	(0.063)	(0.125)	(0.137)	(0.079)	(0.087)
CMR/WPB firm * 1(1966-1970)	0.111	0.089	0.079	0.090	0.074	0.077
	(0.074)	(0.059)	(0.111)	(0.072)	(0.080)	(0.055)
N	3686	3686	3686	3686	3686	3686
R^2	0.30	0.27	0.39	0.33	0.38	0.32
Y mean	0.183	0.157	0.274	0.220	0.204	0.169

Notes: Panel (A) estimates differences in the annual number of new commercially-marketed drugs in de Haen (1976) associated with MeSH terms with CMR funding, relative to others, restricting the sample to terms in drug-related sub-branches of the *pharmacologic actions* branch of the MeSH tree (see text for details). Panel (B) estimates differences in the annual number of new drugs brought to market by firms engaged in the CMR (and WPB) medical research effort vs. others. Even-numbered columns (labeled "Excl. A-I") exclude anti-infective agents to examine the degree to which the results are driven by antibiotics. In preparing the firm sample in Panel (B), we dynamically reassign a small number of firms which merged or were acquired during the sample frame to their subsequent owners using data from FTC (1980). Estimation sample begins in 1940 (the beginning of the de Haen (1976) historical drug data, which follow the FDA's initiation of drug safety approvals). Results are estimated relative to the 1940-1945 period. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by MeSH term (Panel A) or firm (Panel B) in parentheses.

Table 5: Growth of biological approaches to drug development and manufacture

	Any patents?		Num. patents		IHS(Patents)	
	(1)	(2)	(3)	(4)	(5)	(6)
	Ferment.	Bio. drugs	Ferment.	Bio. drugs	Ferment.	Bio. drugs
CMR/WPB firm * 1(1935-1939)	-0.073	-0.066*	-0.236	-0.125	-0.112	-0.083
	(0.058)	(0.034)	(0.218)	(0.225)	(0.090)	(0.083)
CMR/WPB firm * 1(1940-1945)	-0.006	-0.008	-0.118	-0.022	-0.040	-0.004
	(0.065)	(0.058)	(0.268)	(0.209)	(0.110)	(0.093)
CMR/WPB firm * 1(1946-1950)	0.078	0.067	0.068	0.139	0.069	0.095
	(0.086)	(0.072)	(0.335)	(0.297)	(0.145)	(0.131)
CMR/WPB firm * 1(1951-1955)	0.170*	0.266***	0.481	0.746*	0.271	0.418**
	(0.092)	(0.083)	(0.443)	(0.419)	(0.194)	(0.179)
CMR/WPB firm * 1(1956-1960)	0.278**	0.309***	1.304*	1.607**	0.564**	0.662***
	(0.110)	(0.097)	(0.685)	(0.719)	(0.257)	(0.248)
CMR/WPB firm * 1(1961-1965)	0.282**	0.358***	1.043**	1.545***	0.522**	0.710***
	(0.116)	(0.093)	(0.494)	(0.571)	(0.221)	(0.221)
CMR/WPB firm * 1(1966-1970)	0.251***	0.400***	0.448	1.341**	0.316*	0.681***
	(0.094)	(0.089)	(0.363)	(0.525)	(0.164)	(0.210)
N	5172	5172	5172	5172	5172	5172
R^2	0.37	0.42	0.36	0.45	0.42	0.50
Y mean	0.063	0.090	0.139	0.208	0.085	0.124

Notes: Table estimates differences in firms' annual number of drug patents on fermentation processes and on drugs produced from microorganisms, comparing engaged in the CMR (and WPB) medical research effort vs. others. Drug patents defined as those associated with NBER category 31 (Hall et al. 2001). Patents on fermentation processes are those classified into CPC C12P ("Fermentation or enzyme-using processes to synthesise a desired chemical compound or composition"), and patents associated to microorganisms are those classified into CPC Y10S/82 to Y10S/94 (all under "Microorganisms"). The firm smaple consists of firms in de Haen (1976). In preparing this sample, we dynamically reassign a small number of firms which merged or were acquired during the sample frame to their subsequent owners using data from FTC (1980). Results are estimated relative to the 1930-1934 period. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by MeSH term (Panel A) or firm (Panel B) in parentheses.

Online Appendix

World War II and the 20th Century Transformation of Biomedicine

Daniel P. Gross and Bhaven N. Sampat

Table of Contents

A Data Appendix **1**

A.1 OSRD/CMR data sources 1

A.2 Scientific publication data 5

A.3 Pharmaceutical innovation 8

A.4 Mid-century medical textbooks 10

A.5 NIH extramural research grants 11

B Supplementary Results **12**

B.1 Evidence from the raw data 12

B.2 Alternative specifications: Logged and level outcomes 15

B.3 Intensive margin: Value-weighted shock 15

B.4 Comparisons to a matched control group 16

B.5 Controlling for postwar NIH funding 17

B.6 Placebo test: World War I 17

B.7 Growth of the pharmaceutical industry 18

B.8 Cross-country comparisons 21

B.9 Aggregate U.S. patenting 24

C Historical Context **27**

C.1 The need for military medical research 27

C.2 Contemporary accounts 29

A Data Appendix

A.1 OSRD/CMR data sources

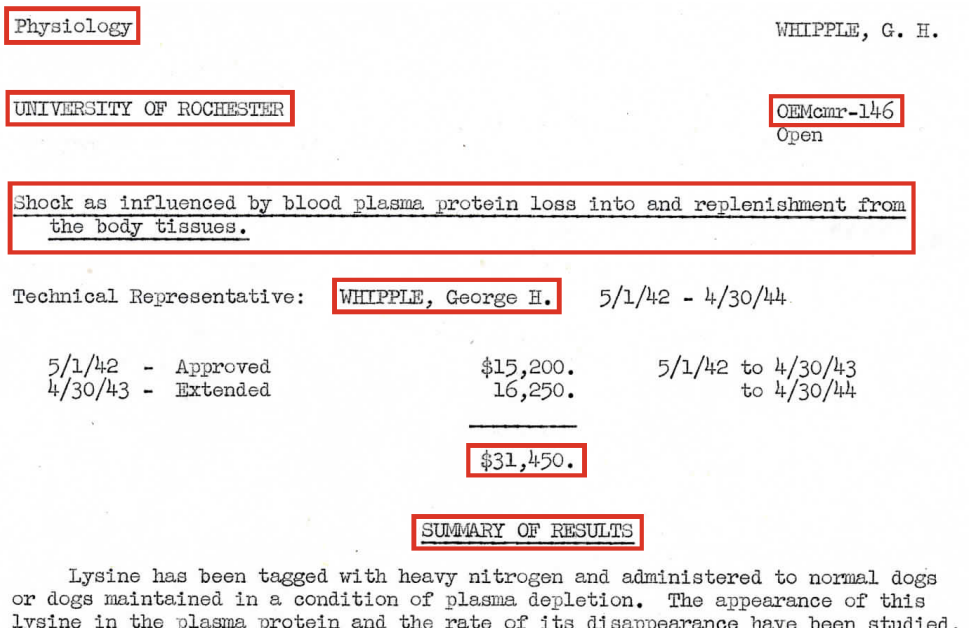
At the heart of this paper are new data on CMR-funded research obtained from OSRD archival records at the U.S. National Archives and Records Administration (NARA).[1] The principal data source for this paper is a set of CMR contract summaries, which identify the CMR division, contract number, principal investigator, institution, project title, value, award period, and a list of all technical reports, interim and final progress reports, and publications produced under the contract. For most contracts it also provided a summary of results. We cross-validate the information in these records against three other sources: (i) contract index in OSRD archival records, (ii) a contract list in the archival records, and (iii) a corresponding contract list in Andrus (1948). Figure A.1 provides a screenshot from an example CMR contract summary, highlighting key fields. Figure A.2 shows the corresponding index card from the OSRD contract index.

From the collective records we identify a total of 590 CMR research contracts: 573 extramural contracts to investigators at 128 universities, firms, hospitals, and institutes (identified in records as contracts OEMcmr-1 to OEMcmr-573), and 17 intramural contracts (primarily with the USDA, FDA, and NIH). The extramural contracts bore a total value of $21.3 million in 1940-45 dollars—around 5% of OSRD's total spending across all research contracts, most of which was comprised of NDRC developing physical war technologies like radar (see Gross and Sampat 2023a,b, Gross and Roche 2026)—equivalent to roughly $400 million in 2024.

We are also able to identify scientific publications produced under these contracts, using the union of (i) publications reported in contract summaries (like the one shown in Figure A.1), (ii) a "CMR bibliography" reported in Andrus (1948), and (iii) an independent CMR bibliography discovered in OSRD records which appears to have been the input for the Andrus list, though these sources mostly intersect. Figure A.3 provides excerpts from the archival and published bibliographies. We digitize and consolidate these bibliographies and link the results to Microsoft Academic Graph (MAG; 82% link rate), Web of Science (79% link rate), and PubMed (55% link rate, due to PubMed's limited coverage in this period). Though CMR publications provide insight into the shape of its research portfolio, throughout our analysis we prioritize contract-based measures over publication-based measures, as they indicate research inputs rather than output.

[1] See NARA Record Group 227, "Records of the Office of Scientific Research and Development". The key record set for this paper are the Committee on Medical Research *Contract Ledgers* (NC-138, Entry 164, Stack area 130, Row 22, Compartment 18, Shelf 2-3, Boxes 1-6). Also relevant were OSRD's *Index to Contracts* (NC-138, Entry 27, Stack area 130, Row 20, Compartment 11, Shelf 1, Boxes 1-5) and lists of CMR contracts and CMR-funded publications found in NARA records which we cross-validate against lists presented in Andrus (1948).

Figure A.1: Example medical research contract summary



Physiology

WHIPPLE, G. H.

UNIVERSITY OF ROCHESTER

OEMcmr-146
Open

Shock as influenced by blood plasma protein loss into and replenishment from the body tissues.

Technical Representative: WHIPPLE, George H. 5/1/42 - 4/30/44

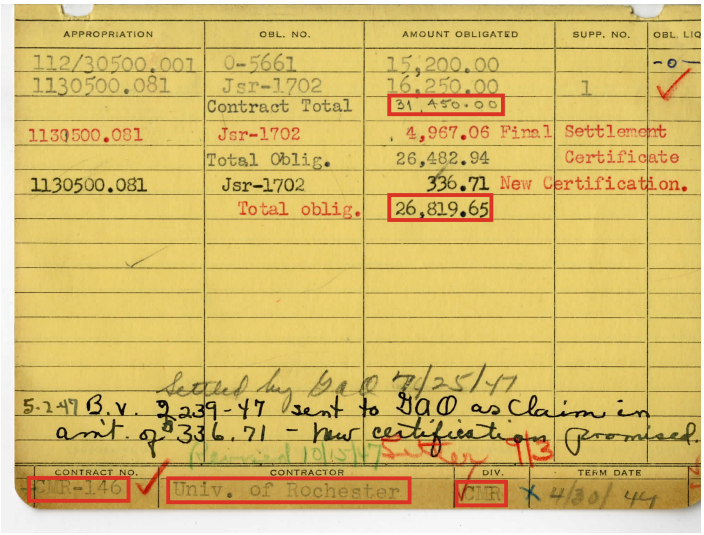
5/1/42 -	Approved	$15,200.	5/1/42 to 4/30/43
4/30/43 -	Extended	16,250.	to 4/30/44
		$31,450.	

SUMMARY OF RESULTS

Lysine has been tagged with heavy nitrogen and administered to normal dogs or dogs maintained in a condition of plasma depletion. The appearance of this lysine in the plasma protein and the rate of its disappearance have been studied.

Notes: Figure shows an excerpt from an example contract summary report from the CMR contract ledgers, for contract OEMcmr-146. The headings provide basic contract information, including the contract number, institution, subject, principal investigator, dates, and total obligated value. Also included in these reports were extended abstracts and publication lists.

Figure A.2: Corresponding contract index card



APPROPRIATION	OBL. NO.	AMOUNT OBLIGATED	SUPP. NO.	OBL. LIQ
112/30500.001	0-5661	15,200.00		-0-
1130500.081	Jsr-1702	16,250.00	1	✓
	Contract Total	31,450.00		
1130500.081	Jsr-1702	4,967.06 Final	Settlement	
	Total Oblig.	26,482.94	Certificate	
1130500.081	Jsr-1702	336.71 New	Certification.	
	Total oblig.	26,819.65		

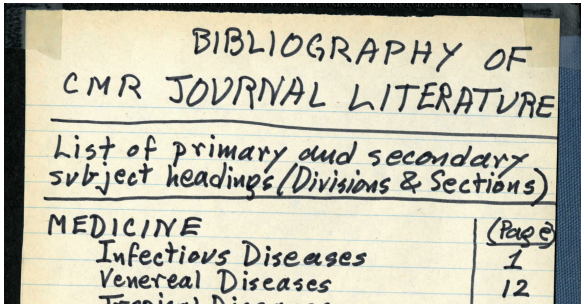
Settled by GAO 7/25/47
5-1-47 B.V. 9239-47 sent to GAO as claim in amt. of $336.71 - new certification promised.

CONTRACT NO.	CONTRACTOR	DIV.	TERM DATE
OEMcmr-146 ✓	Univ. of Rochester	CMR	X 4/30/44

Notes: Figure shows the corresponding index card from the OSRD contract index. The card identifies the contract number, contractor, OSRD division (in this case, "CMR"), and the total contracted and obligated value.

Figure A.3: CMR bibliography, archival and published copies

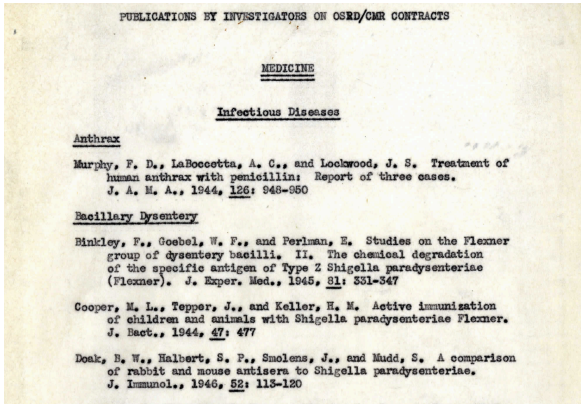
Archival records:



BIBLIOGRAPHY OF
CMR JOURNAL LITERATURE

List of primary and secondary subject headings (Divisions & Sections)

	(Page)
MEDICINE	
Infectious Diseases	1
Venereal Diseases	12



PUBLICATIONS BY INVESTIGATORS ON OSRD/CMR CONTRACTS

MEDICINE

Infectious Diseases

Anthrax

Murphy, F. D., LaBoccetta, A. C., and Lockwood, J. S. Treatment of human anthrax with penicillin: Report of three cases. J. A. M. A., 1944, 126: 948-950

Bacillary Dysentery

Binkley, F., Goebel, W. F., and Perlman, E. Studies on the Flexner group of dysentery bacilli. II. The chemical degradation of the specific antigen of Type Z Shigella paradysenteriae (Flexner). J. Exper. Med., 1945, 81: 331-347

Cooper, M. L., Tepper, J., and Keller, H. M. Active immunization of children and animals with Shigella paradysenteriae Flexner. J. Bact., 1944, 47: 477

Doak, B. W., Halbert, S. P., Smolens, J., and Mudd, S. A comparison of rabbit and mouse antisera to Shigella paradysenteriae. J. Immunol., 1946, 52: 113-120

Andrus (1948):

BIBLIOGRAPHY

Publications by Investigators on OSRD/CMR Contracts

MEDICINE

Infectious Diseases

Anthrax

Murphy, F. D., LaBoccetta, A. C., and Lockwood, J. S. Treatment of human anthrax with penicillin: Report of three cases. *J.A.M.A.*, 1944, *126:* 948–950.

Bacillary Dysentery

Binkley, F., Goebel, W. F., and Perlman, E. Studies on the Flexner group of dysentery bacilli. II. The chemical degradation of the specific antigen of Type Z Shigella paradysenteriae (Flexner). *J. Exper. Med.*, 1945, *81:* 331–347.

Cooper, M. L., Tepper, J., and Keller, H. M. Active immunization of children and animals with Shigella paradysenteriae Flexner. *J. Bact.*, 1944, *47:* 477.

Doak, B. W., Halbert, S. P., Smolens, J., and Mudd, S. A comparison of rabbit and mouse antisera to Shigella paradysenteriae. *J. Immunol.*, 1946, *52:* 113–120.

Dubos, R. J., Hoberman, H. D., and Pierce, C. Some factors affecting the toxicity of cultures of Shigella dysenteriae. *Proc. Nat. Acad. Sc.*, 1942, *28:* 453–458.

Dubos, R. J., Straus, J. H., and Pierce, C. The multiplication of bacteriophage in vivo and its protective effect against an experimental infection with Shigella dysenteriae. *J. Exper. Med.*, 1943, *78:* 161–168.

Ehrich, W. E., Halbert, S. P., Mertens, E., and Mudd, S. Mechanism of the augmenting acting of mineral oil on antibody production. Tissue reactions and antibody response to dysentery vaccine in saline, and in saline-lanolin-mineral oil emulsion. *J. Exper. Med.*, 1945, *82:* 343–360.

Goebel, W. F., Binkley, F., and Perlman, E. Studies on the Flexner group of dysentery bacilli. I. The specific antigens of Shigella paradysenteriae (Flexner). *J. Exper. Med.*, 1945, *81:* 315–330.

Goebel, W. F., Perlman, E., and Binkley, F. Antibody response in man to injection of the specific antigen of Type V Shigella paradysenteriae. *Science*, 1944, *99:* 412–413.

Notes: Figure shows excerpts from the CMR bibliography (publication list). On the left are archival records; on the right is the matching published version in Andrus (1948).

A.1.1 Linking CMR to the MeSH vocabulary

As we explain in Section 2 of the paper, we use the National Library of Medicine's (NLM) Medical Text Indexer (MTI) to connect CMR contracts to medical subjects, measured via MeSH descriptors (which we alternatively call "MeSH terms"). MeSH is the NLM's controlled and hierarchically-organized vocabulary used for indexing and cataloging biomedical and health-related research, and MTI is a natural language processing tool which identifies candidate MeSH terms for journal article indexing and serves as the first-line indexer for a large number of journals. We repurpose MTI to index CMR contracts in our setting, on the basis of their titles and contract summaries. The resulting output identifies associated medical subjects, a relevance score for each subject, and associated MeSH tree codes, identifying subjects' hierarchical relationship.[2]

MTI indexing of CMR contracts (and of MAG publications, as we discuss below) was performed between 2021 and 2022.[3] Figure A.4 provides a screenshot showing the structure of the MeSH tree; though most of our analysis occurs at the MeSH term level, in robustness checks we also make use of this hierarchical taxonomy for medical research space.

Figure A.4: Sample from Medical Subject Heading (MeSH) tree



Notes: Figure displays the MeSH tree, which assigns hierarchical structure to medical subject headings (see paper for a more complete discussion). Left image shows the main branches. Right image illustrates select subcategories of the 'A' branch.

A.1.2 What subjects did CMR support?

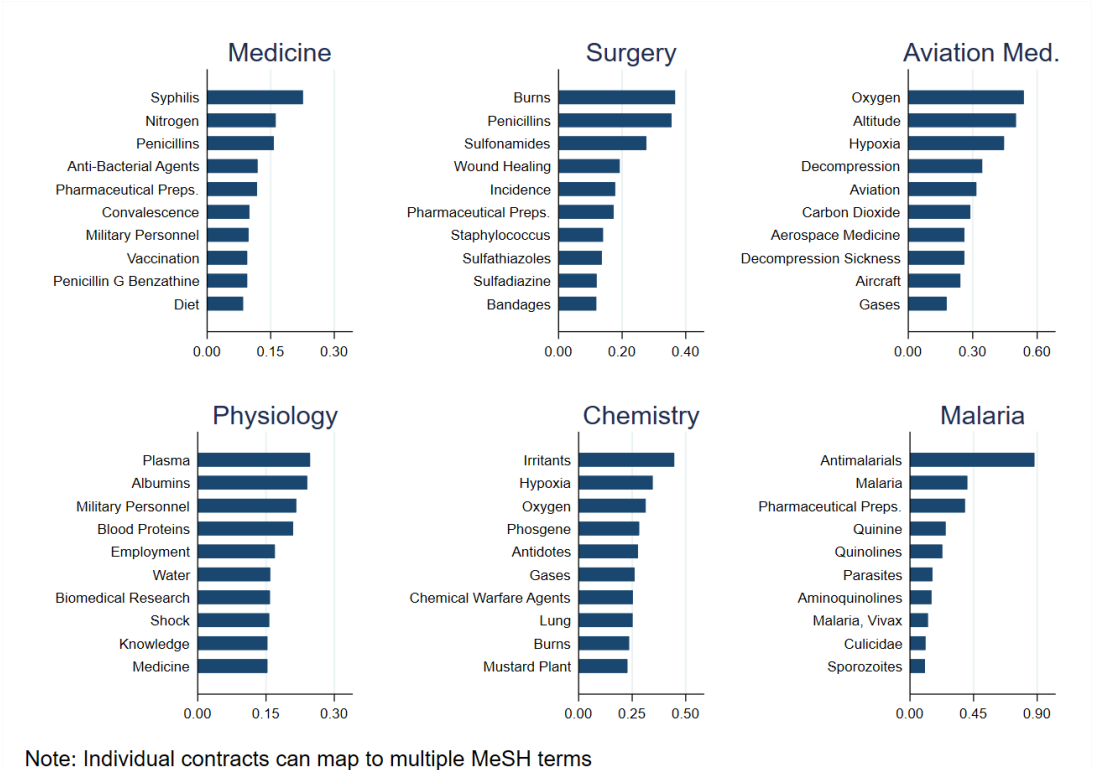
Figure 2 of the paper provides a lens into research subjects CMR funded, listing subjects in each CMR division with the most associated contracts. Here we provide two additional views of CMR's portfolio, empirical and qualitative. Figure A.5 reproduces Figure 2, showing the top subjects

[2]The MeSH vocabulary has roughly 30,000 unique terms (descriptors) and 60,000 tree codes. Some terms link to multiple tree codes, reflecting relationships to distinct regions of biomedical idea space.

[3]Note that as of January 2025, MTI has been decommissioned, and is no longer available to the public. NLM has transitioned internal indexing to a "next-generation" replacement indexer named "MTIX" which uses neural network-based prediction methods, but MTIX is not currently available to the public. In an email exchange, NLM staff explained that there is no timeline for a public release.

weighted by funding. Table A.1 presents the table of contents to Andrus (1948)—a collection of postwar summaries of CMR research programs—as a qualitative window into the research subjects CMR funded, including areas where it failed to make meaningful progress.

Figure A.5: Top 10 MeSH terms by CMR division, value-weighted



Notes: Figure lists the top 10 MeSH terms associated with CMR contracts in each of the six primary CMR divisions, showing what share of divisional contract value each term associates with. Individual contracts map to multiple MeSH terms.

A.2 Scientific publication data

The core outcome data for this paper are biomedical publications, aggregated to the MeSH term-year level. Our base data consists of scientific publications from Microsoft Academic Graph (MAG) which we obtained from the Reliance on Science data repository (Marx and Fuegi 2020, 2022).[4] We filter this sample to publications in the natural and health sciences (OECD field codes 1 and 3) between 1930 and 1970. We then retrieved the titles of these publications and processed them

[4]Though the focus of Marx and Fuegi is measuring patent citations to science, early versions of the Marx and Fuegi repository included a complete MAG dataset, including publications which were not cited by patents. We obtained our MAG data files from these early data deposits. MAG (and its successor OpenAlex, which developed after this project began) is to our knowledge the most complete record of historical science, with roughly 100,000 publications each year in the 1930s. By comparison, NIH's MEDLINE database (the core data behind PubMed) begins in 1966, and historical MEDLINE (a backwards extension of MEDLINE) only goes back to 1946. MAG/OpenAlex is also preferred to Clarivate's Web of Science database, which in our experience appears to have lower historical coverage than MAG/OpenAlex, in addition to being commercially gated and expensive.

Table A.1: Andrus (1948) Table of Contents

Section	Chapter
PART ONE—Medicine	
	Chapter 01 – Introduction
	Chapter 02 – Infectious Diseases
	Chapter 03 – Venereal Diseases
	Chapter 04 – Tropical Diseases
	Chapter 05 – Medical Problems of Convalescence
PART TWO—SURGERY	
	Chapter 06 – Introduction
	Chapter 07 – The Prevention of Infection in Accidental Wounds
	Chapter 08 – Experimental Wound Healing
	Chapter 09 – The Application of Penicillin to Surgical Problems
	Chapter 10 – Orthopedic Problems and Prosthetics
	Chapter 11 – The Problem of Gas Gangrene
	Chapter 12 – The Burn Problem
	Chapter 13 – The Repair of Peripheral Nerve Lesions
	Chapter 14 – Experimental Studies on Concusion
	Chapter 15 – Frostbite and Trench Foot
	Chapter 16 – New Surgical Plastics and Hemostatics
	Chapter 17 – Improvements in X–Ray Devices
	Chapter 18 – Studies on Wound Ballistics
PART THREE—AVIATION MEDICINE	
	Chapter 19 – Introduction
	Chapter 20 – The Study of Crash Injuries and Prevention of Aircraft Accidents
	Chapter 21 – The Effects of Acceleration and Their Amelioration
	Chapter 22 – Visual Problems
	Chapter 23 – Motion Sickness
	Chapter 24 – Anoxia and Oxygen Equipment
	Chapter 25 – Altitude Decompression Sickness
PART FOUR—PHYSIOLOGY	
	Chapter 26 – Introduction
	Chapter 27 – Shock
	Chapter 28 – The History of Plasma Fractionation
	Chapter 29 – Blood Substitutes
	Chapter 30 – Methods of Preservation of Whole Blood
	Chapter 31 – Problems of Nutrition
	Chapter 32 – Acclimatization to Heat and Cold
	Chapter 33 – Protective Clothing
	Chapter 34 – Water Disinfection and Allied Subjects
PART FIVE—CHEMICAL WARFARE AGENTS	
	Chapter 35 – Introduction
	Chapter 36 – Systemic Agents: Action and Treatment
	Chapter 37 – Recent Research on Respiratory Irritants
	Chapter 38 – Protection and Treatment of the Skin Exposed to Blister Gases
	Chapter 39 – The Effects of Toxic Chemical Agents on the Eye and Their Treatment
PART SIX—ANTI—PEST AGENTS	
	Chapter 40 – The Development of New Insecticides
	Chapter 41 – The Action of DDT on Invertebrates
	Chapter 42 – The Toxicology and Mechanism of Action of DDT in Mammals
	Chapter 43 – The Dispersal of Insecticides
	Chapter 44 – The Development of New Insect Repellents
	Chapter 45 – The Development of New Rodenticides
PART SEVEN—ADRENOCORTICOL STEROIDS	
	Chapter 46 – The Synthesis of Adrenocortical Steroids
PART EIGHT—MALARIA	
	Chapter 47 – Introduction
	Chapter 48 – The Synthesis of Antimalarial Drugs
	Chapter 49 – The Biology and Biochemistry of the Malarial Parasites
	Chapter 50 – The Screening Program
	Chapter 51 – The Clinical Testing of Antimalarial Drugs
PART NINE—PENICILLIN	
	Chapter 52 – Penicillin: A Wartime Achievement
	Chapter 53 – Research in the Development of Penicillin
PART TEN—SENSORY DEVICES	
	Chapter 54 – Sensory Devices

through MTI to obtain MeSH subjects and associated weights. We then work with the MTI output. After dropping check tags (MeSH descriptors that specify species, sex, or age), supplementary concepts (terms outside of the MeSH thesaurus), low-scoring returned terms (specifically, those with less than 10% of a publications' remaining MeSH terms' total score) to reduce noise, we then aggregate to count score-weighted publications by subject and year. Using these data we also produce derivative measures, such as the number of unique other MeSH terms a given MeSH term co-publishes with in a given year, which we label "combinations". We measure the subset of these combinations which are new to the publication record in a given year as "new combinations", and count for each MeSH term-year its number of new combinations.

Using the MAG data, we retrieve several other features of each publication, including authors and journals. Unlike modern data, the data from this period lack author affiliations or locations. To evaluate U.S. (versus global) patterns in science we instead obtain the country of each journal in our sample from ISSN, and use this information to filter to US-published science—similar to how we focus our patent analysis on USPTO-issued patents (see below).

An important added step in our data collection is also to classify articles as basic or clinical (applied). As we explain in the body of the paper, there is no commonly agreed method of systematically distinguishing basic and clinical research in biomedicine. Prior research has proposed categorizations based on journal (Narin et al. 1976), title (Lewison and Paraje 2004), or content (Li et al. 2017, Ke 2019), or via machine learning (Boyack et al. 2014). We consider three ways of doing so. First, we rely on OECD subfield codes included in the MAG data which identify articles as basic medical research (3.01) and clinical medicine (3.02), via journals. Second, we identify journals indexed by two historical publications, Current Contents: Life Sciences (CC:LS) and Current Contents: Clinical Practice (CC:CP), from a leading commercial indexing service (the Institute for Scientific Information, or ISI) that were intended to cover basic and clinical research, respectively (Garfield 1972, Cardoni 1973). Concretely, we obtained a list of 702 journals from CC:CP as of January 1973 (when it was first published, and shortly after our sample period ends), and over 1,000 journals from CC:LS in 1973 (for consistency). We hand-matched these journals to those in MAG, successfully linking 80% of the former to the latter. Articles in the linked journals are then categorized as basic, clinical, mixed, or neither based on whether they appear in CC:LS or CC:CP. Our third approach applies the term lists in Lewison and Paraje (2004) to identify articles as basic or clinical based on the presence of those terms in their titles.[5]

[5]The MAG-based basic and clinical subject headings are easy to use, but are opaque in how they are assigned. In comparison to MAG headings, ISI-based classification is better understood, contemporary to the period we study, and evidently was commercially valuable. As Cardoni (1973) writes in a review of CC:CP: "Current Contents/Life Sciences provides tables of contents of over 1,000 medical science journals and includes broad coverage of basic science and medical specialty publications. Current Contents/Clinical Practice is a new service covering 700 journals and emphasizing clinical practice journals while providing minimal coverage of basic science journals." Cardoni goes on to explain that "the majority of journals falling into this category are basic science in nature and are not directly related to clinical topics," which reinforces our preference for these lists.

A.3 Pharmaceutical innovation

Our second set of outcomes measure drug development. We digitize de Haen (1976)'s "Compilation of New Drugs, 1940-1975" to produce a list of new drugs introduced over this period (see Figure A.6 for an excerpt), reporting 1,010 drugs developed by 126 distinct firms, including information on the drug class, trademark name, generic name, and year of introduction. We use these data in two ways. First, we manually crosswalk drug classes to 12-digit MeSH codes on the "therapeutic use" and "physiological effects" subbranches of the "pharmacologic action" branch of the MeSH tree (codes D27.505.954 and D27.505.696, respectively), obtain associated terms, aggregate up to the MeSH code-year of term-year level—in analogous format to our analysis of scientific publications. Second, we aggregate up by firm-year and study effects on firms.

Figure A.6: Sample from de Haen (1976) drugs list

COMPILATION OF NEW DRUGS

Marketed	Trademark	Generic Name	Originator	Developer
Analgesics				
		—MIGRAINE THERAPY—		
1946	D.H.E.45	dihydroergotamine mesylate	Sandoz (Switzerland)	Sandoz
1962	Sansert	methysergide maleate	Sandoz (Switzerland)	Sandoz
		—NARCOTICS—		
1944	Demerol HCl	meperidine HCl	Winthrop (U.S.)	Winthrop
1947	Dolophine HCl	methadone HCl	I. G. Farben (Germany)	Lilly
1947	Metapin	methyldihydro-morphinone	Parke-Davis (U.S.)	Parke-Davis
1949	Nisentil	alphaprodine HCl	Hoffmann-La Roche (U.S.)	Hoffmann-La Roche
1951	Dromoran	racemorphan HBr	Hoffmann-La Roche (Switzerland)	Hoffmann-La Roche

Notes: Figure provides an except from de Haen (1976)'s "Compilation of New Drugs, 1940-1975," which lists chemical entities and synthesized drugs available in the U.S.

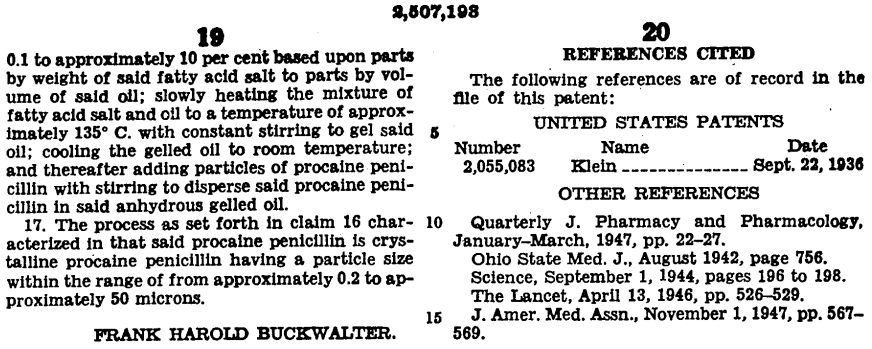
Our firm analysis involves two further steps. Because some firms in our sample merged during our study period, we collect information on M&A from U.S. Federal Trade Commission (1980), which reports acquisitions of manufacturing firms with at least $10 million in assets between 1947 and 1978. We dynamically reassign firms to their contemporary parent in the years after a known merger. Second, we manually crosswalk these firms to assignees in patent data, which we obtain from Google Patents (through Google BigQuery). We then identify drug patents belonging to these firms filed between 1930 and 1970, measuring "drug patents" as patents in NBER patent category 31 (Hall et al. 2001), corresponding to USPC 424 and 514.

Measuring drug patents' connections to science

We further measure whether these drug developers' patents reference scientific literature, focusing on "in-text" citations made in the patent disclosure. Bryan et al. (2020) argue that in-text citations may be a better measure of an invention's knowledge inputs than "front-page" citations to non-patent literature (NPL), whose legal purpose is identifying prior art against which claims are evaluated. Though NPL can nevertheless signal proximity to science, an important drawback to NPL citations for this paper is that they only began to be included in patents granted after February 1947 (at that time, at the end of the patent; see example in Figure A.7), which coincides with the end of the war. Evaluating changes around this period in the rate at which patents filed in the

1940s cite NPL thus risks attributing growth in NPL to the war, when it is a mechanical effect of the introduction of a new requirement to include prior art references in patent publications. In-text citations, on the other hand date back to the establishment of the modern Patent Office in 1836 and can therefore be observed both before and after World War II.

Figure A.7: Example list of patent and non-patent citations from the last page of a 1950 patent (patent 2,507,193, for "Penicillin product", filed by Bristol Laboratories)



2,507,193

19

0.1 to approximately 10 per cent based upon parts by weight of said fatty acid salt to parts by volume of said oil; slowly heating the mixture of fatty acid salt and oil to a temperature of approximately 135° C. with constant stirring to gel said oil; cooling the gelled oil to room temperature; and thereafter adding particles of procaine penicillin with stirring to disperse said procaine penicillin in said anhydrous gelled oil.

17. The process as set forth in claim 16 characterized in that said procaine penicillin is crystalline procaine penicillin having a particle size within the range of from approximately 0.2 to approximately 50 microns.

FRANK HAROLD BUCKWALTER.

20

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,055,083	Klein	Sept. 22, 1936

OTHER REFERENCES

Quarterly J. Pharmacy and Pharmacology, January–March, 1947, pp. 22–27.
Ohio State Med. J., August 1942, page 756.
Science, September 1, 1944, pages 196 to 198.
The Lancet, April 13, 1946, pp. 526–529.
J. Amer. Med. Assn., November 1, 1947, pp. 567–569.

Notes: Figure provides an example list of non-patent literature cited in a post-1947 patent as prior art. Excerpted last page of US patent 2,507,193 ("Penicillin product").

To identify patents which cite science, we use the 2019 version of the Marx and Fuegi (2020, 2022) patent citations to science (PCS) file, which we found to be more complete for this period than the latest file. We restrict to citations measured with a confidence score of 5 (out of 10) or higher, based on manual validation of a subset of the data, though our results are not sensitive to this choice. We further restrict to referenced articles which are identified by the data providers as cited in-text or both in-text and front-page (in our period, final page).

For older patents, the PCS data (in both the 2019 file and the current file) appear to mistakenly count some NPL citations as in-text. Through manual inspection of a random sample of 50 in-text PCS citations over the 1930-1970 period, we found that approximately 40% of the reported in-text citations we reviewed were actually NPL. Mismeasurement is a particular concern prior to USPTO's transition to structured electronic data in the 1970s, since NPL citations in these years have to be extracted from unstructured, digitized patent publications, where algorithmically distinguishing between in-text and front-page (or final-page) citations is more difficult.

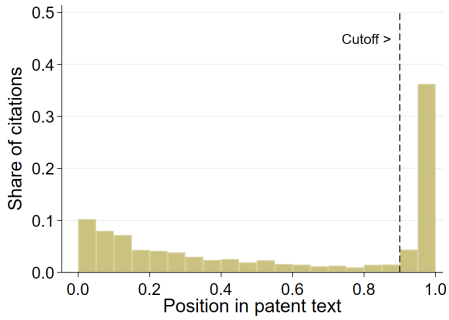
To investigate further, we obtained from Google Patents (via Google BigQuery) the full text of each patent in our sample. For each patent-paper citation, we then merged in publication information (first author, journal, publication year; retrieved from MAG) and patent text, extracted the first author's surname, and looked for the character position of each of these features in the text. When found, we took these positions and divided them by the patent length.

As Figure A.8 shows, the distribution of these positions has a significant mass near the end of a patent, which points to citations which are likely to be NPL rather than in-text. To limit the extent of these false positives (which, again, are only reported after 1947, and thus a particular concern for our study) we set a rule that if any of the publication features (first author surname, journal

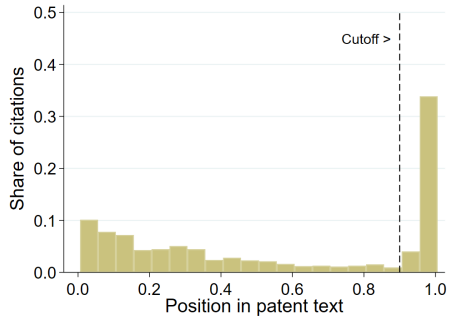
name, or publication year) is found in the patent text and its first position is in the last 10% of the patent, it should be considered an NPL citation and dropped from our in-text citation sample. Out of the initial set of 4,500 reported in-text PCS in the Marx-Fuegi data made by the patents in our sample, this procedure drops approximately 1,650 (36%) of them.

Figure A.8: Distribution of cited author/journal position in patent text

Panel (A): Distribution of last author location in patent text, as a share of all characters



Panel (B): Distribution of journal name location in patent text, as a share of all characters



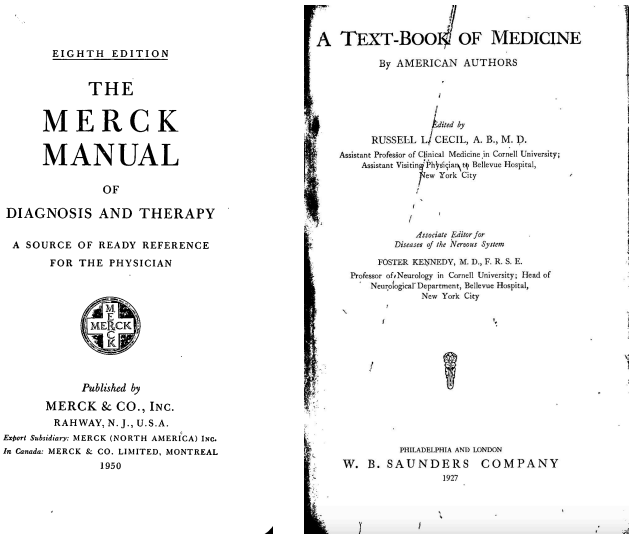
Notes: Figure provides distribution of the character position of cited author/journal names in the text of patents which are measured by Marx and Fuegi (2020, 2022) as science-citing. The mass near one suggests NPL mismeasured as in-text citations. We apply a cutoff of 90% to remove these cases from our in-text citation sample.

A.4 Mid-century medical textbooks

Our third set of outcomes studies knowledge diffusion. We use medical textbooks to measure the diffusion of biomedical research subjects into medical practice, focusing on two textbook series which were published both before and after the war: the *Merck Manual of Diagnosis and Therapy* (MM) and the *Cecil Textbook of Medicine* (CT).[6] Figure A.9 shows the covers of the Merck Manual and Cecil Textbook. We collect four editions of the Merck Manual covering 1940, 1950, 1956, and 1961 (editions 7 to 10) and nine editions of the Cecil Textbook covering 1930, 1933, 1937, 1940, 1943, 1947, 1951, 1955, and 1959 (editions 2 to 10). From each edition, we digitize the index and process it through MTI to identify covered subjects.

[6]Our interpretation of textbooks as an indicator of medical knowledge is based on textbooks historically being a principal source of guidance for practicing physicians (Catillon 2017).

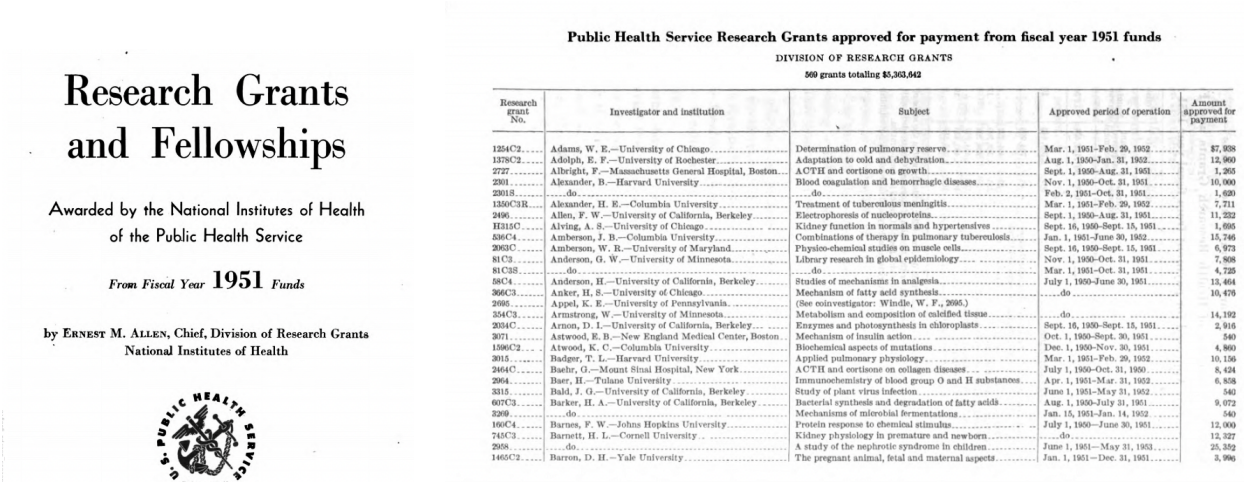
Figure A.9: Merck Manual and Cecil Textbook practitioner texts: sample volumes



A.5 NIH extramural research grants

Our final set of outcomes measures postwar extramural NIH grants. We digitize annual editions of the U.S. Public Health Service's *Research Grants and Fellowships Awarded by the National Institutes of Health* from 1948 to 1970 to collect information on all NIH grants over this period, including the grant number, PI, institution, title, amount and funding institute (see Figure A.10 for an example). Similar to other data sources, we process grant titles through MTI to associate them to medical subjects and measure subject-level NIH support.

Figure A.10: NIH research grant listing: sample volume


Research Grants and Fellowships

Awarded by the National Institutes of Health of the Public Health Service

From Fiscal Year **1951** *Funds*

by ERNEST M. ALLEN, Chief, Division of Research Grants
National Institutes of Health

U.S. PUBLIC HEALTH SERVICE

Public Health Service Research Grants approved for payment from fiscal year 1951 funds

DIVISION OF RESEARCH GRANTS

569 grants totaling $5,363,642

Research grant No.	Investigator and institution	Subject	Approved period of operation	Amount approved for payment
1254C2	Adams, W. E.—University of Chicago	Determination of pulmonary reserve	Mar. 1, 1951–Feb. 29, 1952	$7,938
1378C2	Adolph, E. F.—University of Rochester	Adaptation to cold and dehydration	Aug. 1, 1950–Jan. 31, 1952	12,960
2727	Albright, F.—Massachusetts General Hospital, Boston	ACTH and cortisone on growth	Sept. 1, 1950–Aug. 31, 1951	1,265
2301	Alexander, B.—Harvard University	Blood coagulation and hemorrhagic diseases	Nov. 1, 1950–Oct. 31, 1951	10,000
2301S	do	do	Feb. 2, 1951–Oct. 31, 1951	1,620
1350C3R	Alexander, H. E.—Columbia University	Treatment of tuberculous meningitis	Mar. 1, 1951–Feb. 29, 1952	7,711
2490	Allen, F. W.—University of California, Berkeley	Electrophoresis of nucleoproteins	Sept. 1, 1950–Aug. 31, 1951	11,332
H315C	Alving, A. S.—University of Chicago	Kidney function in normals and hypertensives	Sept. 16, 1950–Sept. 15, 1951	1,695
536C4	Amberson, J. B.—Columbia University	Combinations of therapy in pulmonary tuberculosis	Jan. 1, 1951–June 30, 1952	15,746
2063C	Amberson, W. R.—University of Maryland	Physico-chemical studies on muscle cells	Sept. 16, 1950–Sept. 15, 1951	6,973
81C3	Anderson, G. W.—University of Minnesota	Library research in global epidemiology	Nov. 1, 1950–Oct. 31, 1951	7,808
81C3S	do	do	Mar. 1, 1951–Oct. 31, 1951	4,725
58C4	Anderson, H.—University of California, Berkeley	Studies of mechanisms in analgesia	July 1, 1950–June 30, 1951	13,464
366C3	Anker, H. S.—University of Chicago	Mechanism of fatty acid synthesis	do	10,476
2695	Appel, K. E.—University of Pennsylvania	(See coinvestigator: Windle, W. F., 2695.)		
354C3	Armstrong, W.—University of Minnesota	Metabolism and composition of eviscerated tissue	do	14,192
2354C	Arnon, D. I.—University of California, Berkeley	Enzymes and photosynthesis in chloroplasts	Sept. 16, 1950–Sept. 15, 1951	2,916
3071	Astwood, E. B.—New England Medical Center, Boston	Mechanism of insulin action	Oct. 1, 1950–Sept. 30, 1951	540
1596C2	Atwood, K. C.—Columbia University	Biochemical aspects of mutations	Dec. 1, 1950–Nov. 30, 1951	4,860
3015	Badger, T. L.—Harvard University	Applied pulmonary physiology	Mar. 1, 1951–Feb. 29, 1952	10,156
2464C	Baehr, G.—Mount Sinai Hospital, New York	ACTH and cortisone on collagen diseases	July 1, 1950–Oct. 31, 1950	8,424
2964	Baer, H.—Tulane University	Immunochemistry of blood group O and H substances	Apr. 1, 1951–Mar. 31, 1952	6,858
3315	Bald, J. G.—University of California, Berkeley	Study of plant virus infection	June 1, 1951–May 31, 1952	540
607C3	Barker, H. A.—University of California, Berkeley	Bacterial synthesis and degradation of fatty acids	Aug. 1, 1950–July 31, 1951	9,072
3260	do	Mechanisms of microbial fermentations	Jan. 15, 1951–Jan. 14, 1952	540
160C4	Barnes, F. W.—Johns Hopkins University	Protein response to chemical stimulus	July 1, 1950–June 30, 1951	12,000
745C3	Barnett, H. L.—Cornell University	Kidney physiology in premature and newborn	do	12,327
2958	do	A study of the nephrotic syndrome in children	June 1, 1951–May 31, 1953	25,352
1465C2	Barron, D. H.—Yale University	The pregnant animal, fetal and maternal aspects	Jan. 1, 1951–Dec. 31, 1951	3,996

B Supplementary Results

B.1 Evidence from the raw data

Our analysis of CMR effects on science (Section 4) effectively compares the postwar growth of CMR-funded research subjects against others. Even absent regressions, descriptive evidence from raw publication counts in individual subjects is revealing of the CMR effect, including of the utility in drawing distinctions between existing and new subjects.

The raw data suggest that despite the specificity of the wartime problems CMR targeted, research it funded may have been more broadly impactful. One such indication is visible in publication counts alone. Table B.1 lists the top five MeSH terms entering the publication record (based on titles in the complete MAG corpus) each year between 1939 and 1946. For each term, we also report the number of associated publications over the next 10 years and indicate whether the subject was a focus of CMR research. The final row of each panel shows averages for lower-ranked new subjects for comparison. Treatments and therapies that CMR cultivated were immensely more likely to be the most heavily studied new subjects of this period. Despite that CMR cost only a few hundred million dollars (in 2024 dollars) and produced only around 2,500 scientific publications (out of roughly 280,000 published between 1939 and 1946), nearly half of the eventual top research subjects from this era were introduced or supported by CMR.

Figure B.1(A) shows the time series of publication activity for example MeSH terms in four CMR-funded research areas—antibiotics, steroids, blood, and malaria. Consistent with Stewart (1948)'s observation that "some subjects are born of war," several specific terms in these areas have little pre-war publication activity but take off after the war ends. Others had existing, pre-war research activity but nevertheless grew significantly after World War II (e.g., Oxygen).[7] As we discuss in Online Supplement B, historical accounts of specific CMR research programs at times point out pre-war knowledge they built on, but even more often remark on the subjects of wartime research having been essentially new and unexplored (Andrus 1948). This was the case not only for a range of specific drugs discovered or developed during the war (like penicillin or new classes of antimalarials), but also for the many new physiological problems that World War II presented (like hypoxia or decompression sickness at 50,000-ft. heights).

The data are also revealing of the importance of using inputs, rather than outputs, as a measure of the CMR shock (as we discuss in Appendix A)—especially when read in conjunction with history. Several CMR programs failed to achieve breakthroughs during the war itself but nevertheless may have created a platform for postwar innovation. This was most notably the case for synthetic antibiotics, but also applied in other areas. CMR likewise funded efforts to synthesize cortisone which were unsuccessful during the war itself, but which supported a postwar explosion of research on cortisone and corticosteroids, visible in Figure B.1(A).

As a point of comparison, in Figure B.1(B) we plot similar charts of publications over time in subjects which in 1935, the NIH—then intramural, and with very limited funding—identified as research priorities for civilian health. We see little evidence of growth comparable to that in some

[7] An exception is malaria, which had roughly constant publication activity over time; though research in antimalarials temporarily spiked in World War II, that intensity was not sustained in the postwar era.

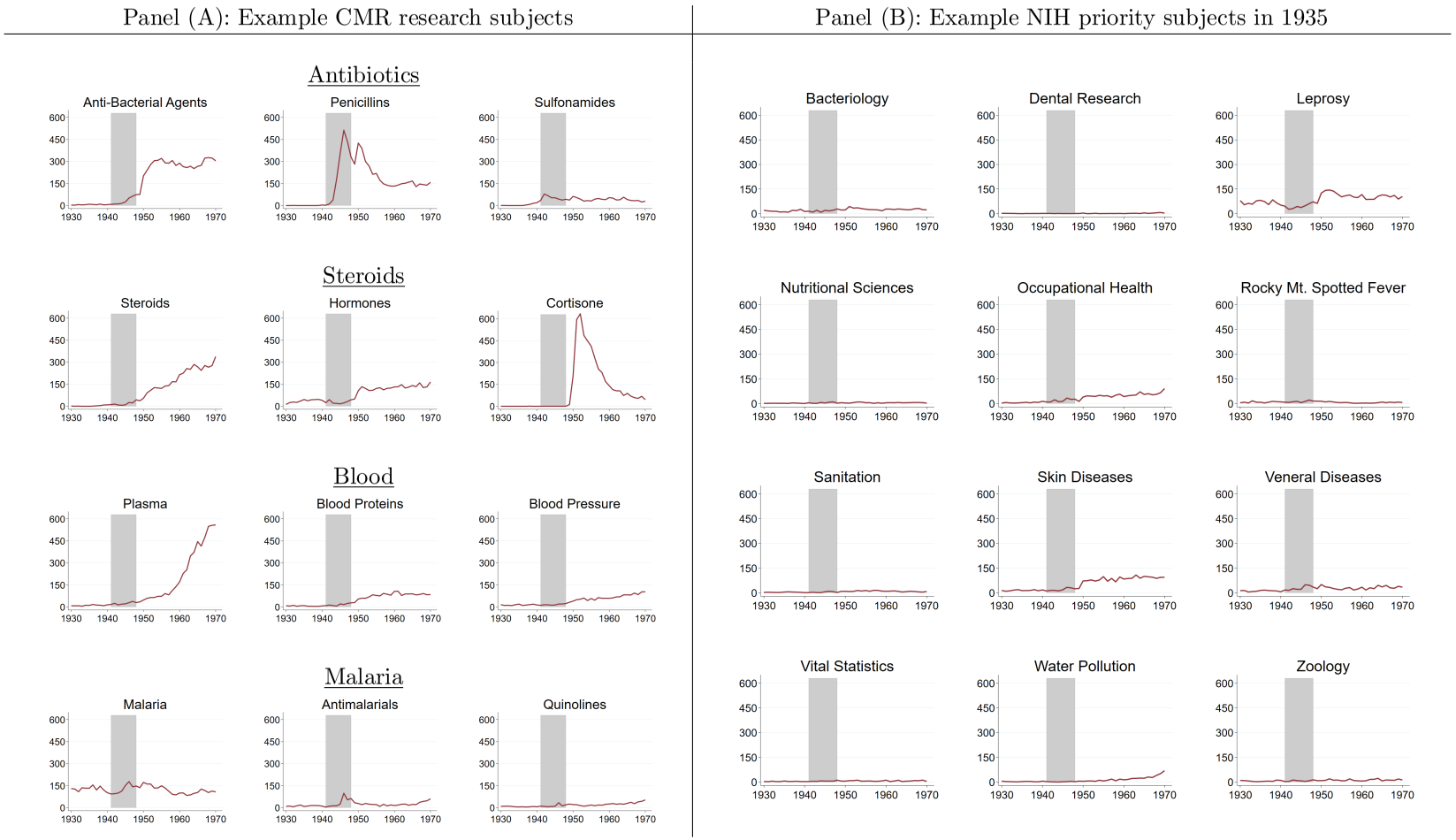
of the faster-growing subjects in Figure B.1(A)—though the comparison may be strained by the NIH priority list being organized around specific diseases (leprosy) or problem-oriented research fields (bacteriology, nutrition), and the CMR subject list including both diseases and therapies, the latter of which are the subjects with the largest postwar growth.

Table B.1: Top new MeSH terms entering the publication record, by year, 1939-1946

Rank	MeSH term	Pubs (10-yr)	CMR	Rank	MeSH term	Pubs (10-yr)	CMR
	1939				1943		
1	Sulfathiazole	407	1	1	Chromatography, Paper	367	0
2	Diphenhydramine	118	0	2	Penicillin G	244	1
3	Phenytoin	101	1	3	Angiocardiography	155	0
4	17-Ketosteroids	96	1	4	Coxsackievirus Infections	99	0
5	Fenestration, Labyrinth	87	0	5	Penicillin V	60	1
average, lower ranked subjects		4.4	0.03	average, lower ranked subjects		5.7	0.02
	1940				1944		
1	DDT	558	1	1	Streptomycin	4685	1
2	Thiouracil	425	0	2	Penicillin G Procaine	249	0
3	Sulfathiazoles	191	1	3	Parathion	212	0
4	Hyaluronoglucosaminidase	181	1	4	Disulfiram	179	0
5	Sulfaguanidine	94	1	5	Polyethylene	149	0
average, lower ranked subjects		4.9	0.02	average, lower ranked subjects		10.4	0.06
	1941				1945		
1	Histamine Antagonists	301	0	1	Nuclear Weapons	225	0
2	Tyrothricin	107	1	2	Dimercaprol	223	1
3	Radioactive Tracers	51	0	3	Methylthiouracil	200	0
4	Fontan Procedure	50	0	4	Nucleons	169	0
5	Folic Acid Deficiency	47	0	5	Histoplasmin	155	0
average, lower ranked subjects		5.2	0.03	average, lower ranked subjects		9.9	0.04
	1942				1946		
1	Dicumarol	371	1	1	Chloroquine	290	1
2	Newcastle Disease	116	1	2	Hypotension, Controlled	205	0
3	Sulfamerazine	84	1	3	Propylthiouracil	202	0
4	Penicillium chrysogenum	67	1	4	Tripelennamine	131	1
5	Stilbamidines	53	0	5	Promethazine	126	0
average, lower ranked subjects		5.0	0.02	average, lower ranked subjects		9.5	0.03

Notes: Table lists the annual top 5 new MeSH terms in our publication data from 1939 to 1946, as determined by our indexing of publication titles. For each term we provide the number of associated publications over the next 10 years, and we indicate whether the subject was CMR-funded, measured as having an associated CMR contract or publication. The last row for each year provides averages for all lower-ranking terms. The evidence in the table suggests that many of the most important new biomedical research subjects and therapies emerging at this time were subjects of CMR research.

Figure B.1: Annual publications in select research subjects around World War II

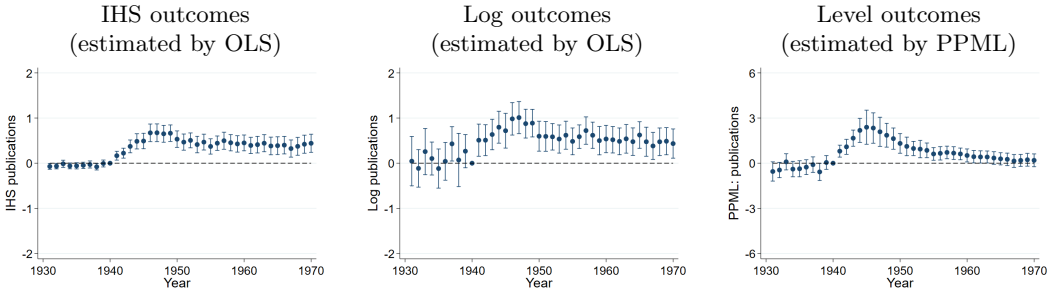


Notes: Panel (A) shows the total publications for select MeSH terms which were major subjects of CMR research. Panel (B) shows the total publications for select MeSH terms which were NIH priorities in 1935. Shaded region in each subfigure marks the war era (1941 to 1948, when most CMR articles were published).

B.2 Alternative specifications: Logged and level outcomes

Figure B.2 presents variants on Figure 3 from the body of the paper using different transformations of the outcome variable (MTI score-weighted publication counts). As in the body of the paper, we focus our analysis on embryonic subjects, defined as those with less than the median number of pre-1940 publications. The first column shows OLS estimates from a specification with inverse hyperbolic sine (IHS) outcomes, as in the body of the paper. The second column presents OLS estimates for log outcomes, dropping MeSH term-years with zero publications. The third column presents PPML estimates for level (i.e., score-weighted count) outcomes.

Figure B.2: Effects of CMR on research publications in treated subjects, 1930-1970; comparison of IHS, logged, and level outcomes



Notes: Figure shows annual estimates of the differential growth of scientific publications in MeSH terms with CMR funding, relative to others. The sample is restricted to MeSH terms with less than the median number of pre-1940 publications. Column (1) shows OLS estimates from a specification with inverse hyperbolic sine outcomes, reproducing the contents of Figure 3 in the paper. Column (2) shows OLS estimates from a specification with logged outcomes. Column (3) shows Poisson pseudo maximum likelihood (PPML) estimates from a specification with level outcomes. Error bars represent 95% confidence intervals, with SEs clustered at the MeSH term level.

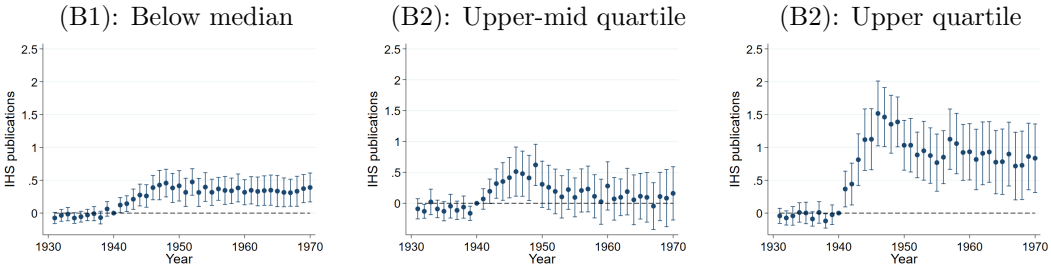
B.3 Intensive margin: Value-weighted shock

Figure B.3 below re-evaluates Figure 3 in the paper, estimating the effects of value-weighted CMR shock (the intensive margin) rather than an indicator for whether a subject was the target of any CMR contracts (the extensive margin). We group subjects into three treatment quantiles, based on (MTI score-weighted) total funding: below-median, upper-middle quartile, and upper quartile. We then estimate the following regression, where q indexes each of these treatment quantiles, and the omitted category consists of subjects with no CMR contracts:

$$Y_{mt} = \sum_{q=1}^{3} \sum_{t=1931}^{1970} \beta_{qt} \cdot \mathbb{1}(\text{Term } m \text{ in treatment quantile } q) + \alpha_m + \delta_t + \varepsilon_{mt}$$

This specification essentially estimates heterogeneous effects in Equation (1) for three groups of subjects: those with the lowest, higher, and highest CMR funding level. Figure B.3, finds the largest effects in the highest treatment quantiles. Our preferred treatment measure is nevertheless an extensive one, for reasons we describe in the paper (Section 4).

Figure B.3: Effects of CMR on research publications in treated subjects, 1930-1970, by quantile of CMR funding (0-50th, 50-75th, 75-100th percentiles)

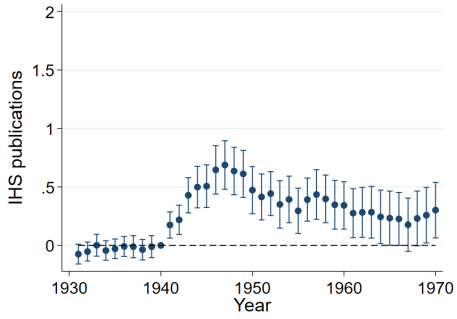


Notes: Figure shows annual estimates of the differential growth of scientific publications in MeSH terms with different levels of CMR funding, relative to others. The sample is restricted to MeSH terms with less than the median number of pre-1940 publications. New combinations are defined as new co-occuring MeSH terms in an article with the given MeSH term. Error bars represent 95% confidence intervals, with SEs clustered at the MeSH term level.

B.4 Comparisons to a matched control group

Figure B.4 below re-evaluates Figure 3 in the paper, comparing treated subjects against a nearest-neighbor matched control group. The matched controls for each treated subject are determined via propensity score matching on pre-1940 observable characteristics, effectively finding subjects which were observably similar up to this moment but were not subsequently treated. Matched controls are identified based on: (i) number of pre-1940 publications, (ii) a categorical measure of new, embryonic, or established subjects (with 0, below median, or above median pre-1940 publications), (iii) a categorical measure of their growth rate from 1930-34 to 1935-39 (shrinking, stagnant, or growing), and (iv) indicators for membership in each MeSH tree branch. We retrieve the two nearest control subjects for each treated subject, which each receive half weight, though results are similar under other configurations. Figure B.4 returns similar but somewhat attenuated results in comparison to those in the body of the paper. We prefer analysis on the full sample, as matching risks conditioning out potential pre-existing trend differences.

Figure B.4: Effects of CMR on research publications in treated subjects, 1930-1970, comparing treated subjects with a matched control group



Notes: Figure shows annual estimates of the differential growth of scientific publications in MeSH terms with CMR funding, relative to others. The sample is restricted to MeSH terms with less than the median number of pre-1940 publications. All results are based on specifications which restricts the sample to treated subjects and a matched control group for each treated subject, determined based on: (i) the number of pre-1940 publications, (ii) a categorical measure of new, embryonic, or established subjects, (iii) a categorical measure of their growth rate from 1930-34 to 1935-39 (shrinking, stagnant, or growing), and (iv) indicators for membership in each MeSH tree branch. Error bars represent 95% confidence intervals, with SEs clustered at the MeSH term level.

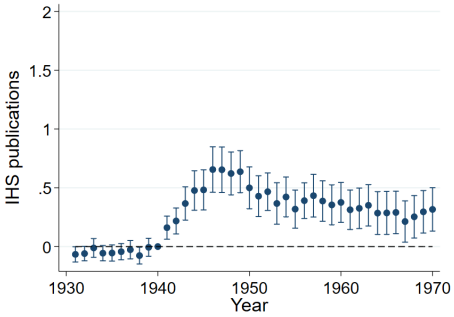
B.5 Controlling for postwar NIH funding

Figure B.5 below presents robustness checks on (i.e., re-estimations of) Figure 3 in the paper, controlling for indicators of whether a given MeSH term was funded by NIH interacted with observation year. Concretely, we estimate the following specification:

$$Y_{mt} = \sum_{t=1931}^{1970} [\beta_t \cdot \mathbb{1}(\text{Any CMR contracts in MeSH term } m) + \gamma_t \cdot \mathbb{1}(\text{Any postwar NIH grants in MeSH term } m)] + \alpha_m + \delta_t + \varepsilon_{mt}$$

The estimated CMR effect are quantitatively and statistically similar, suggesting the CMR effect is neither explained by nor confounded by postwar research funding.

Figure B.5: Effects of CMR on research publications in treated subjects, 1930-1970, controlling for postwar NIH funding (see text for discussion)



Notes: Figure shows annual estimates of the differential growth of scientific publications in MeSH terms with CMR funding, relative to others. The sample is restricted to MeSH terms with less than the median number of pre-1940 publications. All results are based on specifications which control for an indicator of whether the given MeSH term received postwar NIH funding (through 1970), interacted with years. Error bars represent 95% confidence intervals, with SEs clustered at the MeSH term level.

B.6 Placebo test: World War I

Though World War II produced the first large-scale government funding of medical research, it potentially represents a bundle of two shocks: war (a demand shock for new science and technology) and medical R&D funding (a supply shock). Given their coincidence, the results in Section 4 may be difficult to attribute to CMR specifically, particularly if war has a demand-pull effect that brings research attention (and research activity) to subjects that were previously understudied, and that in turn triggers accumulative endogenous growth in science.

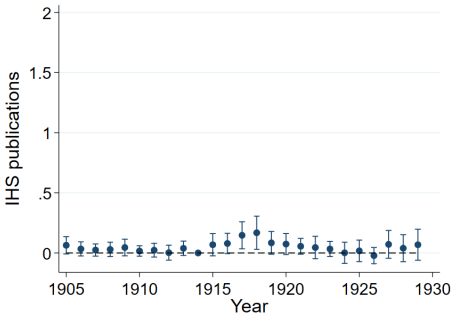
To separate CMR's effects from any general effects of war, we take our research strategy to World War I. We first identify medical subjects implicated in World War I by digitizing the index to American Red Cross (1918) titled *War Medicine*, a publication of the American Red Cross Society in France for medical officers of the U.S. Army presenting war-induced medical conditions, and processing it with MTI (see Appendix A) to link it to MeSH space. We then extend our MAG publication sample backwards to 1905 and run analogous regressions to those in Section 4 of the paper on a sample of MeSH terms between 1905 and 1929 (immediately preceding our World War

II sample). Formally, we estimate the following specification:

$$Y_{mt} = \sum_{t=1906}^{1929} \beta_t \cdot \mathbb{1}(\text{MeSH term } m \text{ relevant to WWI}) + \alpha_m + \delta_t + \varepsilon_{mt} \tag{3}$$

where m and t index MeSH terms and years, and standard errors clustered by MeSH term. Following Section 4, in Figure B.6 we estimate this regression for subjects with below median pre-1914 publications, though results are similar for others. In contrast to the effects of CMR in this paper, we find little evidence of a generic effect of war on science.

Figure B.6: Pseudo-effects of "war shock" in World War I, 1905-1929



Notes: Figure shows annual estimates of the differential growth of scientific publications around World War I (sample period: 1905-1929, with the war taking place in 1914-1918) in MeSH subjects implicated in World War I (according to American Red Cross publications), relative to others. Panel (A) does so for all MeSH terms. The sample is restricted to MeSH terms with less than the median number of pre-1914 publications. Omitted (reference) year in all figures is 1914. Error bars represent 95% confidence intervals, with SEs clustered at the MeSH term level.

B.7 Growth of the pharmaceutical industry

This appendix provides additional context, descriptive data, and results with respect to the postwar pharmaceutical industry and its relation to World War II. Section B.7.1 examines the growth of the industry, and Section B.7.2 changes in the nature of drug discovery.

B.7.1 The "golden age" of drug discovery

As we explain in the paper, several important changes to pharmaceutical science and drug innovation are understood to have taken place in the mid-20th century, such as the rise of synthetic chemistry and molecular biology, the growth of rational drug design and systematic drug screens, or advances in clinical testing. Many of these changes ostensibly have links to the war, including in efforts to synthesize new treatments for specific diseases or in large-scale testing, such as the first application of high-throughput screening in the search for new antimalarials.

The degree to which these changes were in fact triggered by the war is potentially an empirically-detectable question, and data on 20th century drug innovation (from de Haen 1976) may provide a window into the answer. Some initial indications are shown in Table B.2, which lists CMR- and WPB-contracted pharmaceutical firms in the De Haen data, along with their total number of drugs introduced in 5-year intervals from 1940 to 1970. By sheer counts, the late 1940s and 1950s was a revolutionary period for drug discovery, especially among CMR/WPB firms, whose average annual new drug introductions more than tripled to over 10 per firm every five years. Other firms increased their average 5-year drug introductions from 0.7 to 1.5 per firm.

Table B.2: Postwar new drugs developed by CMR- and WPB-contracted firms

	New drugs introduced in:					
Firm	1940-45	1946-50	1951-55	1956-60	1961-65	1966-70
Abbott	5	10	14	11	3	2
American Cyanamid	4	7	12	8	4	3
Armour	0	1	2	2	1	0
Bristol	0	0	2	6	4	1
Commercial Solvents	0	4	3	0	0	0
Hoffmann-La Roche	7	7	15	10	7	4
Lilly	4	9	17	11	11	2
Merck, Sharp & Dohme	8	11	12	19	10	4
Parke-Davis	6	8	4	10	2	3
Pfizer	0	2	7	11	1	5
Squibb	0	6	9	7	2	3
Upjohn	1	6	10	12	4	4
Warner	0	1	5	5	5	1
Winthrop	3	3	7	6	2	3
Wyeth	1	5	7	18	6	6
CMR/WPB, Average	2.8	5.3	8.4	9.1	4.1	2.7
Others, Average	0.8	0.8	1.0	1.4	0.7	0.4

Notes: Table reports the number of new drugs developed and brought to market by CMR and WPB pharmaceutical contractors between 1940 and 1970, according to de Haen (1976), in five-year intervals. A small number of firms which merged during this period are combined throughout the sample (e.g., Merck and Sharpe & Dohme merged in 1953, and are reported as a single unit). The bottom row of the table compares these counts to the other-firm average.

Table 4 of the paper evaluates this growth econometrically in Panel (B), and formalizes this result: new drug development grew much more quickly in the first two postwar decades at CMR/WPB firms than others. By 1960, these firms were 20% more likely to introduce a new drug each year than non-CMR/WPB firms (Column 1), with similar effects for antibiotics and hormones (Column 2) and other drugs (Column 3). In percentage terms, the effect was to increase annual drug innovation by roughly 50% at these firms, relative to peers (Columns 4 to 6).

B.7.2 Growth of science-based drug discovery

Beyond its effects on postwar drug innovation, we can also explore whether CMR changed how firms approached drug discovery—i.e., the drug development process itself. To do so we shift our analytical unit from drugs to drug-related patents, focusing on patents filed between 1930 and 1970 by the firms in de Haen (1976). For the purposes of this analysis, we define "drug patents" as patents in the NBER patent category for drugs (Hall et al. 2001). This choice excludes other categories where pharmaceutical firms may have filed patents (such as organic or inorganic chemistry), in order to focus the sample on potential therapeutically-relevant inventions and exclude others—particularly because many drug-developing firms in this era (including the De Haen sample) were industrial chemical companies or had a parallel chemical business.

Through patent data we can get more granular insight into any potential changes in the nature pharmaceutical R&D. Our focus is on its relationship to science, for which we use existing data on patent citations to science (Marx and Fuegi 2020, 2022). For each patent in our sample, we measure whether it makes any in-text citations to scientific literature, limiting to in-text citations (rather than front-page) because (i) these are more likely to reflect intellectual inputs to the invention

and (ii) front-page citations were only written into patents beginning in 1946. Patents which cite science we will call "science-citing" or "science-based".

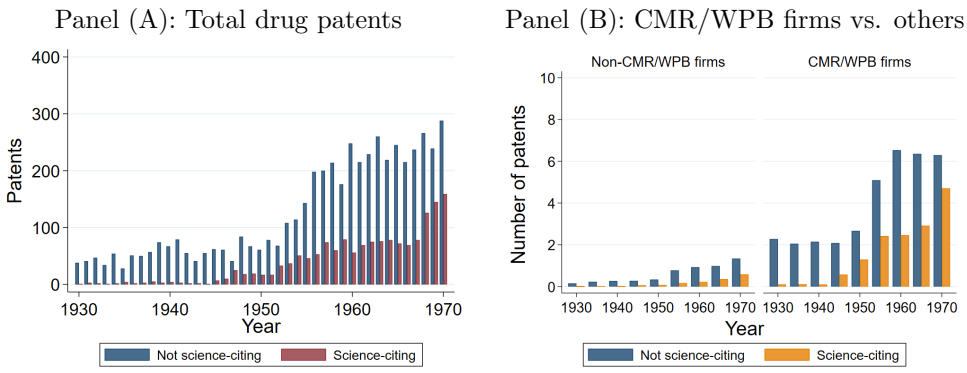
Figure B.7(A) plots annual counts of non-science and science-based patents in our sample. The figure provides two insights: first, prior to the late 1940s, total annual drug patenting by these firms was more or less constant; second, essentially none of these patents were based in science. Both patterns change after World War II: starting in the late 1940s, drug patenting begins to grow, with a rapid increase in science-based invention—whose share of patents grows substantially. Figure B.7(B) disaggregates this pattern further, showing average annual non-science and science-based patenting by non-CMR firms and CMR firms, respectively (presented in five-year intervals), where we see that these changes were mainly driven by CMR firms.

In Table B.3, we evaluate these differences econometrically. Specifically, for the De Haen (1976) firm sample, we estimate differences between CMR/WPB-contracted firms and others in their (i) science-based patenting and (ii) non-science based patenting, with parameters in 5-year intervals. We estimate a two-way fixed effects specification, as follows:

$$Y_{it} = \sum_t \beta_t \cdot \mathbb{1}(\text{CMR/WPB firm})_i + \alpha_i + \delta_t + \varepsilon_{it}$$

where i and t index firms and years, and the sample runs from 1930 to 1970, with standard errors clustered by firm. For precision we limit the panel to firm-years between each firm's first and last observed drug or patent, to ensure it only includes firm-years when the firm was known to be alive, though this restriction has little impact on the results.

Figure B.7: Total annual drug patents, science-citing and non-citing, 1930-1970, and average annual drug patents by CMR/WPB-contracted firms vs. others



Notes: Panel (A) shows the number of drug patents filed by firms in de Haen (1976), separately reporting science-citing and non-citing patents. Panel (B) shows the average annual number of science-citing and non-citing patents drug patents filed by CMR/WPB-contracted firms vs. other firms. Drug patents defined as those associated with NBER category 31 (Hall et al. 2001), and science-citing patents as those which cite non-patent literature (typically, scientific literature) in their text (Marx and Fuegi 2020, 2022).

We estimate this specification for three outcomes: (i) an indicator for whether the firm filed any science and non-science based patents (Columns 1 and 2, respectively), (ii) the number of such

patents (Columns 3 and 4), and (iii) the inverse hyperbolic sine (IHS) number of such patents (Columns 5 and 6). In all columns, time-varying parameters are estimated relative to the omitted 5-year interval of 1930-1934. The table shows several patterns. First, CMR/WPB firms rapidly increased their propensity to file science-based drug patents after World War II, with no discernable pre-trends pre-1940. Second, we find no such difference for non-science based patenting. On the intensive margin, we find growth in science-based patenting that roughly equals or exceeds growth in non-science based patenting. By the 1960s, CMR/WPB firms were roughly 50% more likely to file at least one drug-based patent in a given year (Columns 1 vs. 2) and increased their drug-based patenting nearly 50% more than other firms (Columns 5 vs. 6). The combination of results in Columns (1) and (2) in a triple-difference forms the basis for Figure 4(B) of the paper, which effectively shows the Column (1)-(2) difference in graphical form.

Table B.3: Science-citing patents by CMR- and WPB-contracted firms

	Any patents?		Num. patents		IHS(Patents)	
	(1)	(2)	(3)	(4)	(5)	(6)
	PCS	No PCS	PCS	No PCS	PCS	No PCS
CMR/WPB firm * 1(1935-1939)	0.010	-0.044	0.009	-0.067	0.010	-0.060
	(0.066)	(0.089)	(0.099)	(0.455)	(0.067)	(0.164)
CMR/WPB firm * 1(1940-1945)	0.052	-0.024	0.061	0.040	0.049	-0.001
	(0.053)	(0.097)	(0.099)	(0.779)	(0.056)	(0.210)
CMR/WPB firm * 1(1946-1950)	0.247***	-0.059	0.490*	-0.238	0.322**	-0.108
	(0.080)	(0.111)	(0.250)	(0.866)	(0.133)	(0.270)
CMR/WPB firm * 1(1951-1955)	0.528***	0.010	1.390***	0.772	0.826***	0.209
	(0.080)	(0.111)	(0.245)	(1.044)	(0.126)	(0.311)
CMR/WPB firm * 1(1956-1960)	0.491***	0.015	2.165***	2.650*	0.976***	0.510
	(0.093)	(0.097)	(0.615)	(1.581)	(0.217)	(0.316)
CMR/WPB firm * 1(1961-1965)	0.554***	0.043	2.277***	3.906**	1.043***	0.749**
	(0.071)	(0.100)	(0.619)	(1.512)	(0.201)	(0.310)
CMR/WPB firm * 1(1966-1970)	0.457***	0.015	2.821***	2.994**	1.099***	0.575*
	(0.095)	(0.104)	(0.710)	(1.479)	(0.236)	(0.313)
N	5172	5172	5172	5172	5172	5172
R^2	0.39	0.46	0.45	0.51	0.49	0.59
Y mean	0.133	0.275	0.307	0.987	0.180	0.445

Notes: Table estimates differences in pharmaceutical firms' annual science-based and other drug patenting, comparing CMR/WPB-contracted pharmaceutical firms to others. Sample consists of firms which introduced at least one new drug between 1940 and 1970, according to de Haen (1976). A small number of firms which merged or were acquired during the sample frame are dynamically reassigned to their subsequent owners using data from FTC (1980) (see text for details, including specific exceptions). The unit of analysis is a firm-year, and outcomes measure: (i) whether a firm filed any patents in drug classes (NBER category 31; Hall et al. 2001) in the given year (Columns 1 and 2), (ii) the number of such patents (Columns 3 and 4), and (iii) inverse hyperbolic sine (IHS) patents (Columns 5 and 6). Table separately estimates changes in patents that do vs. do not cite non-patent literature (typically, scientific literature) in their text (Marx and Fuegi 2020, 2022). Results are estimated relative to the 1930-1934 period. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by firm in parentheses.

B.8 Cross-country comparisons

One question raised by this paper is whether CMR's effects were specific to the United States or had wider reach. Both empirically and anecdotally, the CMR effort appears linked to the growth of U.S. biomedicine, including with some direct institutional legacies, up to the development of NIH's extramural research program. On the other hand, science and innovation are often considered non-excludable, and CMR could have conceivably had global impacts, including in very different

institutional environments. If other countries experienced similar growth in innovative output in CMR-supported subjects, relative to others and relative to the U.S., then the interpretation we offer in the paper of CMR's long-lived impacts being related to the growth of a distinctive and integrated biomedical innovation system may come into question.

In this appendix we examine this possibility more directly, asking whether biomedical science and technology in the U.S. and other countries were similarly affected. Section B.8.1 evaluates differences over time in biomedical scientific publications in CMR-supported subjects versus others in (i) U.S., (ii) German, (iii) Japanese, (iv) Dutch, and (v) Swiss journals. Because author affiliations and locations are not available from our data sources for this period, here we use journal countries as a proxy. After the United States, the largest publisher countries of biomedical research in our study period were Great Britain, Germany, Japan, and the Netherlands; we emphasize non-English speaking countries (namely, excluding Great Britain) to avoid contamination, as American authors published in British journals regularly (e.g., ≈10% of CMR-funded publications were published in British journals, whereas the other 90% were in U.S. journals).

In Section B.8.2 we compare drug discovery by CMR-supported firms versus others, or in CMR-supported drug classes and others, in the U.S. and Europe. We do so using additional data from de Haen (1976), which includes each drug's originating country, allowing us to make cross-country comparisons in the rate of new drug introductions over time. Here we compare U.S. and European drug discovery, grouping European countries in the De Haen data.

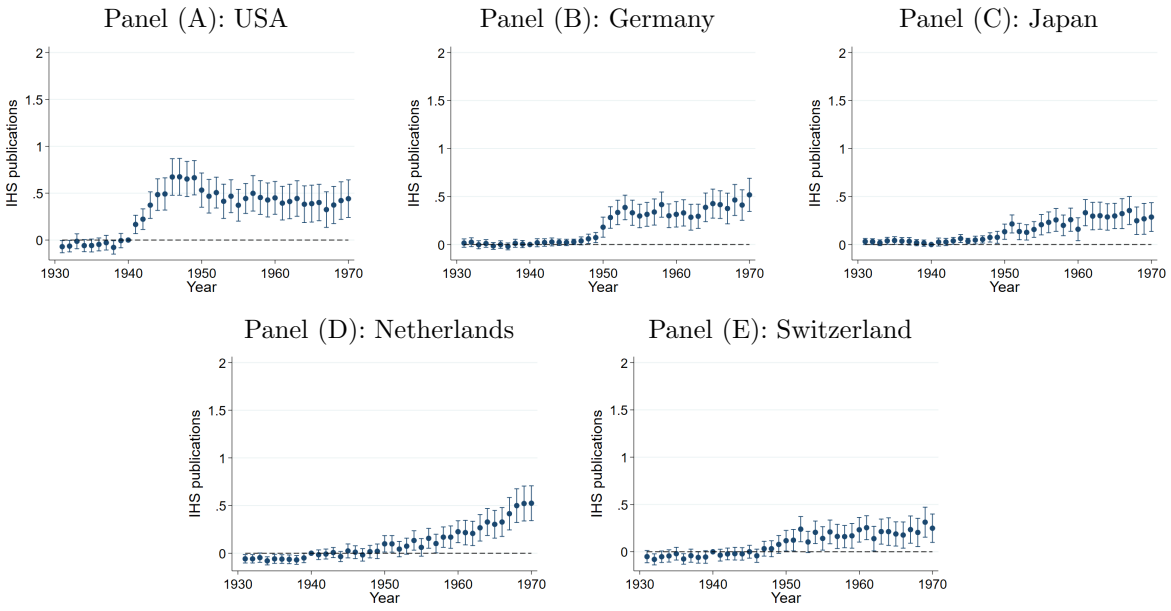
B.8.1 CMR and postwar science: Publications in foreign country journals

Figure B.8 re-estimates Figure 3 from the body of the paper for publications in U.S. and other country journals, focusing on embryonic subjects (with below-median pre-1940 publications). The evidence indicates that CMR subjects had differential publication growth in all of the countries shown, albeit of different magnitudes and over different time horizons: U.S. journals see the most immediate impact (as early as during the war) and largest sustained effects, whereas effects in other countries are more muted and slower to develop. The evidence suggests that CMR's effects spilled over globally, perhaps because science travels relatively freely.

B.8.2 CMR and postwar drug development: U.S. vs. Europe

Tables B.4 and Figure B.9 present evidence on new drugs. The table shows the average (per firm) number of new drugs introduced in five year intervals by CMR/WPB contractors in the U.S., other firms in the U.S., and other firms in Europe. The table shows that the postwar surge in new drug discovery was specific to U.S. drugs and CMR/WPB firms. The figure then transitions to drug classes as a unit of analysis and estimates annual differences in new drug introductions in CMR-supported drug classes versus others, in the U.S. and in Europe. The figure indicates that our results are driven entirely by the U.S. pharmaceutical sector, which has a surge in new drug discovery, with no comparable effect in Europe. Additional analysis similarly suggests that the increase in science-citing drug patents was specific to the U.S. Putting this evidence together, and considering the scale, scope, and rate of growth of the NIH, we see the evidence as broadly consistent with an interpretation of the emergence of a distinctive U.S. biomedical innovation system—one with faster-growing science and an increasingly productive, science-driven pharmaceutical sector.

Figure B.8: Effects of CMR on research publications treated subjects, 1930-1970, by publication country (i.e., country of the publication journal)



Notes: Figure shows annual estimates of the differential growth of scientific publications in MeSH terms with CMR funding, relative to others, in U.S. and other country journals. We treat journal country as an (imperfect but directional) proxy for author location, which is not available from MAG (or its successor, OpenAlex) for publications from this time period. Sample is restricted to "embryonic" subjects (with below-median pre-1940 publications). Each panel presents results for journals in the given country. Error bars represent 95% confidence intervals, with SEs clustered at the MeSH term level.

That drug development concentrated in the U.S. even as science globalized further suggests that specific firm capabilities or linkages bred in the war contributed to the emerging U.S. advantage in commercializing drug-related science, including foreign science.

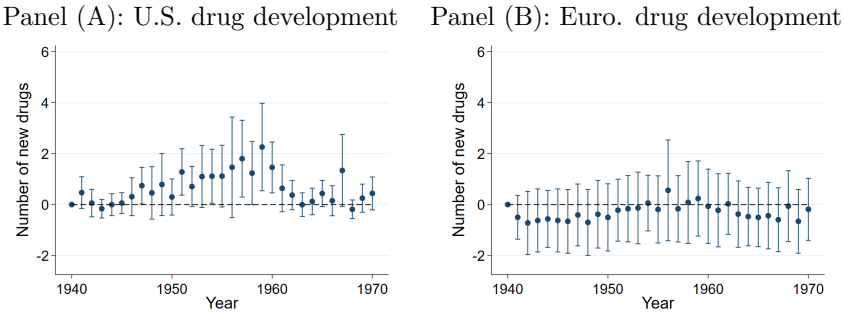
We find similar results at the firm level, comparing counts of drugs originating with CMR/WPB contractors and other firms, in the U.S. and Europe: large, statistically significant differences among US-originated drugs, but no such differences among European-originated drugs. These differences extend to patenting activity: the same firms' US-based drug patenting increases relative to other firms, but no differences emerge for European-based drug patenting; in particular, science-citing patenting increases in the U.S., but not in Europe (Figure B.10).

Table B.4: Postwar new drugs originated in U.S. by CMR- and WPB-contracted firms, in U.S. by other firms, and in Europe, 1940-1970, in 5-year intervals

	New drugs introduced in:					
Firm	1940-45	1946-50	1951-55	1956-60	1961-65	1966-70
CMR/WPB, Average	1.5	4.2	6.5	7.8	2.5	2.8
Other US Firms, Average	0.6	0.6	0.7	1.1	0.5	0.2
Europe Firms, Average	0.6	0.5	0.9	1.2	0.6	0.5

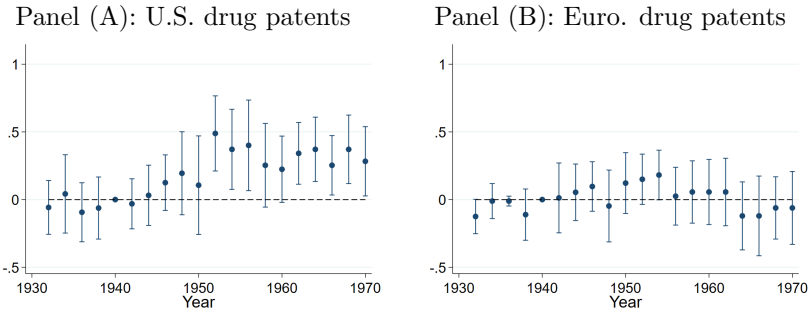
Notes: Table reports the average number of new drugs originated (i) in the U.S. by CMR and WPB pharmaceutical contractors between 1940 and 1970, (ii) in the U.S. by other firms, and (iii) in Europe, according to de Haen (1976). A small number of firms which merged during this period are combined throughout the sample (e.g., Merck and Sharpe & Dohme merged in 1953, and are reported as a single unit).

Figure B.9: Differences in annual drug counts in CMR-supported MeSH terms versus others, 1940-1970, for drugs originating in the U.S. and in Europe



Notes: Figure estimates differences in the annual number of new commercially-marketed drugs in de Haen (1976) associated with MeSH terms with CMR funding, relative to others, restricting the sample to terms in drug-related sub-branches of the *pharmacologic actions* branch of the MeSH tree (see text for details). Panel (A) reports differences for U.S. drug development, and Panel (B) for European drug development, using information in de Haen (1976) on the origin country. Error bars represent 95% confidence intervals, with SEs clustered at the MeSH term level.

Figure B.10: Differential growth in annual likelihood of filing science-citing vs. non-citing drug patents, by CMR/WPB-contracted firms vs. others, 1930-1970, U.S. vs. Europe



Notes: Panel (A) estimates differential growth in CMR/WPB-contracted firms' propensity to file US-invented, science-citing patents, relative to other pharmaceutical firms in the De Haen list. Panel (B) estimates differential growth in these firms' propensity to file European-invented, science-citing patents. Patent country measured using first inventor locations, and most CMR/WPB-contracted firms had Europe-based R&D (and patent filings) during our sample period by this measure; several had substantial Europe-based patent filings. Error bars represent 95% confidence intervals, with SEs clustered at the firm level.

B.9 Aggregate U.S. patenting

In this appendix we study changes in U.S. patenting over time across technology areas with differential CMR exposure. We do so in a CPC subclass x year panel from 1930 to 1970, restricting to CPCs where at least one patent in this period cites a biomedical research publication. For each such CPC-year we measure (i) the number of patents filed by U.S. inventors, (ii) the number with firm vs. other assignees, and (iii) the number produced with government funding, using data and measures produced in our own prior work (Gross and Sampat 2023a).

To measure each CPC's exposure to CMR, we begin by observing that individual technology areas' exposure to different fields of biomedical science is visible through the subjects of the publications

that patents in those areas cite—some of which were targets of CMR research. The share of cited science that is in CMR-supported subjects is an indicator of broad, technology-level exposure. To operationalize this idea we return to the Marx and Fuegi (2020, 2022) PCS data, but now expand the PCS sample to include both in-text and front-page citations, which also indicate proximity of an inventive area to particular scientific subjects. For each citation to a scientific publication that meets our confidence screen, we retrieve that publication's MTI-indexed MeSH terms (with MTI score weights) and calculate the weighted share of the publication's associated subjects that were CMR supported (publication-level exposure). We then aggregate this measure to the CPC level by a simple average, effectively measuring the share of a CPC's cited biomedical research subjects that were CMR supported, with values in the [0,1] range (mean 0.13).[8]

The resulting exposure measure is continuous but uneven, due to small denominators in some CPCs. To simplify comparisons, we divide the sample into above- and below-median exposure CPCs and estimate differential changes in patenting across them over time, as follows:

$$Ln(Patents)_{jt} = \sum_{t=1931}^{1970} \beta_t \cdot \mathbb{1}\left(\text{Above-median exposure}\right)_j + \alpha_j + \delta_t + \varepsilon_{jt} \tag{4}$$

where j and t index CPCs and years, and standard errors are clustered by CPC. In order to evaluate impacts on U.S. technology specifically, we restrict our measurement to patents with U.S.-based first inventors, which indicates domestically-developed innovation.

Results are presented in Table B.5, where we evaluate changes over time in (log) total patents (Column 1), firm patents (Column 2), and non-firm patents (Column 3) in CPCs with above versus below median CMR exposure. The evidence indicates a differential ∼20% increase in postwar patenting in CPCs which were more exposed to CMR research, significant at the 5% or 10% level (depending on the year), driven by firm patents. In Columns (4) to (6) we repeat this analysis specifically within the Chemistry branch of the CPC classification. Among chemical inventions, we find much larger differences, which begin to emerge during the war years, attain statistical significance in the late 1940s, and continue growing through the end of our sample period, with parameters reaching 0.7 by the late 1960s (indicating an approximate a doubling, as $\exp(0.7) \approx 2$), with similar patterns obtained for both firm and non-firm patenting.

[8] In this exercise we use patent citations instrumentally to measure the relevance of particular research subjects to specific technology areas, as we build a CPC-level CMR exposure measure. Because the PCS in our data are largely made post-1945, doing so potentially conflates a target feature with an evolving outcome, which could in principle confound the analysis. However, science-citing patents are a small subset of total patents, and the results persist when they are excluded from the estimation sample, ruling out that the LHS and RHS are simultaneous determined. The results should nevertheless thus be read cautiously.

Table B.5: Log patents in technology areas with above- vs. below-median CMR exposure

	All CPC sections			CPC Section C (Chemistry)		
	(1)	(2)	(3)	(4)	(5)	(6)
	All	Firm	Non-firm	All	Firm	Non-firm
Above-median exposure * 1(1935-1939)	0.023	0.056	0.025	-0.012	-0.013	-0.009
	(0.042)	(0.045)	(0.045)	(0.125)	(0.144)	(0.117)
Above-median exposure * 1(1940-1945)	0.066	0.066	0.012	0.277	0.191	0.109
	(0.078)	(0.080)	(0.071)	(0.189)	(0.198)	(0.133)
Above-median exposure * 1(1946-1950)	0.127	0.141	0.055	0.334*	0.216	0.348**
	(0.085)	(0.086)	(0.077)	(0.179)	(0.199)	(0.172)
Above-median exposure * 1(1951-1955)	0.193**	0.204**	-0.003	0.487***	0.356**	0.174
	(0.095)	(0.094)	(0.087)	(0.173)	(0.174)	(0.168)
Above-median exposure * 1(1956-1960)	0.197*	0.186*	0.072	0.555***	0.415*	0.436**
	(0.107)	(0.104)	(0.097)	(0.208)	(0.219)	(0.191)
Above-median exposure * 1(1961-1965)	0.195*	0.192*	0.013	0.727***	0.542**	0.542**
	(0.113)	(0.108)	(0.103)	(0.242)	(0.254)	(0.214)
Above-median exposure * 1(1966-1970)	0.223*	0.202*	0.087	0.729***	0.540**	0.613***
	(0.119)	(0.114)	(0.110)	(0.233)	(0.238)	(0.230)
N	13023	12738	12064	2920	2846	2507
Y mean	3.637	3.242	2.508	3.171	3.027	1.584
Method	OLS	OLS	OLS	OLS	OLS	OLS
CPC FEs	Y	Y	Y	Y	Y	Y
Year FEs	Y	Y	Y	Y	Y	Y

Notes: Table estimates differences over time in US-wide log patenting across technology areas (CPC subclasses) with differential exposure to CMR research. Exposure is calculated by (i) beginning with a dataset of patents filed by US inventors and merging in their in-text citations to scientific publications, (ii) crossing these citations with the MeSH terms associated with the cited science, (iii) identifying MeSH terms which were CMR-supported, and (iv) computing the share of citations made by patents in the given CPC subclass which are to papers in CMR-supported subjects. Subclasses where most citations are to papers in CMR-supported subjects will thus be measured as more exposed. We restrict the sample to patents filed by US inventors and associate patents to their primary inventive CPC. Columns (1) to (3) report results estimated across all CPC subclasses, and Columns (4) to (6) across those in the Chemistry branch of the CPC classification (where many drugs are classified). We separately report results for all patents and those assigned to firms vs. other entities. Results are estimated relative to the 1930-1934 period. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by CPC in parentheses.

C Historical Context

C.1 The need for military medical research

As we note in the paper, disease killed more soldiers than battlefield injuries in nearly every major war prior to World War II. The top panel of Table C.1 shows statistics on deaths from disease versus injury in eight military conflicts in various regions between the Mexican-American War (1846-48) and World War I (1914-1918; U.S. at war 1917-1918), where the ratio of deaths from disease:injury varied from 0.9 to 12, and averaged 1.7—including a ratio >1 for the U.S. in World War I. In World War II, this ratio was 0.07 for the U.S. Army overall and 0.01 for the U.S. Army in Europe. In essence, disease was effectively eliminated as a cause of military mortality.

Table C.1: Deaths from disease versus battlefield injury in prior wars

		Deaths from...		
	Years	Disease	Injury	Ratio
Pre-World War II				
Mexican-American War (U.S.)	1846-48	11,155	1,721	6.48
Crimean War (France)	1854-56	70,000	7,500	9.33
U.S. Civil War (Union)	1861-65	199,720	138,154	1.45
Franco-Prussian War (Germany)	1870-71	14,904	17,225	0.87
Sino-Japanese War (Japan)	1894-95	15,850	1,311	12.09
Philippine-American War (U.S.)	1899-1902	4,356	1,061	4.11
Boer War (British)	1899-1901	11,377	6,425	1.77
World War I (U.S.)	1917-18	51,447	50,510	1.02
Weighted average				1.69
World War II				
U.S. Army, total	1941-45	15,779	234,874	0.07
U.S. Army in Europe	1941-45	1,779	135,576	0.01

Notes: Table reports deaths from disease and battlefield injuries, and the ratio of the former to the latter, for the U.S. Army and foreign armies in major wars of the late 19th century, World War I, and World War II. Data from Coates and Hoff (1958), page 21, Table 7.

Table C.2 puts these patterns in further context for the U.S. Army specifically, comparing per-capita, per-year hospital admissions and deaths from infectious diseases in the Civil War (1861-65), Spanish-American War (1898), World War I (1917-18), and World War II (1942-45). Hospital admissions declined from >1 per soldier-year in the Civil War to roughly 0.1 per soldier-year in World War II, and deaths from 0.03 to 0.0015—a 99.5% decline.

Table C.2: U.S. Army admissions and deaths from infectious diseases, by war

		Per 1,000 soldiers/year	
War	Years	Admissions	Deaths
U.S. Civil War (Union)	1861-65	1,030.34	34.77
Spanish-American War	1898	986.89	20.81
World War I	1917-18	427.03	10.43
World War II	1942-45	112.46	0.15

Notes: Table reports U.S. Army hospital admissions and deaths from infectious diseases in four major wars of the 19th and 20th centuries, per 1,000 soldiers per year. Data from Coates and Hoff (1958), page 11, Table 2.

Tables C.3 and C.4 provide a more detailed accounting of (i) per-capita hospital admissions rates and (ii) death rates per hospital admission in World Wars I and II, based on military statistics

published in the same U.S. Army Medical Department series. We present data for specific major infectious diseases (which were subjects of CMR medical research in World War II) and compare them to cancer (which was not). The right-most columns in each table compute percentage changes from World War I to II for the U.S. Army worldwide, in the U.S., and in Europe (geographies shared across the conflicts, notwithstanding some residual differences, such as northern vs. southern Europe—where the latter was a theater of war only in World War II).

Despite the implicit association to the research effort, direct comparisons of admissions and death rates across the two wars is complicated by changing theater of war (e.g., World War II was fought in more tropical environments with higher incidence of mosquito-borne diseases like malaria or Japanese B encephalitis) and changes in diagnostics. Similarly, attribution to World War II medical research specifically is also complicated by the possibility of interwar progress in specific disease areas (e.g., malaria). The evidence is nevertheless provocative and potentially suggestive of causal effects. Hospital admissions rates for nearly all infectious diseases declined dramatically, albeit with a few exceptions, primarily malaria and encephalitis (Table C.3). Death rates (per admission) also declined dramatically for most infectious diseases (Table C.4). Mortality from influenza, for example, declined 100%, and mortality from pneumonia, meningitis, and encephalitis—among the most lethal diseases for hospital admits in World War I—declined nearly as much. Large declines were also observed for other diseases like tuberculosis, typhoid fever, and scarlet fever. Cancer death rates, by comparison, declined only incrementally.

The impact of war on military health, and the improvements achieved by or in World War II, can be seen most clearly in the time series. Figure C.1 plots U.S. Army annual hospital admissions and deaths from infectious disease per capita between 1895 and 1955. Both series show significant spikes in earlier wars but no such spike in World War II.

Table C.3: Disease hospital admissions in World War II vs. World War I

			Per 1,000 average strength, per annum								
			World War I (1917-19) Admissions			World War II (1942-45) Admissions			Pct. change Admissions		
Disease category	Etiology	Disease	Global	USA	EUR	Global	USA	EUR	Global	USA	EUR
Infectious diseases	Bacterial	Diphtheria	2.670	2.630	2.920	0.190	0.040	0.530	-93%	-98%	-82%
Infectious diseases	Bacterial	Scarlet fever	2.850	4.040	1.420	1.120	1.710	0.510	-61%	-58%	-64%
Infectious diseases	Bacterial	Tuberculosis	9.300	13.520	4.290	1.110	1.430	0.620	-88%	-89%	-86%
Infectious diseases	Bacterial	Typhoid fever	0.370	0.240	0.530	0.020	0.010	0.010	-95%	-96%	-98%
Infectious diseases	Viral	Influenza	191.560	238.700	137.150	7.430	9.290	3.460	-96%	-96%	-97%
Infectious diseases	Viral	Measles	23.650	38.200	5.500	2.380	3.650		-90%	-90%	
Infectious diseases	Viral	Mumps	56.120	63.360	49.140	4.020	5.530		-93%	-91%	
Infectious diseases	Viral	Rubella	4.160	7.230	0.350	5.300	8.400		27%	16%	
Infectious diseases	Bacterial or viral	Encephalitis	0.020	0.020	0.020	0.070	0.070	0.010	250%	250%	-50%
Infectious diseases	Bacterial or viral	Meningitis	1.300	1.400	1.260	0.560	0.740	0.430	-57%	-47%	-66%
Infectious diseases	Bacterial or viral	Pneumonia	19.030	20.540	18.030	10.680	12.990	8.090	-44%	-37%	-55%
Infectious diseases	Venereal	Chancroid	9.470	9.650	7.990	3.710	1.370	3.750	-61%	-86%	-53%
Infectious diseases	Venereal	Gonococcus	61.300	94.670	18.730	33.350	30.460		-46%	-68%	
Infectious diseases	Venereal	Syphilis	16.250	23.050	7.610	11.750	14.390	0.150	-28%	-38%	-98%
Infectious diseases	Parasitic	Malaria	3.450	4.700	0.570	15.930	3.530	6.470	362%	-25%	1035%
Neoplastic diseases		Cancer	0.150	0.180	0.100	0.300	0.330	0.270	100%	83%	170%

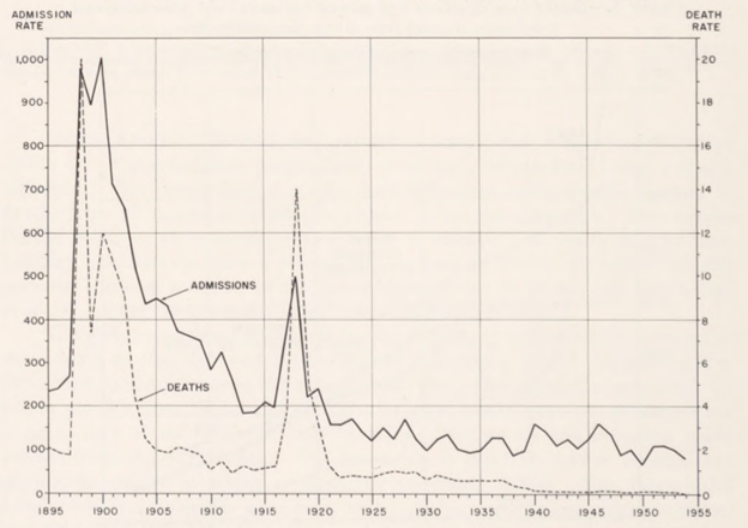
Notes: Table compares U.S. Army hospital admissions per 1,000 soldiers per year from select infectious diseases in World War I and World War II, with an added comparison to cancer (final row). Data reported for global personnel, U.S.-based personnel, and the European theater. World War I data reported for 1917-1919 only and World War II data for 1942-1945. Data from Love (1925), Tables 47 and 49 and Reister (1975), Tables 29, 29a, 31a.

Table C.4: Disease death rates in World War II vs. World War I

			Per 1,000 average strength, per annum								
			World War I (1917-19) Deaths:Admissions			World War II (1942-45) Deaths:Admissions			Pct. change Deaths:Admissions		
Disease category	Etiology	Disease	Global	USA	EUR	Global	USA	EUR	Global	USA	EUR
Infectious diseases	Bacterial	Diphtheria	0.015	0.015	0.017	0.026	0.025	0.032	76%	64%	87%
Infectious diseases	Bacterial	Scarlet fever	0.032	0.030	0.028	0.002	0.002	0.002	-94%	-92%	-93%
Infectious diseases	Bacterial	Tuberculosis	0.072	0.048	0.172	0.029	0.018	0.074	-60%	-62%	-57%
Infectious diseases	Bacterial	Typhoid fever	0.162	0.125	0.170	0.050	0.000	0.100	-69%	-100%	-41%
Infectious diseases	Viral	Influenza	0.031	0.031	0.032	0.000	0.000	0.000	-100%	-100%	-100%
Infectious diseases	Viral	Measles	0.025	0.023	0.038	0.000	0.001		-98%	-98%	
Infectious diseases	Viral	Mumps	0.000	0.000	0.000	0.000	0.000				
Infectious diseases	Viral	Rubella	0.005	0.004	0.000	0.000	0.000		-100%	-100%	
Infectious diseases	Bacterial or viral	Encephalitis	0.500	0.500	0.500	0.057	0.057	0.300	-89%	-89%	-40%
Infectious diseases	Bacterial or viral	Meningitis	0.392	0.343	0.444	0.045	0.043	0.047	-89%	-87%	-90%
Infectious diseases	Bacterial or viral	Pneumonia	0.244	0.216	0.282	0.004	0.004	0.005	-98%	-98%	-98%
Neoplastic diseases		Cancer	0.200	0.222	0.200	0.183	0.182	0.167	-8%	-18%	-17%

Notes: Table compares U.S. Army death rates per hospital admission from select infectious diseases in World War I and World War II, with an added comparison to cancer (final row). Data reported for global personnel, U.S.-based personnel, and the European theater. World War I data reported for 1917-1919 only and World War II data for 1942-1945. Data from Love (1925), Tables 47 and 49 and Reister (1975), Tables 29, 29a, 31a.

Figure C.1: Admission and death rates for infectious diseases, U.S. Army, 1895-1954
(measured as number of admissions or deaths per 1,000 soldiers per year)



Notes: Figure shows time series of U.S. Army admission and death rates from infectious diseases, per 1,000 soldiers per year. Reproduced from Coates and Hoff (1958), page 20, Chart 6.

C.2 Contemporary accounts

The results of Sections 4 and 5 leave us with the deeper question of why CMR—an intrinsically temporary project that ended with the war—had long-lasting effects. Beyond the empirical evidence, contemporary and historical accounts provide a range of clues.

New therapies and therapeutic candidates

Table B.1 illustrates several subjects "born of war" (Stewart 1948): mass-produced penicillin, streptomycin, DDT, chloroquine, and dimercaprol each effectively launched research in new directions to understand their chemistry, physiological effects, mechanisms of action, applications to myriad organisms and diseases, and more. Geer et al. (1948, p. 636), for example, explain that the development of DDT as an insecticide "opened a new era in insect control," prompting a surge of new investigation. Similar observations could be made for penicillin and later other antibiotics, which drove an (even larger) surge in clinical studies on their effects. Much of this research had a combinatoric flavor: for example, Lockwood (1948, p. 92) observes "the proper combination of surgery and chemotherapy would permit the surgeon far greater latitude"—reflecting new opportunities for studying the interaction of old procedures and new therapies.

Even when CMR research was not successful during the war itself, but it may have opened up new lines of inquiry which postwar investigators continued: Carden Jr (1948, p. 670) anticipated that although "many of the most promising [antimalarial] compounds were developed too late in the program" to be useful during the war, these "unfollowed leads and current loose ends will undoubtedly be explored." Slater (2009) confirms that research on these "lead compounds" continued—one of which (chloroquine) became a revolutionary malaria treatment in the years after the war, and a major new subject of study (as Table B.1 clearly illustrates).

New research tools and techniques

CMR also developed new research methods to meet the war's specific demands, many of which were useful in new problems after it ended. For example, CMR's massive drug screening efforts—including in the hunt for antimalarials, treatments for other tropical diseases, and insect repellents, which collectively screened nearly 20,000 compounds—later became a model for cancer chemotherapy research and other efforts at the NIH (Slater 2009). Techniques developed by the blood substitute research program "provided a technical framework for [a] productive research field" after the war (Creager 1999) on blood-related disorders and blood-derived therapeutics. Cohn (1948, p. 436) writes that the separation of blood "[made] possible the [further] discovery of the function and the uses in therapy" of different components in blood fractions.

Though malaria and blood were among CMR's largest programs, CMR developed new research tools and methods across its portfolio to address questions the war presented. For example, Windle (1948, p. 174) explains that "The introduction of methods of reproducing standard degrees of cerebral concussion and of measuring both the quantity of injury inflicted and the amount of effect produced have opened the possibility of measuring the relation of concussion to nervous metabolism, ... to shock, to fatigue, and to changes induced by anoxia, acidosis, electrical shock, and so forth." Millikan (1948, p. 317) writes of respiratory research that "The technics [sic] and instruments developed for aviation are already widely employed. Few researches on respiratory problems now fail to make use somewhere of a gas-analysis device, or of an instrument for measuring blood gases, or of a demand valve, developed by [OSRD] for war purposes."

New technology platforms

For several major drug categories, the CMR effort also introduced new techniques and platforms that supported continued development after the war ended. Chief among these was in the synthesis of new antibiotics: as Swann (1983, p. 189) points out, although CMR's synthetic penicillin program was a flop during the war, knowledge developed through this work "paved the way for [the] general synthesis of penicillins in the 1950s, [leading] to the development of the therapeutically invaluable semisynthetic penicillins," including dozens of antibiotics introduced in the 1950s (many of which form the basis for results in Section 5; also see de Haen 1976).

In vaccines, methods developed during the war (e.g., centrifugation techniques) subsequently became "state of the art" to the industry by the 1960s (Hoyt 2006, p. 47), contributing to the surge in new vaccines introduced in the 1950s and 1960s. Similar dynamics applied to steroids: the methods developed for producing the "miracle drug" cortisone (a general purpose steroid) during the war were used for developing other corticosteroids afterwards, and Achilladelis (1999, p. 62) writes that "because the technology had diffused among participants of the OSRD project, all of [the firms involved] introduced corticosteroid drugs in the 1950s."

New research capabilities

Beyond specific drugs, several scholars have argued that the war significantly expanded American pharmaceutical companies' general research capabilities, drawing them closer to science, and that this was an important catalyst for a more innovative and competitive U.S. pharmaceutical industry (e.g., Temin 1979, Cockburn et al. 1999, Pisano 2002). Landau et al. (1999), for example, claim that "To a great extent the U.S. government's wartime policies led to the emergence of the American pharmaceutical industry as the undisputed worldwide leader," observing that "the federal war effort encouraged corporate research and development, widened and deepened the companies' cooperation with academic institutions, and catalyzed the diffusion of new technologies across the industry." This was the case for both incumbent drug companies and new ones, as some non-pharmaceutical firms that became involved in drug development during the war continued in it afterwards—most notably Pfizer, which prior to the war was a chemical manufacturing company, became involved in the natural penicillin program due to its experience with fermentation, and after the war pivoted to drug development, initially focusing on antibiotics.

New fundamental knowledge

The most consistent pattern in contemporary accounts is that despite CMR's applied focus, its work produced fundamental understanding which could enable postwar research in new directions—for example, knowledge of the composition of separated blood fractions, the etiology of specific ailments like motion sickness, the epidemiology of diseases like streptococcal infections and rheumatic fever, and many insights into human, animal, and insect physiology.[9]

[9]Other examples (among many) include "fundamental knowledge related to clothing and climatic problems" Robinson and Belding (1948, p. 519), "the fundamental biochemistry of water disinfection" Fair (1948, p. 521), "fundamental studies [of] toxic chemicals in the chemistry and physiology of the cornea" Friedenwald and Hughes Jr (1948, p. 603) and "the fundamental mechanisms" of malaria Carden Jr (1948, p. 666).

This anticipated postwar scientific opportunity is described in several contemporary accounts. For example, Youmans and Guest (1948, p. 487) write of nutrition: "The research program ... produced an enormous amount of new scientific information which, aside from its immediate practical value, forms a firm basis for advancing research to be continued in peacetime." Of aviation research, Millikan (1948, p. 316) writes: "As a result of the intensive study of the mechanism of respiratory processes stimulated by aviation's need, there is now a much wider understanding [of] these problems. The application of this knowledge to respiratory abnormalities of disease, in poliomyelitis, emphysema, tuberculosis, and pneumonia, is widespread." Hirshfeld (1948, p. 126) similarly observes of penicillin that "as [its] supply ... became more abundant and the knowledge concerning its action became available, it was possible to expand the categories of infections on which it could be tried" as well as the contexts where it could be applied.

These opportunities also emerged from unlikely topics like chemical warfare. Gilman and Cattell (1948, p. 546) explain that "[CMR's] approach has yielded unsuspected and fruitful byproducts ... not only have valuable research tools for the solution of many of the problems of cellular physiology and metabolism been uncovered, but also many potential therapeutic agents have appeared." With respect to the study of toxic chemicals on the eyes, Friedenwald and Hughes Jr (1948, p. 620) argue that "the net result ... has been to disclose that mustard and related compounds are useful tools in the study of a number of recondite fields of cellular and tissue physiology. In these fields more questions have been made accessible to study than have so far been answered." Regarding research on treatments for respiratory irritants, Gerard (1948, p. 566) explains: "Although the immediate practical results from the current studies have been few ... it has given us far deeper understanding ... and it has pointed the directions in which further research may be expected to yield profit." He later goes on to explain that "much knowledge on the physiology of respiration and circulation has accrued" that was valuable in attacking related medical problems.

Given CMR's heavy focus on developing new chemicals and drugs, a common theme emerges around opportunities to study mechanisms of action. This was especially the case with regards to malaria, parasites, and insect control. On insect repellents, Scholz (1948, p.651) writes: "It is only now becoming possible to correlate the chemical properties and physical characteristics of compounds with their insect-repellency effectiveness. Thousands of candidates remain to be analyzed in this light." Haller and Cristol (1948, p. 626) similarly explain of new insecticides: "No satisfactory correlations between chemical structure and toxicity to insects have yet been discovered ... [and] until the effect of various materials on biologic processes is fully understood, it will not be possible to systematize research in the chemistry of insecticides." Yeager (1948, p. 631) continues by explaining that "a generally acceptable theory of the lethal action of DDT must await the acquisition of more experimental data," but that "promising lines of attack ... have been opened up." Regarding the hunt for antimalarials, Carden Jr (1948, p. 670) notes that "intense efforts were made to coordinate the relation between the action of a compound and its chemical configuration, [and] although the complete answer was not found, interesting correlations of the accumulated data, which may bear fruit in the future, were brought to light. Likewise, intense efforts were made to understand the basic biochemical and biologic characteristics of the various malarial parasites, [and] much knowledge was gained that not only throws light on the basic biology of this disease but may also add to knowledge in other lines of investigation."

Appendix references

Achilladelis, Basil. 1999. "Innovation in the pharmaceutical industry." In *Pharmaceutical innovation: Revolutionizing human health*, edited by Ralph Landau, Basil Achilladelis, and Alexander Scriabine. Philadelphia: Chemical Heritage Press.

American Red Cross. 1918. *War Medicine*.

Andrus, Edwin C. 1948. *Advances in military medicine*. Boston: Little, Brown, and Company.

Boyack, Kevin W, Michael Patek, Lyle H Ungar, Patrick Yoon, and Richard Klavans. 2014. "Classification of individual articles from all of science by research level." *Journal of Informetrics* **8**(1):1-12.

Bryan, Kevin A, Yasin Ozcan, and Bhaven Sampat. 2020. "In-text patent citations: A user's guide." *Research Policy* **49**(4):103946.

Carden Jr, George A. 1948. "Introduction: Malaria." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 665-670. Boston: Little, Brown, and Company.

Cardoni, Alex A. 1973. "Comparison of Current Contents' Life Sciences and Clinical Practice Editions." *American Journal of Health-System Pharmacy* **30**(8):721-722.

Catillon, Maryaline. 2017. *Medical knowledge synthesis: A brief overview*. Working paper.

Coates, John Boyd Jr. and Ebbe Curtis Hoff (eds.). 1958. *Preventative Medicine in World War II, Volume IV: Communicable Diseases Transmitted Chiefly Through Respiratory and Alimentary Tracts*. Washington DC: Department of the Army.

Cockburn, Iain, Rebecca Henderson, Luigi Orsenigo, and Gary Pisano. 1999. "Pharmaceuticals and biotechnology." In *U.S. industry in 2000: Studies in competitive performance*, edited by David C. Mowery, pp. 363-398. Washington DC: National Academies Press.

Cohn, Edwin J. 1948. "The History of Blood Plasma Fractionation." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 364-443. Boston: Little, Brown, and Company.

Creager, Angela N. H. 1999. "'What Blood Told Dr Cohn': World War II, plasma fractionation, and the growth of human blood research." *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* **30**(3):377-405.

de Haen, Paul. 1976. "Compilation of New Drugs: 1940 thru 1975." *Pharmacy Times* **March**:40-74.

Fair, Gordon M. 1948. "Water Disinfection and Allied Subjects." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 520-531. Boston: Little, Brown, and Company.

Friedenwald, Jonas S and W P Hughes Jr. 1948. "The Effects of Toxic Chemical Agents on the Eyes and Their Treatment." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 603-620. Boston: Little, Brown, and Company.

Garfield, E. 1972. "Current Contents/Clinical Practice: New tool for optimum selection in maintaining current awareness."

Geer, Harriet A, Randall Latta, and Arthur W Lindquist. 1948. "The Dispersal of Insecticides." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 636-645. Boston: Little, Brown, and Company.

Gerard, Ralph W. 1948. "Recent Research on Respiratory Irritants." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 565-587. Boston: Little, Brown, and Company.

Gilman, Alfred Z and McKeen Cattell. 1948. "Systemic Agents: Action and Treatment." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 546-564. Boston: Little, Brown, and Company.

Gross, Daniel P. and Maria P. Roche. 2026. *Coordinated R&D Programs and the Creation of New Industries*. Working paper.

Gross, Daniel P. and Bhaven N. Sampat. 2023a. "America, jump-started: World War II R&D and the takeoff of the US innovation system." *American Economic Review* **113**(12):3323-3356.

Gross, Daniel P. and Bhaven N. Sampat. 2023b. "The World War II crisis innovation model: What was it, and where does it apply?" *Research Policy* **52**(9):104845.

Hall, Bronwyn H, Adam B Jaffe, and Manuel Trajtenberg. 2001. *The NBER patent citation data file: Lessons, insights and methodological tools*. NBER Working Paper No. 8498.

Haller, H L and Stanley J Cristol. 1948. "The Development of New Insecticides." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 621-626. Boston: Little, Brown, and Company.

Hirshfeld, John Winslow. 1948. "Introduction: Surgery." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 123-133. Boston: Little, Brown, and Company.

Hoyt, Kendall. 2006. "Vaccine innovation: Lessons from World War II." *Journal of Public Health Policy* **27**(1):38-57.

Ke, Qing. 2019. "Identifying translational science through embeddings of controlled vocabularies." *Journal of the American Medical Informatics Association* **26**(6):516-523.

Landau, Ralph, Basil Achilladelis, and Alexander Scriabine. 1999. *Pharmaceutical innovation: Revolutionizing human health*. Philadelphia: Chemical Heritage Foundation.

Lewison, Grant and Guillermo Paraje. 2004. "The classification of biomedical journals by research level." *Scientometrics* **60**(2):145-157.

Li, Danielle, Pierre Azoulay, and Bhaven N. Sampat. 2017. "The applied value of public investments in biomedical research." *Science* **356**(6333):78-81.

Lockwood, John S. 1948. "Introduction: Surgery." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 91-94. Boston: Little, Brown, and Company.

Love, Albert G (ed.). 1925. *The Medical Department of the United States Army in the World War, Volume XV: Medical and Casualty Statistics*. Washington DC: Department of the Army.

Marx, Matt and Aaron Fuegi. 2020. "Reliance on science: Worldwide front-page patent citations to scientific articles." *Strategic Management Journal* **41**(9):1572-1594.

Marx, Matt and Aaron Fuegi. 2022. "Reliance on science by inventors: Hybrid extraction of in-text patent-to-article citations." *Journal of Economics & Management Strategy* **31**(2):369-392.

Millikan, G A. 1948. "Anoxia and Oxygen Equipment." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 296-317. Boston: Little, Brown, and Company.

Narin, Francis, Gabriel Pinski, and Helen Hofer Gee. 1976. "Structure of the biomedical literature." *Journal of the American Society for Information Science* **27**(1):25-45.

Pisano, Gary. 2002. "Pharmaceutical biotechnology." In *Technological Innovation and Economic Performance*, edited by Benn Steil, David G Victor, and Richard R Nelson, pp. 347-365. Princeton: Princeton University Press.

Reister, Frank A (ed.). 1975. *Medical Statistics in World War II*. Washington DC: Department of the Army.

Robinson, Sid and H S Belding. 1948. "Protective Clothing." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 497-519. Boston: Little, Brown, and Company.

Scholz, Roy O. 1948. "The Development of New Insect Repellents." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 646-651. Boston: Little, Brown, and Company.

Slater, Leo Barney. 2009. *War and disease: Biomedical research on malaria in the twentieth century*. New Brunswick: Rutgers University Press.

Stewart, Irvin. 1948. *Organizing scientific research for war: The administrative history of the Office of Scientific Research and Development*. Boston: Little, Brown, and Company.

Swann, John Patrick. 1983. "The search for synthetic penicillin during World War II." *The British Journal for the History of Science* **16**(2):154-190.

Temin, Peter. 1979. "Technology, regulation, and market structure in the modern pharmaceutical industry." *The Bell Journal of Economics* pp. 429-446.

U.S. Federal Trade Commission. 1980. *Statistical Report on Mergers and Acquisitions*. Produced by the Federal Trade Commission (FTC) Bureau of Economics.

Windle, William F. 1948. "Experimental Studies on Concussion." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 168-175. Boston: Little, Brown, and Company.

Yeager, J Franklin. 1948. "The Action of DDT on Invertebrates." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 627-631. Boston: Little, Brown, and Company.

Youmans, John B and George M Guest. 1948. "Problems of Nutrition." In *Advances in Military Medicine*, edited by Edwin C. Andrus, pp. 473-487. Boston: Little, Brown, and Company.