Coordinated R&D Programs and the Creation of New Industries*

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Abstract:

Complex systems technologies—including "deep tech"—are prone to numerous frictions that stymie commercial development. Yet technologies with these features underpin some of the most valuable industries of the past century. We examine how large, coordinated R&D projects have overcome these obstacles to instigate commercial industry takeoffs using a seminal example: radar in World War II. We show that this effort established the building blocks of a multi-billion dollar commercial radar industry by (i) establishing radar's technical foundations and (ii) organizing an ecosystem of researchers, manufacturers, input suppliers, and customers. The combination of both public funding and coordinated investments across the value chain were needed to surmount erstwhile market failures. The evidence from this case extends prior research on industry emergence by identifying coordinated R&D programs as an instrument for industrial development and documenting several channels through which they can influence industry outcomes.

JEL Classification: O31, O33, O38, N42, N72

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1 Introduction

A central question in strategic management is where and when commercial opportunities emerge. Technological innovation has long been seen as one of the main primogenitors of opportunity, and many of the most valuable companies and industries of the past century are rooted in innovation (Klepper 2015). At the same time, firms often face significant strategic and financial headwinds in commercializing new technologies (Arrow 1962, Lerner and Nanda 2020)—not only in financing and performing research and development (R&D), but even simply finding inputs and customers.[1] These challenges are especially large for so-called complex technologies, which depend on the simultaneous development and integration of many interdependent components and suppliers, and must be woven into users' practices—in contrast to discrete technologies like drugs, which can often be commercialized through relatively self-contained R&D and established distribution channels (Cohen et al. 2000). Despite these hurdles, several major industries today are based in highly intricate systems technologies that are among the most expensive, complex undertakings of the past century—from jet aircraft to semiconductors, computers, autonomous vehicles, and commercial space exploration. While strategy scholars have largely emphasized market mechanisms in explaining industry emergence (Moeen and Agarwal 2017, Agarwal et al. 2017), the aforementioned examples also benefited from government demand, coordination, and subsidy.

In this paper, we assess the effects of coordinated public R&D programs in catalyzing commercial innovation, new firm entry, and industry takeoffs around complex emerging technologies. We do so through an archetypal example which set the precedent for several modern R&D institutions with the potential for similar effects: radar in World War II.[2] At the outset of the war, Allied countries faced a major challenge in Germany's air supremacy over Europe, which was largely defenseless without a technology for detecting aircraft at a distance or in fog or darkness. The war triggered a large, coordinated, U.S. government-led, cross-sectoral effort to develop microwave radar—an acronym for RAdio Detection And Ranging—to meet this need, and to transition it into mass production and practice. By the end of the war, U.S. firms had produced over (2022 USD) $40 billion of military radar equipment for a wide range of land, sea, and air applications. In the war's

[1] As Stigler (1951) observes, "Young industries are often strangers to the established economic system. They require new kinds or qualities of materials and hence make their own; they must overcome technical problems in the use of their products and cannot wait for potential users to overcome them; they must persuade customers to abandon other commodities and find no specialized merchants to undertake this task" (p. 190).

[2] Bonvillian (2018) observes that the World War II radar program has had a large imprint on U.S. R&D policy institutions, especially as the institutional ancestor of the U.S. Defense Advanced Research Projects Agency (DARPA), whose historical performance has inspired several efforts to replicate its model in other contexts and countries. Other R&D institutions have developed with similar principles. Most recently, philanthropic research funders' interest in operating coordinated R&D programs to support emerging complex, science-based emerging technologies has also begun to grow (Convergent Research 2025, Renaissance Philanthropies 2025).

immediate aftermath, a commercial industry then took off: despite being an infant technology in 1940, nearly 200 U.S. firms were producing radar by the early 1950s.

Our goal is to understand why a commercial radar industry did not exist prior to 1940, despite its significant commercial potential, and how progress made during the war relates to the commercial industry which emerged after the war ended. We combine information from the war effort, firms that entered the postwar commercial market, and historical accounts and use abductive historical methods (Argyres et al. 2020) to link the war effort to postwar commercial entry, innovation, and industrial growth. The evidence points to two major links. First, the World War II radar program established a technical framework which the postwar industry could apply and build upon. Second, it brought a full value chain into existence by guiding coordinated investments across manufacturers, suppliers, and applications—surmounting the coordination failures, input gaps, and uncertainties that impede ecosystems from forming around complex new technologies like radar.[3] We show that firms subsequently harnessed these resources to continue developing radar technology and tailor it to new applications where demand already existed or was rapidly growing.

To draw these links, it is useful to first describe what took place in World War II. The U.S. radar program was born in October 1940, when the National Defense Research Committee (NDRC; later the Office of Scientific Research and Development, or OSRD) began organizing an effort to develop microwave radar as a weapon of war. This followed a secret demonstration by British scientists of the cavity magnetron—the first device for producing high-power radio waves at microwave frequencies, which were necessary to track distant objects precisely. Building radar systems around it was a formidable problem requiring new understanding of microwave engineering and electronics, numerous components, advances in signal processing, and integration into other military technology—and one for which there was limited knowledge or expertise at the time. To take on this problem, NDRC contracted with MIT to create the Radiation Laboratory (colloquially, the Rad Lab): a government-funded, university-based hybrid research enterprise, and the first instance of "big science" being directed to large, applied problems such as those the war presented.

Working in partnership with the military and industrial firms, the Rad Lab played a pivotal role

[3] Throughout this paper we use two terms to describe related phenomena: the radar ecosystem and the radar industry value chain. In both cases, we have in mind the set of actors and activities required to produce and implement radar systems to deliver on their value proposition. During World War II, this included researchers, component suppliers, system manufacturers, standard setters, and numerous offices in the military including acquisition offices and end users (implementors), among others. Whereas a "value chain" typically describes a set of sequential value-adding activities, accumulating either within the firm or through arms-length transactions, our setting is distinguished by its multilateral interdependence, nonlinear relationships, and presence actors which may fund or coordinate other parties' activity but not undertake it themselves. These features are more characteristic of ecosystems, in the sense of Adner's definition of the term as a "multilateral set of partners that need to interact in order for a focal value proposition to materialize" (Adner 2017, p. 40). Embedded in this radar ecosystem was a value chain running from R&D to component and system supply to adoption and implementation.

in bringing microwave radar from an idea to an operational military technology—developing radar science and prototype systems, supporting handoffs to manufacturers, aiding diffusion, and bringing feedback from military users back into research and development (R&D). Alongside R&D, however, it guided a wider industrial mobilization to produce radar in many varieties and large volumes, coordinating a network of radar system and component manufacturers and downstream application sectors, which integrated radar into other products like ships and aircraft.

When the war ended in 1945, the Rad Lab and wider OSRD radar program were wound down. Immediately in their wake, however, emerged a dynamic industry serving both defense and commercial buyers. Radar had diffused broadly during the war into military systems, where its importance only grew afterwards, including in new applications like guided missiles and missile defense. Firms also quickly began pursuing commercial sales, first by firms which had supplied military demand during the war, and soon after by others, especially by firms in adjacent industries like radio or electrical equipment. Promotional material from Western Electric in 1946, for example, described commercial applications of radar in aircraft, including navigation, altitude control, collision avoidance, airstrip approach, or air traffic control, and similar material from Sperry Gyroscope marketed its commercial marine radar, again with new uses like river navigation.

In the path from the war to a commercial industry we observe the radar program undertaking two activities which accelerated commercialization. The first is in establishing the technical foundations for commercial product development, by (i) bringing the science and technology underpinning radar to an advanced state, (ii) making this new knowledge publicly available, and (iii) training experts that could drive continued progress. In addition to new science and technology, the wartime radar program also created an industrial base. Rad Lab records describe deliberate efforts to grow the set of firms with the capabilities to produce radar beyond a few large companies, efforts to coordinate production of components—many of which "had never been made before by anyone" and required new tools and know-how (Radiation Laboratory 1945b, p. 16)—and standards-setting to ensure all equipment worked together. Alongside supply, the wartime project also cultivated sustained demand, as much from manufacturers of downstream products that incorporated radar as from end users. Radar thus exited the war with a fully-formed value chain.

Using a combination of narrative archival evidence and empirical evidence, we find a large number of direct linkages from World War II radar R&D to the postwar industry, including at firms which were not engaged in the war effort but rather entered the radar business afterwards. Several major electrical and instrumentation firms participating in the war program have records documenting their postwar transition into commercial markets, including specific plans to repurpose wartime R&D to civilian uses. Empirical evidence from the patent record and from employment records both show these and other firms making use of Rad Lab-produced resources, namely, radar-related science, technology, and human capital, for the next two decades.

In analyzing the radar case, we follow an established tradition in the strategy literature of studying individual industries to identify generalizable insights based on the underlying primitives.[4] Our work is motivated by the insights the radar example presents—including for research in industry evolution, industrial policy, and the strategic implications of crises and grand challenges—as well as the myriad settings where these insights might apply. The main contribution is to show that coordinated government technology programs can catalyze new industries around complex, science-based systems technologies, and to explain why: by providing public R&D funding where incentives for private investment are lacking, and coordinating into existence a highly interdependent ecosystem. Against the backdrop of the large industry studies literature, we deepen understanding of this pathway for industry incubation. In doing so we connect research on industry emergence (Agarwal et al. 2017, Moeen and Agarwal 2017, Moeen and Mitchell 2020) with the business ecosystems literature (Adner and Kapoor 2010, Jacobides et al. 2018), building on prior research which has examined nascent industry ecosystems (Hannah and Eisenhardt 2018), as well as other research which connects actor- and system-based views (Guerra and Agarwal 2025).

The approach we examine in this paper—what we call "coordinated R&D programs"—adds to a wider set of industry-shaping government activities that have been studied in strategy and adjacent fields, such as investments in public science or infrastructure, guaranteed demand, subsidies, intellectual property protections, trade protections, and knowledge transfer. In contrast to all of these mechanisms, technology development programs like the radar project are distinguished by active management and the presence of an integrator—an approach which can access the advantages of both centralized and decentralized R&D (Argyres 1995, 1999, Argyres and Silverman 2004) and coordinate ecosystems (Iansiti and Levien 2004, Adner 2012). This may make coordinated R&D programs particularly impactful for complex technologies with many parts and interrelationships (relative to other industrial policies), and conversely overly complicated for simpler, discrete technologies. We see this as the crucial role the Rad Lab played for radar.[5]

[4] For example, prior research has examined industry evolution in agricultural biotechnology (Moeen 2017, Moeen and Agarwal 2017, Moeen and Mitchell 2020), fiber optics (Cattani 2006), solid-state lighting (Sanderson and Simons 2014), lasers (Suh 2022), personal genomics (Gao and McDonald 2022), typesetting equipment (Tripsas 2008), and rubber tires (Klepper and Simons 2000b, Buenstorf and Klepper 2009). The closest paper to this one in its focus on systemic innovations and coordination mechanisms is arguably Kapoor (2013) study of the semiconductor industry—though whereas Kapoor examines how integrated firms survive and compete in the later stages of the high-tech industry lifecycle (when other industry participants typically become more specialized), we examine how coordination high-tech industries' early development, from incubation to takeoff.

[5] Interestingly, in both the radar example case and in other military R&D programs (e.g., DARPA), commercial impact was (and typically is) incidental to the specific mission objectives related to warfighting, and not a target in and of itself. Despite this, we do not view the commercial outcome as accidental, nor unpredictable. To the

Based on these findings, we suggest two extensions and refinements to existing models of the industry emergence process. One is to emphasize coordinated R&D programs as a specific institutional mechanism that can catalyze nascent industries, along with the market gaps they may fill. The second is to separate short-run "mission" outcomes and long-run commercial outcomes and deepen understanding of what lies behind successful transitions. We view the principles that emerge from this study as applicable to any setting where coordinated investments might create the conditions for industry takeoffs, in both technology-based industries and others. The most direct parallel may be DARPA R&D programs, which resemble the World War II radar program in linking science and engineering and cultivating ecosystems around emerging technologies—though we argue the principles apply more broadly, including beyond the public sector.

We proceed as follows. Section 2 provides a conceptual foundation for the paper. Section 3 reviews the history of the World War II radar program. Section 4 describes the data and methods we use to evaluate its relationship on industry development. Section 5 examines the radar program's specific impacts during the war in advancing radar technology and orchestrating the nascent value chain, why it mattered, and the challenges it faced. Section 6 then documents the postwar emergence and evolution of the U.S. radar industry and identifies specific capabilities and resources borne of the war program which these firms put to use in order to subsequently enter and compete. With these findings in hand, Section 7 discusses the generalizable insights from this existential case, the limits to generality, and potential questions for future study.

2 Conceptual Foundations

The study of technology industries and their evolution is a major theme in strategic management (Schumpeter 1942, Nelson and Winter 1982), where a substantial literature seeks to explain regularities in technology and industry lifecycles (e.g., Abernathy and Utterback 1978, Gort and Klepper 1982, Klepper and Graddy 1990, Klepper 1996, Agarwal and Tripsas 2008).

One stage of the industry lifecycle which scholars increasingly view as formative and important is the pre-commercial incubation stage, when technologies are being developed and markets identified but no products have yet been commercially sold (Agarwal et al. 2025). A common theme across much of this research is an emphasis on market-led industry development (Agarwal et al. 2017).Yet market logic alone may not fully explain research-intensive industries, which are widely understood to face structural challenges in profiting from innovation, like the cost of R&D, the difficulty of appropriating value, and both technical and market uncertainty (Nelson 1959, Arrow 1962). Even

contrary, it took public investment, and the urgency of a war, to overcome the incentive challenges and coordination failures that incubating a complex new technology like radar presented.

when innovation seems ripe for picking, commercial activity can thus be slow to emerge (Agarwal and Bayus 2002), and in some cases, private investors can be discouraged altogether (Ewens et al. 2018, Lerner and Nanda 2020). This has been argued to be especially true for complex, science-based technologies, where R&D challenges (namely: indivisible costs, development timelines, value capture, and uncertainty) can be particularly acute (Arora et al. 2024).

2.1 Challenges of Complex Technologies

The innovation policy toolkit in use today to try to remedy Nelson-Arrow type market failures has many instruments (Bloom et al. 2019), some of which have been studied in the industry emergence literature, such as public funding for science, which flows to new technologies like drugs and medical devices (e.g., Zucker et al. 1998, McMillan et al. 2000, Azoulay et al. 2019). Yet drugs are comparatively simple, discrete technologies relative to systems technologies with components and architectures, and where many parts must come together to deliver the whole.[6] On top of usual Nelson-Arrow type challenges, developers of frontier systems technologies may also face input gaps, coordination failures, and the added cost of architectural design (Baldwin and Clark 2000). The consequences of this complexity can be seen in decades of systems technology projects, from the IBM System 360 (which cost nearly (2022 USD) $50 billion to develop in the 1960s) to the Airbus A380 and Boeing 787 Dreamliner (which cost roughly (2022 USD) $35 and $40 billion to develop in the 2000s). In these projects, coordination failures can be spectacularly costly: the Airbus A380 suffered a multi-billion dollar added cost due to members of the Airbus consortium using different versions of an agreed computer-aided design software (Clark 2006).

Yet even these projects had a leg up, with nearly a century of accumulated scientific understanding of aerodynamics and electronics, decades of technical knowledge and experience in aircraft design, and established customers and supply chains. For truly nascent, science-based systems technologies, potential entrants have limited resources (private or public) to build upon. Developing and/or absorbing new fundamental understanding is a well-known challenge for firms, due to incentives, organization, and knowledge transfer (among others). For a complex systems technology like radar, which has many parts and subsystems, ecosystems present a whole other category of challenges. For example, as Adner and Kapoor (2010, p. 213) observe, technologies that require component innovation face hurdles in "specifying, sourcing, and integrating" these inputs. Downstream, systems technologies must also be woven into the practices of their adopters (Argyres 1995). Cultivating a component supply for complex systems, and integrating systems into practical application, thus

[6] Radar designs in the 1940s, for example, could involve "as many as 7,000 interrelated parts [in] a space not larger than a hat box," and modifications could induce "thousands of changes in the elemental manufacturing operations or in the timing or grouping of those operations" (Lack 1946, p. 69).

benefits from coordination up and down the value chain, without which innovation may fail, as Jacobides et al. (2018) and Hannah and Eisenhardt (2018) predict.

2.2 Ecosystem Leadership and Other Solutions

We have thus far examined the challenges that complex technology-based industries face in commercial incubation. What evidence or understanding is there of solutions? Beyond science funding, prior research has emphasized the value of an "ecosystem leader" (typically, the developer of the technology at the center) which "sets, and often enforces, the governance rules, determines timing, and often reaps the lion's share of gains," and "to whose vision of structure and roles others defer" (Adner 2017, p. 48). In comparison to the emphasis on firms as ecosystem leaders, coordinated and actively-managed government R&D programs have not received significant attention as potential orchestrators. However, not only are these institutions a fixture of modern R&D, but sometimes—perhaps even often—they may be more effective than firms: government R&D organizations may be endowed with more credibility, resources, and legal authority to organize, incentivize, or even compel ecosystems' development than private sector counterparts.

We are not the first to study mission-driven industry incubation (e.g., Agarwal et al. 2021), nor coordinated government research programs (e.g., Fuchs 2010), but the radar example provides a richness hard to achieve elsewhere, partly due to its scale, and partly the passage of time, which creates opportunities to access more primary evidence and observe long-run outcomes. But there are other governance structures which can serve as potential solutions to coordination challenges. An extensive literature studies vertical integration (e.g., Williamson 1975, Teece 1996, Farrell et al. 1998), including in specific complex technologies like semiconductors and automobiles (Monteverde 1995, Novak and Stern 2009). Firms may also engage in joint ventures to overcome coordination challenges (e.g., Mowery et al. 1996, 1998) although past research suggests joint ventures face substantial difficulties in aligning incentives. Argyres (1999) examines the "systems integrator" model prevalent in the defense sector for the development and procurement of large weapons systems where a prime contractor is tasked with architectural design, project management, and assembling finished products from components supplied by its subcontractors.

Relative to these alternatives, the setting we study is distinguished in both the nature of the problem and the approach taken. Radar technology was dependent on science which was not yet established, components that had never-before been made, and technology that had not yet been demonstrated. The approach was characterized by (i) the pairing of public funding and coordination, and (ii) the delegation of program management to a university-based hybrid research laboratory. In the context of what thus appears to be a tough technology problem, this approach may offer advantages that other structures are unlikely to deliver, while taking advantage of the benefits of both centralized and decentralized R&D (Argyres and Silverman 2004, Arora et al. 2014). These advantages include a central organization undertaking the requisite science, establishing proof-of-concept, developing prototype systems, distributing knowledge, and coordinating efforts of ecosystem partners up and downstream, and satellite participants using this general-purpose foundation to develop components and systems tailored to specific applications serving users' needs.

3 Historical Background

3.1 The Beginnings of the World War II Radar Program

World War II began in September 1939 with Germany's invasion of Poland and quickly ignited across most of Europe. As it did, Germany swiftly established air supremacy, making clear that aerial warfare, and in turn, the ability to track and target enemy craft, would be fundamental in this war. Radio detection (i.e., radar) at the time was an experimental technology that had been under development for several years at the (U.S.) Naval Research Laboratory and Army Signal Corps and the (British) Air Ministry Research Establishment, each of which had independent research streams. In the U.S., efforts by the NRL and Signal Corps were given relatively few resources and low priority, and in turn made limited progress, while failing to exploit opportunities for coordination.[7] British efforts were more focused, and produced a wider range of radar equipment as well as some principles of systems design. But these systems were "crude, half-engineered, and often unreliable" (Guerlac 1987, p. 122). In all three cases, these prototypes were constrained to ultra-high frequency (UHF) wavelengths and had significant limits in range, accuracy, resolution, sensitivity, and bulk/size, which impeded many useful applications (Rigden and Rabi 1987). Microwave frequencies held more promise for technical performance, but would require "a whole new art" (Guerlac 1987, p. 40), and as of 1940 was technically infeasible.

Around this time, a small group of high-ranking science administrators convinced U.S. President Franklin Roosevelt to create a National Defense Research Committee (NDRC; later subsumed by the Office of Scientific Research and Development), a wartime agency for supporting research by civilian scientists on military problems, arguing that the U.S. was technologically unprepared for a modern war (Stewart 1948, Gross and Sampat 2023). Radar was a priority from the beginning, being among NDRC's first requests from the Army and Navy (Baxter 1946). An initial assessment

[7] Guerlac (1987, p. 85) recounts that the NRL and Signal Corps worked "along parallel, but essentially separate, lines," with "no exchange of engineering personnel, no coordination of programs, [and] no jointly planned attacks on any of the basic problems." The result was three primitive systems (one from NRL, two from the Signal Corps) which entered small-quantity production (20 to 200 units) in late 1940.

of the radar problem quickly affirmed that a solution would likely require microwave frequencies—but also acknowledged there was no known device which could generate microwaves with enough power for use in radar. Following the serendipitous receipt of such a device from a British technical mission to the U.S. in September 1940—the recently-invented cavity magnetron—NDRC agreed to undertake an effort to try to develop around it new radar systems for airborne interception, automatic anti-aircraft artillery, and long-range navigation (Rigden and Rabi 1987). Anticipating that this might be a project of significant scope and scale, NDRC leaders decided it would operate most effectively under a central laboratory model staffed with civilian scientists and engineers from universities and industry. After a brief search, it chose to establish, fund, and site at MIT a new research organization: the Radiation Laboratory (the "Rad Lab").

3.2 The MIT Radiation Laboratory

The Rad Lab eventually evolved to be the epicenter of World War II radar development. When it held its first meeting in November 1940, however, it had three dozen staff, and almost no specific knowledge on the problem: Rad Lab Director Lee A. DuBridge explained that "little to nothing" was then known about "the microwave electronics that would be needed to translate the British 10-centimeter magnetron into a working radar system" (Zachary 1997, p. 134). Despite this, there was an urgent need to establish that microwave detection was possible. With little understanding of its inner workings, by February, it had jury-rigged a radar system on an MIT rooftop that could track an airplane taking off from Boston's Municipal Airport.

Following this successful demonstration, the Rad Lab was given additional funding and began to grow, recruiting scientists and engineers to Cambridge from universities and firms across the country. The attack on Pearl Harbor on December 7, 1941 and America's formal entry into the war the next day increased the urgency of the Rad Lab's work—both because the U.S. was now at war, and because the Pearl Harbor attack could have been mitigated by a more successful implementation of early warning systems.[8] By the end of 1941, the Rad Lab had transformed from a small, experimental laboratory to a large professional R&D organization of nearly 500 staff. By late 1943 it employed nearly 3,000 people, and in 1944 nearly 4,000, including many of the country's top academic physicists and electrical engineers (MIT 1946).

Organization, collaboration, and coordination

The Rad Lab, and the wider NDRC radar program of which it was the central actor, was a complex undertaking from the start. To see why, it is useful to first have a clear understanding

[8] The incoming Japanese attack on Pearl Harbor was (infamously) detected by radar nearly an hour before it took place, but the radar signature was misinterpreted and disregarded (Baxter 1946).

of what radar is: a radar system (illustrated in a block diagram form in Figure 1) must be able to: generate, amplify, and propagate microwaves; receive the reflected radio waves; process these signals; transform them into a human-readable display; and manage signal timing, synchronization, and interactions between components to ensure they successfully work together. At the dawn of World War II, essentially none of these pieces had yet been created.

[Figure 1 about here]

For most of the war, the Rad Lab was organized in 12 divisions (Appendix Figure A.2): four covering basic science and major categories of components (transmitter components, receiver components, and beacons), four for major categories of systems (airborne, ground and shipborne, navigation, fire control), three for business operations (buildings, personnel, administration), and a field service. Component divisions in turn had working groups for specific parts seen in Figure 1, like transmitters, modulators, antennas, receivers, and indicators.[9] Together, they did the yeoman's job of developing the science of microwave engineering, radar components, and prototype systems. The Rad Lab also had an internal shop for "crash" production, facilities for testing, and field service division which put scientists in the battlefield to support users and collect feedback. Midway through the war, its countermeasures (i.e., radar jamming) division was spun out as the Harvard-based Radio Research Laboratory (RRL). Throughout the war, co-location supported coordination and collaboration (Roche et al. 2024b), with constant information exchange.

The Rad Lab's specialization throughout the war was radar R&D. Both the military and industrial firms were key partners in the enterprise: the former to identify problems that R&D was needed to solve and collaborate on implementation, and the latter to produce parts and systems at scale. Reflecting these interdependencies, collaboration with upstream and downstream partners was a part of the Rad Lab's operation, and on-site personnel spanned the value chain: it hosted representatives from (i) the armed services and (ii) manufacturers, who sent their own personnel for training and to collaborate on product designs, embedding an understanding of the challenges that mass production would present. The Rad Lab similarly placed its own staff at industrial partners, where they supported the creation of production lines for Rad Lab-designed technology while preserving functionality, and in the military. Baxter (1946, p. 155) writes that over time, "this type of liaison came to constitute a large and increasing part of its activity."

[9]The Rad Lab thus explicitly modularized radar development and created an organization that matched this structure—consistent with the logic of Sanchez and Mahoney (1996), who argue that organizational structures which match product architecture can facilitate coordination in development.

Role of firms in the enterprise

Firms were a crucial partner in the wartime radar program in part due to the size, depth, and sophistication of U.S. electrical equipment and communications industries (such as radio and telephony) at the dawn of the war. The largest industry contractors included General Electric, Western Electric, Westinghouse, and RCA, though many other firms were also involved in the effort; monthly surveys conducted by the Rad Lab of available industrial capacity for expanding the production of radar equipment consistently enumerated 80 different companies.[10]

These firms played a dual role in the wartime radar ecosystem, supplying both parts and systems, and through 1945 had fulfilled (2022 USD) tens of billions of dollars of military radar supply contracts (see Table 1 for a list of the top wartime suppliers by value). Although initially they produced Rad Lab-designed parts and systems, over the course of the war they developed independent R&D capabilities and increasingly began to supply distinct in-house designs. Contemporary documents further indicate that they drew from a robust network of subcontractors that supported radar production. Throughout the war, however, the Rad Lab remained the principal organizing body for wartime radar research and product development (Stewart 1948).

[Table 1 about here]

3.3 Impacts and Demobilization

Despite its embryonic state in 1940, within five years microwave engineering was a highly developed art, and radar had become standard equipment on military ships and aircraft, was deeply integrated into military strategy, and had an annual U.S. production volume in the tens of thousands of units. By the end of the war, NDRC had spent over (2022 USD) $1.5 billion on the Rad Lab alone, and over $2.5 billion on radar R&D overall, and roughly 80% of microwave radar systems by volume and value produced during the war were based on Rad Lab designs.[11] After Germany surrendered on May 7, 1945, the Rad Lab began to wind down, and when Japan surrendered on August 14, it triggered its termination plans, shifting its focus to getting patents filed, cataloging discoveries, and finding jobs for staff. It officially dissolved on December 31, 1945, and its remnants were repurposed into MIT's new Research Laboratory for Electronics.

[10] Radiation Laboratory archival records, U.S. National Archives and Records Administration, Record Group 227, NAID 894515, Project Administration Records, 1941-1945, Box 7.

[11] Radiation Laboratory archival records, U.S. National Archives and Records Administration, Record Group 227, NAID 894515, Project Administration Records, 1941-1945, Box 7.

4 Data and Methods

To evaluate the link between the wartime radar program and the postwar radar industry we draw on several data sources. The most important of these is an expansive set of archival records from central actors in the wartime and postwar radar ecosystem, including records from the Rad Lab and from participating firms. We augment these records with data on or from (i) historical industry directories, (ii) Rad Lab-developed inventions, which we link to U.S. patents, and (iii) lists of Rad Lab and RRL researchers, which we link to postwar professional society directories to identify their postwar employers. These data sources provide a quantitative window into the scale and scope of the emerging radar industry and its antecedents. We describe the data in greater detail below and in later sections (where used) and discuss them further in Appendix B.

Our inferential approach is primarily abductive. The object of analysis (a single industry, observed over time) is both singular and lacking a clear counterfactual, and thus does not lend itself naturally to econometric assessment of causal factors in a potential outcomes causal framework. We instead look to the preponderance of evidence, which we will argue suggests a causal connection between the wartime radar program and postwar commercial activity. In doing so, we follow prior strategy research which uses abductive methods to study industry evolution, especially (though not exclusively) in single-industry studies or in historical contexts (Agarwal et al. 2025). As Pillai et al. (2024) have observed, an abductive approach involves distinct inferential logic and benefits from a detailed understanding of context—in this case, through the combination of primary source records, historical analysis, and data—which we will suggest supports a causal inference over the impacts of wartime R&D on industry emergence and evolution.

Measuring Radar Industry Participation

Parts of our analysis will use the Thomas Register of American Manufacturers (TRAM) to measure industry participation over time. The Thomas Register is a historical industry directory in the U.S. that listed manufacturers, suppliers, and distributors of industrial products by category and was periodically updated and re-issued. Since Gort and Klepper (1982), TRAM has been frequently used in industry studies research to study industry evolution, especially in seminal works by Klepper (see Appendix B.2 for a sample). Yet TRAM is also limited in important ways: its sampling procedure (i.e., how firms are selected for inclusion and classified) is opaque, and for complex technologies like radar which are supported by a broad range of inputs, industry boundaries are hard to discretely define, making a TRAM-based accounting liable to be incomplete. Moreover, TRAM reports only a few firm features: name, location, size, and a brief description.

We complement the TRAM data with a patent-based sample, which offers a distinct window into the evolution of radar technology and the firms and inventors behind it. To construct this sample we compile data on U.S. patents granted between 1920 and 1979 with filing and issue dates, patent class, harmonized assignee names and types (to isolate firms), and inventors. Using OSRD archival records, we identify all patents produced under the Rad Lab's and RRL's OSRD contracts, and we identify inventors which participated in wartime radar research by linking inventors to Rad Lab and RRL staff rosters (see Appendix B.3 for details of the patent data). A particular focus in our analysis will be radar-related innovation, which we measure in two ways, first by identifying patents in technology areas (USPCs) where the Rad Lab and RRL patented most heavily during the war, and second by identifying patents classified to detailed CPC codes representing specific categories of radar components or systems which also have keywords such as "radar" or "microwave" in the patent specification. We additionally measure patents building on Rad Lab technology and science as those which cite Rad Lab (and RRL) patents or Rad Lab publications, the latter using data on patent citations to science from Marx and Fuegi (2020, 2022).

Using these measures we can identify both firms and individuals producing radar-related innovation. We then construct two panels: an individual-level panel measuring inventors' propensity to file patents in radar-related classes over time, and a firm panel measuring firms' radar-related patenting over time—and which can be used to produce distinct measures of industry participation among R&D-performing firms. We augment the firm panel by additionally measuring postwar employment of former Rad Lab and RRL researchers, which we determine using membership directories of the Institute of Radio Engineers (a professional society for radio and electronic engineers, with tens of thousands of members during our study period), which include a large number of researchers from the radar program and consistently report employers.[12] Though these patent-based samples also present limitations, including in conditioning to firms with patents or in the occasional judgment calls we must make (e.g., in determining radar-related patents), these samples complement TRAM-based analysis with more flexible industry boundaries while creating opportunities to study other features of industry evolution unmeasured by the TRAM data.

5 Wartime Radar Development

Commercial activity around nascent technologies faces several fundamental hurdles—one of which is capabilities and resources for innovation itself. Motivated by prior research emphasizing technical breakthroughs as triggers for new industries to take shape around them (e.g., Agarwal et al. 2017, Moeen and Agarwal 2017) and ecosystem bottlenecks to industry growth (e.g., Adner and Kapoor

[12] We thank Jingyuan Zeng for generously sharing the Institute of Radio Engineers directory data. Of roughly 2,400 known Rad Lab/RRL staff members, we find 800 in IRE directories. See Appendix B.4.

2010, Jacobides et al. 2018), in this section we identify technical resources which the radar program generated and the emerging ecosystem of suppliers, assemblers, and integrators it organized before turning to analysis of their postwar applications in Section 6.

5.1 New Science and Technology

Historians describe the radar program as having generated a large amount of new fundamental understanding in microwave physics and engineering and in solid-state electronics, which were in turn assimilated into radar technology (Guerlac 1987, Martin 2018). At the end of the war, however, this knowledge was a closely guarded secret (due to its national security value during the war; Gross 2023) and concentrated in the Rad Lab and its closest R&D partners. Recognizing that this would both limit its use and advantage incumbents in its future application, Rad Lab records document that dissemination rose to "near the top of our official Laboratory priority list" at the end of the war (Radiation Laboratory 1945a).[13] The result of this dissemination effort was the *MIT Radiation Laboratory Series*—a 27-volume encyclopedic introduction to radar and microwave engineering published shortly after the war which became "the authoritative reference in the field of microwave electronics" Rigden and Rabi (1987, p. xxiii), an "occupational bible" for researchers (Buderi 1996, p. 251), and the handbook to the field (Morrow 2010).[14]

Alongside its publication of the *Radiation Laboratory Series*, in the late stages of the war the Rad Lab also began filing patent applications on its technological output: according to OSRD records (see Appendix B.3), the Rad Lab and RRL together produced over 2,500 patentable inventions, on which roughly 750 patent applications were filed and 600 patents issued. These patents described the technical underpinnings of many modern radar components and systems, and because under their contract terms title to these patents went to the U.S. government, this technology was also publicly owned (to our knowledge, these patents were not enforced). In Table 2(A) we list the top six patent classes (USPCs) with Rad Lab/RRL patents, highlighting that the labs were the top or near-top producers of patents in associated classes in the mid-1940s. Table 2(B) lists specific radar systems and components which are identifiable using CPC codes and shows that the Rad Lab and RRL were also top producers of patents in these categories.

[Table 2 about here]

[13] The Rad Lab's Associate Director (I. I. Rabi) explained the risk of industry capture more bluntly: "unless we put it down in the form of books, then after the war, there will only be one group who would know all this technology: the Bell Telephone Laboratories" (Rabi, quoted in Buderi 1996, p. 250).

[14] A former director of MIT Lincoln Laboratory later explained in an oral interview that "These were the textbooks that you looked for ... They were unique in the world. Foreign countries desperately scooped them up, and many places in this country used them" (Morrow 2010). As testament to its staying power, according to WorldCat the Rad Lab Series remains in circulation at hundreds of libraries today.

A third resource the Rad Lab/RRL had to develop is human capital—especially since at the dawn of World War II there were few people familiar with the science and technology of radar or microwave engineering (Zachary 1997). Because innovation in radar components and systems was frequently patented, the patent record lends itself to systematic tests of growing human capital in the radar field. Table 3 examines Rad Lab and RRL researchers' differential propensity to patent in radar-related technology classes over time. Our sample for this exercise consists of inventors with patents before (1933-1940), during (1941-1948), and after the war (1949-1956). We estimate difference-in-differences in these propensities for Rad Lab/RRL vs. other inventors in the pre- to mid-, mid- to post-, and pre- to post-war era, as in the following specification:

$$Y_{it} = \beta \cdot \mathbb{1}(\text{Is RL/RRL alum}) + \alpha_i + \delta_t + \varepsilon_{it}$$

where i and t index inventors and periods, and β is the parameter of interest. Columns (1) through (3) present results for intensive measures of radar-related patenting (the fraction of an inventor's patents in radar classes, defined as the top six classes with Rad Lab/RRL patents), and Columns (4) to (6) extensive measures (an indicator for any patents in these classes). Table 3 shows that Rad Lab/RRL staff were far more likely to continue patenting in radar after the war ended, with the magnitude of the effect many multiples of the sample mean.

[Table 3 about here]

5.2 Coordinated Development of a Radar Value Chain

5.2.1 Establishing the industrial base

To reduce these technical advances to practice required also developing an ecosystem of component suppliers, systems developers, and and downstream complements.

Rad Lab records identify nearly 20 firms which were contracted into producing specific Rad Lab-designed systems, such as those shown in Appendix Table D.2, which lists firm production by system type. But in the early years of the war, developing an industrial base for components was a precursor to and of even greater importance than systems (Radiation Laboratory 1945b): radar systems contained multiple interacting subassemblies (as in Figure 1) and could include thousands of parts. A fundamental problem for a novel technology like radar was input gaps: many of the necessary components "had never before been made by anyone, and special equipment and know-how were usually necessary" (Radiation Laboratory 1945b, p. 16).

Over the course of the war, the radar program trained and engaged hundreds of firms in component production. Fortune (1945) describes it as having involved "200 prime manufacturers" and "8,000 subcontractors." Table 4 shows a sampling of suppliers of specific major components which could be identified in Guerlac (1987), already illustrating the breadth of this ecosystem—though additional sources, including Rad Lab records, directly name dozens more. Individual firms' capacity constraints forced this ecosystem broadening: although "early in the war most Service contracts for radar were being placed with a very few large concerns such as Western Electric and General Electric," these firms quickly grew overloaded, necessitating that "many smaller firms [also] be introduced to the radar art" (Radiation Laboratory 1945b, p. 11).[15]

[Table 4 about here]

5.2.2 Ecosystem orchestration

The size and complexity of this ecosystem made it intrinsically susceptible to misalignment and supply chain bottlenecks, even despite the urgency of war. Dow (1945, p. 89) describes early military difficulty in "co-ordinating the production of Navy electronics equipment among the many prime contractors" and limited component availability causing "serious delay[s]," further noting that the "[t]he magnitude of this problem" is partly attributable to a dependence on "some thousand different plants ... supplying military electronic components and equipment." Other challenges emerged in transitioning lab models into mass production, where "many serious design problems arise which usually require the continued advice and assistance of the engineers and scientists who were responsible for the initial development" (DuBridge 1943, p. 1).

The Rad Lab served a prominent role in addressing these challenges through its integrated research model. Exter (1944, p. 2) describes a typical project as follows:

> A typical new development begins with the responsible systems division outlining a possible design. Since the components divisions will do a large share of the development work, they are called in at the beginning ... Since these parts have never before been produced, manufacturers [are also] introduced so that all parts will be in production by the time the prime contractor for the complete system is ready to start assembly ... Frequently the manufacturer's engineers have come to the Laboratory and worked side by side with our engineers in an effort to telescope the usually separate stages of development and production engineering.

An internal Transition Office had the explicit task of managing relationships across this ecosystem and attempting to keep it in concert. This office was explicitly created to be a "liaison office for the Laboratory with the Services and manufacturers in the transition of new projects from research and

[15] Records show the Rad Lab taking a systematic approach to doing so, tracking monthly production capacity and utilization of American electrical equipment firms to identify those with enough slack to take new contracts.

development to production and operational use" (Radiation Laboratory 1945b, p. 26). With respect to the military, the Transition Office connected radar development to specific needs and coordinated demand from a diffuse set of customers—an activity which required reconciling "interdepartmental friction" within the military itself.[16] It also played a similar role with manufacturers, building relationships between firm and Rad Lab personnel through which R&D, engineering, and production was coordinated and "aid[ing] to a large extent in the initial contacts between manufacturers and the Army and Navy" (Radiation Laboratory 1945b, p. 12). Firms likewise describe a high degree of exchange: Bell Labs accounts, for example, observed that "any day of 1944 or 1945 might have seen from five to 20 Bell Laboratories men [conferring] at the Radiation Laboratory and a corresponding number from there at Bell Laboratories" (Kelly 1946, p. 16).

Example impact: Compatibility standards

One area where the effects of ecosystem coordination are visible is in the development of technology standards. Due to the complexity of radar, the myriad variants being designed and produced, the many firms supplying components that needed to work together, and the number of components which were shared across systems, compatibility standards were a high-value potential addition to the ecosystem. Yet converging diffuse industry participants around common standards is known to be a difficult problem for markets to resolve on their own (Farrell and Saloner 1988). Although Army-Navy standards existed for some military equipment at the dawn of the war, because radar was new, no coordinating mechanisms were in place when it began.

As a result, the first two years of the radar program produced a proliferation of variants of specific components, many bespoke to individual projects and systems. As component variety grew, so did its cost. Rad Lab staff observed that "use of non-standard parts in military equipment aggravates an already difficult supply problem" (Willett 1944, p. 2) and necessitated significant reengineering when prototypes moved from the lab into production (Radiation Laboratory 1945b), while Navy administrators noted the costs associated with having "vast numbers of components with respect to types, sizes, and ratings, which must be dealt with in regard to improvement, testing, inspection, procurement, stock upkeep, issue, and cataloging" (Dow 1945, p. 89), as well as delays this variety caused due to frequent stock-outs of distinctive, irreplaceable parts.

To overcome these challenges, midway through the war the Rad Lab organized an internal stan-

[16] According to Rad Lab records (Radiation Laboratory 1945b, p. 26), "Transition Office personnel became acquainted with key officers in the Navy's Bureaus of Ships, Aeronautics and Ordnance and in many branches of the Army ... [It also] became familiar with the responsibilities and powers of the various organizations and how they fitted into the total radar picture. A knowledge of the limitations of the authority of each Service organization was as important as a knowledge of its authority. Until quite recently there was much interdepartmental friction and procurement and engineering officers were apt to talk without basis on matters outside their respective jurisdictions. This was frequently misleading unless one was acquainted with the true situation."

dards committee with representatives “from each component and operating division” (Curtis 1942, p. 1), which collaborated with manufacturers as well. This activity eventually spun out component committees which were subsequently led and managed by the Army and Navy. As it did so, the Rad Lab’s function evolved from developing standards to ensuring that manufacturers were “conform[ing] to Service specifications” (Sechrist 1945, p. 1). The benefits were recognized at the time by Rad Lab staff (Willett and Bridge 1943) as conferring flexibility (to source and combine parts from different manufacturers), resilience (with multiple sourcing), scale (enabled by interchangeable parts), and repair (facilitating maintenance and parts replacement).

5.2.3 Frictions in the ecosystem

The Rad Lab also faced several challenges in orchestrating this ecosystem. One was in ascertaining the boundaries of its authority in the absence of a clear ecosystem hierarchy and operating within them, and especially in tension with military offices. Though the Rad Lab was the de facto ecosystem leader, The Naval Research Laboratory and Army Signal Corps also sought (and had) a role in promoting radar R&D. The multilateral relationships that the Rad Lab managed (between itself, military offices, and manufacturers) also created confusion around ultimate authority, especially when the services placed orders with firms for Rad Lab-designed systems. The Army and Navy “at times desire[d] that [the Rad Lab] assist them and the manufacturer during the transition stage and occasionally for some time after production [was] underway,” but because “final responsibility for satisfactory production lies by contractual arrangement between the Army or Navy and the manufacturing company,” the Rad Lab was typically limited to an advisory or consultant role without any formal managerial or decision authority (NDRC 1943, p. 19).

A challenge which presented a more direct threat to postwar activity was intellectual property rights (IPR). As Fortune (1945, p. 203) explains, by the end of the war there were in 1945 an estimated “2,000 and 3,000 patents that are basic to radar production,” with “some 1,500” of them having been developed during the war. Of these, “roughly a third [we]re government-owned” (consistent with our counts from OSRD records), but although largely government-financed, most of the rest belonged to firms. These diffuse patent rights threatened to obstruct commercialization. To “avoid pyramided royalty payments and a long period of interference litigation,” the Navy proposed that firms create a patent pool among the major manufacturers of “all patents essential to radar production”—though this would intrinsically advantage these incumbents and limit entry. The proposal received a mixed response from the major firms and failed to materialize into concrete action. Gaps in the remaining evidence leave it somewhat opaque to how serious a problem patent thickets were in the postwar period, or how they were overcome.

6 The Takeoff of the Postwar Radar Industry

6.1 From Military to Civilian Markets

Through late 1945, radar was produced exclusively for military use—in part because nearly all production capacity was mobilized for war, and in part due to government restrictions on the public disclosure of radar technology itself (Gross 2023). Despite this, radar had already grown to be one of the largest U.S. electrical industries by the time the war ended, as a result of military demand. A Fortune magazine article in October 1945 (one month after the war ended) introducing this industry to the public established it was “larger than radio”, with “more than a billion dollars’ worth of radar systems, tubes, and accessories were produced in the U.S. last year”, and explicitly attributed it to a “cooperative effort on the part of government laboratories, 200 prime manufacturers, and an estimated 8,000 subcontractors” (Fortune 1945, p. 146).

The same article concluded by anticipating the imminent takeoff of a (civilian) commercial industry. As predicted, within a year, radar had begun to spread to the civilian sector, driven by its diffusion from military to civilian applications in air and sea transportation, such as air traffic control, long-range navigation, and detection in low-visibility conditions. Military demand also continued growing as radar became a critical defense technology in the Cold War and its uses expanded into guided missiles and air defense systems. By 1960, nearly 50 civil airports had adopted radar systems for modern areal surveillance (Federal Aviation Agency 1960), weather radar had become standard on large civil aircraft and navigation radar on merchant ships, and the military had begun operating the nationwide, radar-driven SAGE air defense system.

Measuring participation in the radar industry is difficult, in part because its boundaries are fuzzy, as many radar input suppliers (e.g., antennas, diodes, or cathode ray tubes) might be reasonably classified in other sectors. One approach to measuring industry size is to count firms in the Thomas Register (TRAM). Radar was first added to TRAM in 1944, but for security reasons no firms were named; it was then listed in 1947 and every edition thereafter.

We follow Gort and Klepper (1982), Klepper and Graddy (1990), and Agarwal and Gort (1996) in reporting firm counts in TRAM for radar. Many of these firms are radar systems manufacturers and include known World War II suppliers; others are described as supplying specific components (see Appendix Figure B.4 for a sample). Figure 2 shows the number of firms growing from (implicitly) zero in the 1930s to roughly 50 in 1947 and 175 by 1956, covering the industry’s initial era of rapid expansion (according to Gort and Klepper 1982). Given the scope of the wartime effort, and the reporting limitations of TRAM, we think these counts are directionally accurate but likely to be an underestimate of the full scope of the postwar radar ecosystem. As Figure 2 also shows, industry participants included both wartime suppliers and new entrants—many of whom were existing firms entering from adjacent industries (e.g., aircraft manufacturers or electrical or marine equipment suppliers), and a smaller number of which were de novo startups.

[Figure 2 about here]

Archival records from the largest firms involved in the war effort provide a window into their commercial transition. Promotional material (e.g., Appendix Figures A.5 and A.6) from Western Electric and Westinghouse advertised radar systems for air and sea, consistently emphasizing their World War II experience. Sperry Gyroscope records include newspaper clippings of commercial radar demonstrations, such as in river navigation and harbor traffic control (Appendix Figure A.7). Sperry records also document that by 1948, over 250 vessels belonging to nearly 100 different firms were using Sperry radar for water navigation, including customers with significant international shipping like Standard Oil or United Fruit (Sperry Gyroscope 1948). Appendix Table A.3 reproduces internal accounting records from the company documenting the profitability and growth of its marine radar business, with the majority of sales to domestic or foreign commercial markets, and a growing share to internal units for incorporation into other Sperry-made products—one of the rare instances where we can see product-level performance.

6.2 Impacts of World War II on Industry Emergence

We consider several ways in which the war effort may have been linked to postwar commercial activity in radar. The first is the emergence of technological opportunity in translating wartime progress in radar to commercial applications. This was an opportunity widely recognized at the time and the October 1945 Fortune article identified explicitly (Fortune 1945). Beyond opportunity, however, we consider the possibility that the wartime radar program also established new structures and resources around which the nascent industry could grow. Although wartime effort provided the "push" which created these structures and resources, their commercial application required specific firm choices and investments to incorporate them into new products, decide where to compete, and establish competitive positions in the emergent postwar industry.

6.2.1 Capabilities and resources

Archival documents from many World War II contractors indicate an explicit choice to redeploy resources towards commercial markets. An internal Westinghouse review of wartime work circulated in October 1946, for example, predicted that "[t]he techniques and 'know-how' gained from [its work on radar] equipment will without doubt be applied to numerous post-war developments," noting that aircraft landing in low visibility conditions would be one of its first applications (Westinghouse Electric Corp. 1946, p. 137). Sperry Gyroscope records argued that entering commercial markets was a "logical step" due to its "accumulated experience in [radar] applications" (Bigelow 1961, p. 5). Both firms appear in our TRAM firm list from 1947 onward.

Despite this continuity, Figure 2 makes clear that the postwar radar industry included many firms which were not involved in the war effort, including many firms which were seemingly founded after war ended altogether. These firms did not have war-borne resources to redeploy, but nevertheless may have benefited from resources which the war effort cultivated. To evaluate this possibility, we empirically examine both incumbents' (i.e., World War II firms') and entrants' use of three resources: Rad Lab science, technology, and human capital.[17]

For this analysis, we transition from the TRAM records to our sample of patenting firms, which we believe covers firms engaged in new product development and enables us to look beyond the boundaries of the TRAM sample itself. We construct a panel of firms with radar-related patents (see Section 4 or Appendix B.3) spanning 1940 to 1965, and in each year measure (i) their number of radar-related patents, (ii) whether these patents cite Rad Lab or RRL patents, and (iii) whether they cite the Rad Lab series (i.e., Rad Lab science).[18] We additionally measure whether and when each firm employed Rad Lab/RRL researchers, using data collected from membership directories of the Institute of Radio Engineers, as described in Section 4.

Figure 3 first documents the growth of radar-related firms and patents over this period, with Panel (A) showing the number of firms each year with $\geq$1 radar-related patent and Panel (B) showing the number of such patents, separately reporting (i) World War II program participants ("WW2 incumbents"), (ii) non-World War II firms with one non-radar patent before their first radar patent ("Diversifying entrants"), and (iii) firms whose first patent is a radar patent ("New firms"). In the years immediately after the war, World War II firms enjoyed a "dominance by birthright" (Klepper and Simons 2000a), but this position eventually gave way to a large wave of entry by firms entering radar from other industries (especially other electronics and communications industries), which by 1960 accounted for the majority of radar-related patenting.

[Figure 3 about here]

[17] Qualitative evidence suggests other Rad Lab-developed resources also extended to the postwar commercial industry. For example, an article describing the "Commercial Applications of Wartime Science" largely focused on the civilian value of radar and emphasized that the "Standardization of many components of electronic equipment [that] was brought about during the War to simplify production and distribution problems ... will now be available to industry as a guide wherever high quality is demanded" (Van Deusen 1946, p. 371).

[18] We limit this panel to years after a firm's first USPTO patent filing (of any kind), to exclude firm-years where a given firm may not yet exist. A small number of firms in this sample experienced M&A during our sample period, according to merger statistics from the Federal Trade Commission; for these firms, we dynamically reassign their patents to ultimate owners in post-acquisition years. See Appendix B.3.

In Figure 4 we explore the degree to which these firms built on Rad Lab science and technology and employed former Rad Lab researchers. Panel (A) shows the share of patenting firms in biennial intervals who cite Rad Lab patents or the Rad Lab series in at least one patent, and Panel (B) the share of these firms whom we can identify as employing at least one Rad Lab researcher; in both panels, we report these rates for World War II firms and postwar entrants (combining diversifying entrants and new firms). Both World War II firms and postwar entrants made use of these resources, though the former did so at a much higher rate: at the peak, 60-80% of these firms cited Rad Lab science and technology in at least some of their radar patents (versus ≈40% for postwar entrants), and around 50-60% employed Rad Lab researchers (versus 20%). Appendix Figures D.1 and D.2 build on this evidence further: the former by showing that both component and system innovation drew on Rad Lab science and technology, and the latter by showing that the Rad Lab's footprint continued into later generations of radar-related technology.[19]

[Figure 4 about here]

How broadly accessible these resources were is a distinct question. Knowledge is in theory mobile but has long been recognized to localize (Jaffe et al. 1993, Rosenthal and Strange 2003, Roche 2020), and knowledge workers even more so (Rice et al. 2006, Rosenthal and Strange 2008). Table 5 asks whether having a physical presence in Cambridge was advantageous for harnessing these resources. We evaluate whether firms with recent R&D in Cambridge or its surrounding county (Middlesex, MA) were more likely in a given year to (i) cite Rad Lab/RRL patents or (ii) the Rad Lab series (conditional on patenting), or (iii) employ a former Rad Lab/RRL researcher. To do, we regress indicators for these outcomes on an indicator for whether the firm filed any radar-related patents in Middlesex in the prior year (a proxy for local operations), initially with no fixed effects and then with firm and year fixed effects. Firms of both types were similarly likely to cite Rad Lab patents and science, but those located near Cambridge were much more likely to employ former Rad Lab staff, indicating that codified knowledge in patents and publications was more widely accessible, and vindicating the intent behind the Rad Lab's effort to proactively disseminate knowledge while highlighting the limits to its newly-developed human capital.

[Table 5 about here]

6.2.2 Persistence of market structures

Beyond emerging opportunities and specific resource usage, a third way the war may have facilitated commercial activity is by giving structure to the radar ecosystem, which during the war was

[19] Though only 5% of radar-related patents directly cited Rad Lab patents by the 1960s (as the technology continued evolving), roughly 50% had a 3rd-degree or lower linkage through the citation record.

organized around component suppliers and systems developers and was largely vertically disintegrated but supported by centralized coordination. To test for potential continuity of this industry structure, we return to TRAM, where most firm listings were accompanied by business descriptions. Tabulating the frequency of words in these business descriptions, the most common words (in order, and singularized) are *Component*, *Equipment*, *Radar*, *Part*, and *Microwave*. Shortly after these are names of specific components and system types, such as *Waveguide*, *Antenna*, *Tube*, *Navigation*, and *Airborne*—indicative that this industry structure persisted. To more formally evaluate post-war industry structure, we manually classify each business description into four categories: radar systems, components, services (e.g., design or custom manufacturing to specifications), and other or missing. Figure 5 shows the distribution of TRAM-listed firms across these categories each year from 1947 to 1956 and demonstrates how this structure persisted.

[Figure 5 about here]

6.2.3 Assessing causal linkages and counterfactuals

Because we do not have a counterfactual to empirically compare the radar industry's history against, our analysis is intrinsically abductive. A possibility remains that the Rad Lab was not strictly necessary to obtain microwave radar (and the resultant radar industry), particularly in light of evidence from prior research that firms or other organizations can also be ecosystem leaders (Iansiti and Levien 2004, Adner 2012). However, even if microwave radar were inevitable, contemporaries argued that the war sped its development by decades (Baxter 1946, MIT 1946). The most specific counterfactual analysis arguably comes from archival records. When OSRD Director Vannevar Bush asked Rad Lab staff near the end of the war "why manufacturers had not become more independent of the Laboratory" sooner, several reasons were given, including that (i) most firms had lacked the capabilities to undertake the necessary basic research which the Rad Lab performed, as well as "adequate engineering staff," (ii) private firms lacked the close interaction that the Rad Lab maintained with the military services, and (iv) firms lacked adequate testing facilities and equipment—infrastructure which would benefit the full ecosystem, but which the Rad Lab had the necessary scale and incentives to invest in (Exter 1944, p. 7).

These insider observations reinforce an inference that absent the war, there might not have been a commercial radar industry to write of. They also resurface the central thesis of this paper: that by both (i) establishing the underlying science and technology of microwave radar and (ii) organizing and coordinating actors across the nascent value chain, the radar program brought into being the resources and ecosystem needed to stimulate private investment in this emerging technology and in turn enabled a commercial industry to grow around them.

7 Discussion

7.1 Insights for Research

7.1.1 Reflections on industry dynamics

Industry dynamics have been among the central themes of strategy research for decades. As this literature has evolved, attention has increasingly gravitated to high-tech industries and especially their initial stages, including a pre-commercial "emergence" phase. The recently burgeoning literature on industry emergence has sought to identify systematic features underpinning early high-tech industry development, often focusing on actors, motives, and knowledge accumulation milestones in relation to not only technology but also institutions and demand (Moeen et al. 2020). Despite the size of this literature, relatively little of it examines the impact of government R&D policies. That which does has often focused on public research as feedstock for new technology-based industries, such as in biotechnology (e.g., Zucker et al. 1998, McMillan et al. 2000), where discrete innovations like drugs can be linked directly to NIH-funded biomedical science (Azoulay et al. 2019). Here we study a different institutional mechanism—actively-managed government R&D programs—and a different category of innovation—complex technologies—building on recent work which emphasizes public sector missions as industry catalysts (Agarwal et al. 2021).

Reflecting on the state of this literature, our results suggest that existing models of industry emergence might be extended in two substantive ways. One is deepening understanding of the role that government (or similar) actors can play in supporting technological breakthroughs and instigating commercial takeoffs, which extends beyond priority-setting and funding to coordinating a range of actors and investments needed to make progress on complex problems. The richness of the radar case provides detailed insight into this type of actor and its activities, sharpening understanding of how public agencies may participate in industry incubation and the impacts they may have on knowledge accumulation, uncertainty reduction, and collective investment (Moeen et al. 2020). In doing so, we complement recent comparative case studies which trade off this depth for the insights that comparative analyses provide (e.g., Agarwal et al. 2021).

The second addition this paper makes to models of industry emergence is to deepen understanding of transitions: how participants in public "mission" programs pivot to commercial markets and what features of these programs create the conditions for wider commercial entry. Agarwal et al. (2021), for example, present a model of mission-oriented industry incubation that begins with a grand challenge, proceeds through goal definition and knowledge-deepening activities, and ends in mission and industry outcomes. Though this work generally lumps these outcomes together, industry impacts may not be not guaranteed, and more generally the mission-to-industry link is underexplored. In this paper, we have effectively split them apart, identified links, and highlighted choices (such as knowledge dissemination and the orchestration of a diffuse and distributed ecosystem) that ostensibly increase the odds of a successful transition.[20]

7.1.2 Sufficient vs. necessary conditions

Although our evidence indicates clear links between wartime and postwar activity, a question we are left with is whether a mission program was specifically needed to generate a commercial radar industry. In evaluating this question it is useful to restate what the war effort did for industrial development: we see its main effects as advancing science and technology, cultivating input and output markets, and connecting the value chain through collaborative structures. Our view of the evidence is that all three were important activities which private firms lacked the capabilities or incentives to do independently—a feature attested by the Rad Lab's own assessments—and the Rad Lab thus addressed gaps which markets often struggle to fill.

Despite this view, the most we can establish from this single case study is that the radar program was a sufficient (rather than necessary) mechanism to catalyze a commercial industry. Other governance structures—including vertical integration, alliances, and even decentralized markets—have yielded similar outcomes in other settings, though typically more slowly: Kim et al. (2024), for example, show that over 40+ years, the bionic prosthetics industry progressed through a combination of small entrants who developed components and large incumbents focused on systems integration. Other examples are relatively common. Within this context, we view our findings as an existence result, reinforcing that coordinated R&D programs are one pathway to industry incubation (Agarwal et al. 2021, among others), while deepening understanding of why and how.

That said, we argue that the war program had two effects that were otherwise unlikely. One is speed: the historical consensus is that the World War II dramatically accelerated the development radar.[21] This accelerated incubation was valuable for firms and users, shifting profits and surplus forward by decades. Beyond speed, the other distinction is entry barriers, resource access, and the resultant dynamism of the postwar radar industry. In many complex technologies, coordination structures like alliances or vertical integration feature prominently in industry evolution, but the resulting control over inputs, and specificity of outputs, can limit subsequent entry and industry growth. The radar program, in contrast, lowered barriers to entry through a combination of public

[20]In relation to Agarwal et al. (2021)'s industry emergence model, this effectively adds a new step to the end of the model for the industry outcome, and a process flow from the mission to that industry outcome.

[21]Rad Lab documents describe having achieved decades of progress in a few years of war (MIT 1946), and Guerlac (1987, p. 687) similarly writes of "25 years of change telescoped into five."

goods provision and its cultivation of a distributed ecosystem. Absent this, the radar industry might have otherwise developed around a few large, vertically integrated firms producing for the military. Concentration might have in turn stifled long-run innovation by creating a closed ecosystem with limited competitive pressure and little recombinant influence.

7.2 Applications and Limitations

We think the evidence from this case is most directly relevant to technology problems and (public or private) R&D institutions with similar goals and features. Several public R&D organizations operating today are direct descendants of the Rad Lab or other World War II-era research projects, and others share the same ambitions of cultivating ecosystems around complex technologies. The institution that bears the closest resemblance to OSRD is arguably DARPA, and the closest parallel to the wartime radar program today may be some DARPA-led technology development projects. To be clear, DARPA is not a monolithic agency, and the R&D programs it runs have substantial heterogeneity (Bonvillian et al. 2019). But they have several features in common, including specific (defense-related) mission goals and active management, and they often (i) invest in both science and technology, aiming to convert high-risk science into useful innovation, and (ii) build cross-sectoral networks and ecosystems to bring emerging technologies to fruition.

Other related examples include integrated industrial R&D programs such as aircraft development projects, where coordinated efforts across multiple stakeholders may be needed to overcome technological and market challenges (e.g., Argyres 1999). Similarly, industry consortia like SEMATECH (Grindley et al. 1994, Link et al. 1996, Mowery 1998, Langlois and Steinmueller 1999)—a collaborative, publicly-funded industrial R&D program in the 1980s and 1990s which sought to improve the competitiveness of the U.S. semiconductor industry—can guide cooperative efforts across firms and other ecosystem players to advance complex technology. In contrast to the radar program, SEMATECH saw suppliers, manufacturers, and end users voluntarily coordinating with each other (without strong government leadership) using Moore's law to align investments across stages of technology development. Thus in both cases (radar/semiconductors), coordination facilitated interdependent choices across the value chain, albeit at different speeds.[22]

Despite the richness of the setting, there are limits to what we observe. For example, an important distinction can be drawn between the commercial viability of an emerging high-tech industry—

[22]Though SEMATECH was U.S.-focused and wound down in 1997, the challenges of interdependency continue to resurface in the (complex) semiconductor industry: for example, improvements in ASML's photolithography equipment hinge on improvements in its light source, which is supplied by a third party (Cymer) and which struggled to produce a light source that met the requirements of extreme ultraviolet lithography. It was not until ASML acquired Cymer in 2013 that meaningful progress could be made: vertical integration, in this case, gave ASML control over the development and integration of the light source into its equipment, supporting a closer alignment between the design of its machines and critical components (Roche et al. 2024a).

based on the accumulation of knowledge and other key assets (Moeen et al. 2020)—and its takeoff, when sales begin to grow. Because commercial activity had to wait until the war ended, we cannot determine precisely when commercial viability was achieved, though we can infer it arrived sometime prior to 1945, such as when military sales began to grow.

There are also potential limits to generalizability. The World War II radar program was operated to meet an urgent military need in a global war—not to remedy peacetime market failures—and its commercial impacts were incidental to the primary goal of creating technology for war. There are potentially ways in which this may not be general. The urgency of war motivated a level of public investment rarely seen in history. It also supported a level of cross-sectoral collaboration not often attained and overcame frictions that could prevail in other contexts.

7.3 Final Remarks

Our main result is thus demonstrative: a coordinated, use-oriented government R&D program can cultivate commercial industries around complex new technologies. This does not mean it always will. Given that this example was borne out of a crisis, and that others are often also driven by urgent needs, a basic question is whether "mission" approaches have similar impacts in other contexts—especially when the need is less urgent, harder to articulate, diffuse across many users, or requires more than technological innovation to resolve. This question is more widely contended in academic literature, with advocates of mission approaches to R&D and industrial policy (e.g., Mazzucato 2018, 2021), cautionary voices (Mowery et al. 2010), and recent and ongoing research continuing to explore this question (Agarwal et al. 2021, Sohn et al. 2024).

Additional research is needed on whether similar effects may be produced by other mission-oriented R&D efforts, including in emerging sectors like renewable energy or artificial intelligence today. But beyond reproducibility, this study points to new questions. Examples include questions of under what conditions do coordinated R&D programs create entry barriers at the same time as they cultivate commercial activity, entrenching participants as industry leaders, versus enable wider entry, mitigating the commercial effect? Which firms choose to engage in coordinated R&D programs, and why? With growing interest in these structures (e.g., Renaissance Philanthropies 2025), we believe these questions will likely be fertile grounds for future study.

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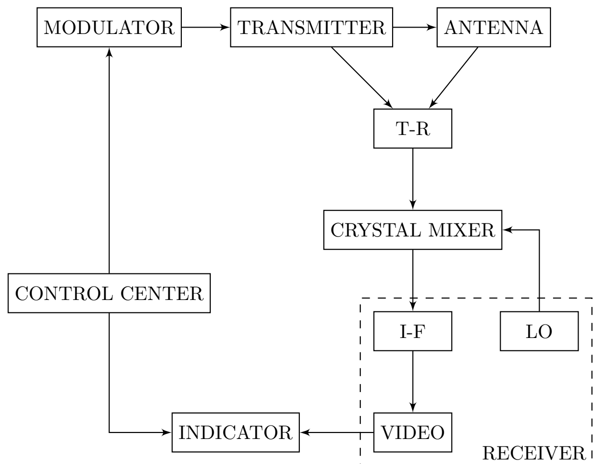
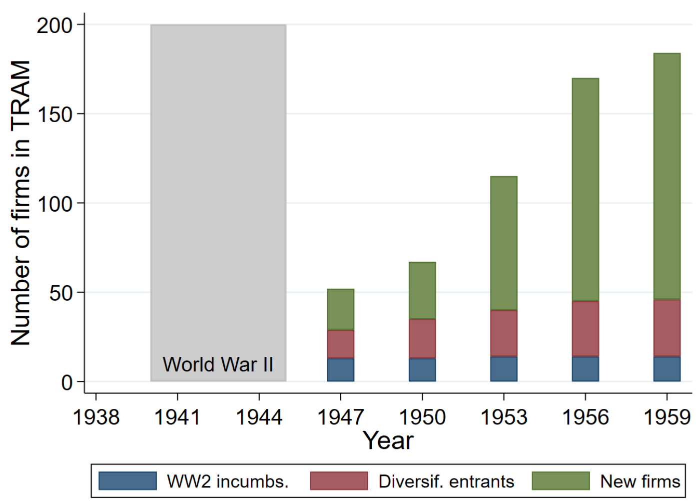
Figures and Tables

Figure 1: Radar system: Block diagram



Notes: Figure presents a block diagram of a radar system. Adapted from Guerlac (1987), Figure 2-17.

Figure 2: Radar industry participants in the Thomas Register, 1940s-1950s

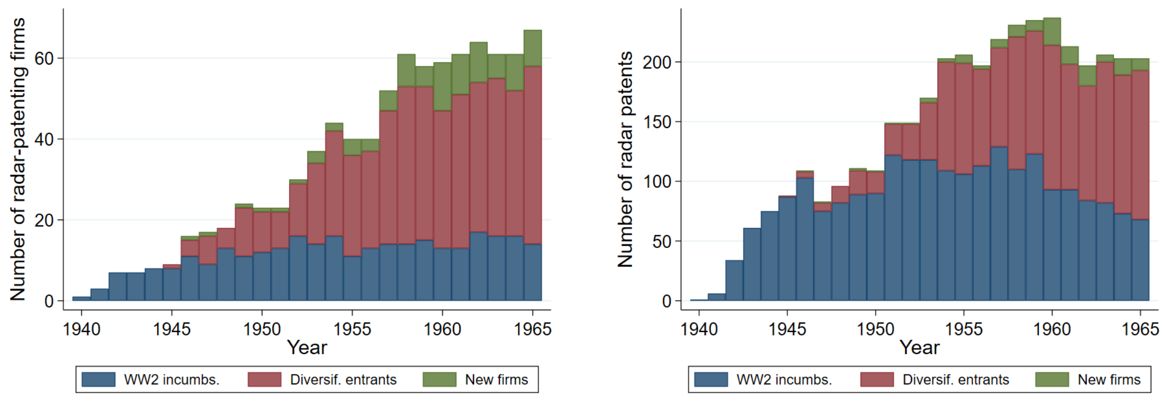


Notes: Figure shows count of radar industry participants in successive editions of the Thomas Register of American Manufacturers (TRAM). The first edition to include radar as a product category was 1944, though firm listings were suppressed for security reasons until 1947, when industry participants already numbered >50 firms. "WW2 incumbents" are those which we can identify as having participated in the wartime program, based on Rad Lab records, information in Guerlac (1987), and war supply contract data from Li and Koustas (2019) (where we searched for contracts with the word "radar" in the product description). "Diversifying entrants" are non-WW2 suppliers which are present in the TRAM index in 1941 or 1944. Firms which are neither war suppliers nor in previous editions of TRAM we label "new".

Figure 3: Annual number of radar-patenting firms and radar patents, 1940-1965

Panel (A): Radar-patenting firms

Panel (B): Radar patents

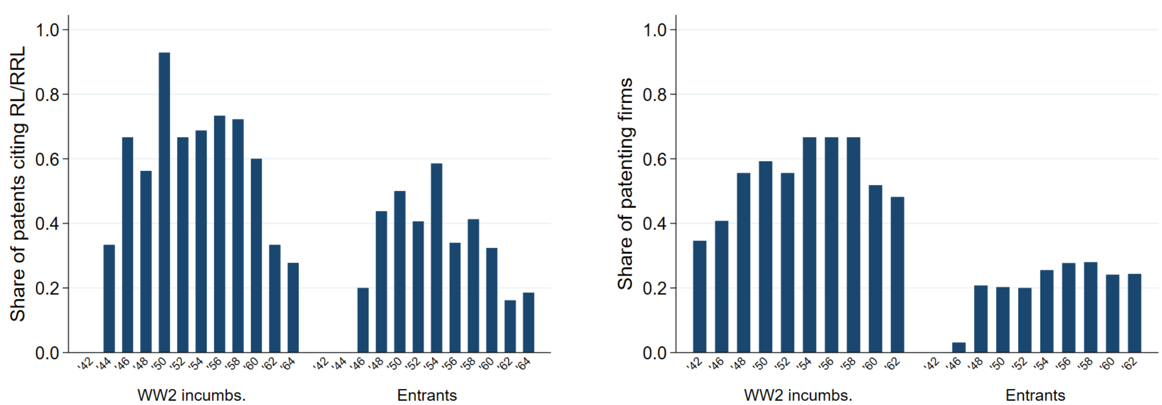


Notes: Panel (A) shows the number of firms each year from 1940 to 1965 with at least one radar-related patent, by firm type. We associate patents to firms through assignees. "WW2 incumbents" are those which we can identify as having participated in the wartime program, based on Rad Lab records, information in Guerlac (1987), and war supply contract data from Li and Koustas (2019) (where we searched for contracts with the word "radar" in the product description). "Diversifying entrants" into radar are non-WW2 firms which had at least one non-radar patent before their first radar patent. "New firms" comprise all other entrants. In Panel (B) we report the number of radar-related patents over time by firm type.

Figure 4: Rate at which radar-patenting firms used or extended RL/RRL-developed science, technology, and human capital

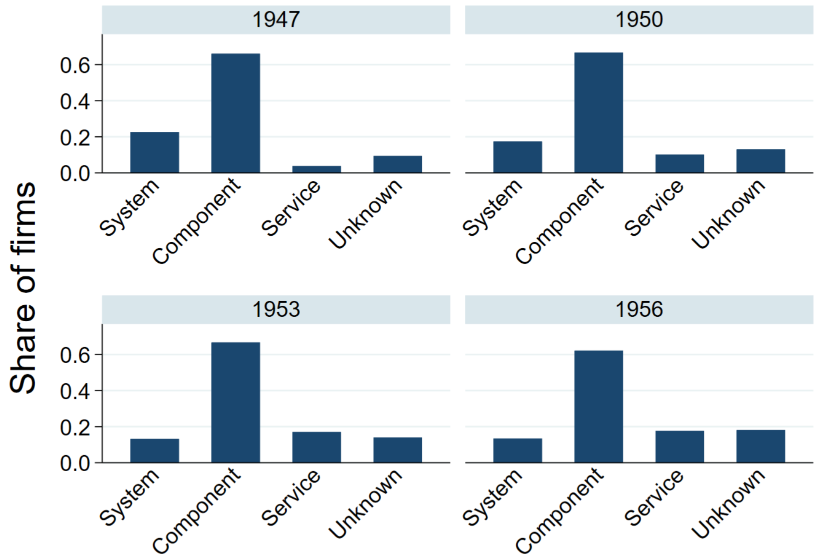
Panel (A): Share of firms citing RL/RRL science or patents

Panel (B): Share of firms employing ≥1 former RL/RRL researchers



Notes: Panel (A) shows the share of radar-patenting firms between 1940 to 1965 which cite RL/RRL patents or the Rad Lab series in at least one radar patent, by firm type. We associate patents to firms through assignees. "WW2 incumbents" are those which we can identify as having participated in the wartime program, based on Rad Lab records, information in Guerlac (1987), and war supply contract data from Li and Koustas (2019) (where we searched for contracts with the word "radar" in the product description). "Entrants" are all other firms. Panel (B) shows the share of radar-patenting firms between 1940 and 1965 which we identify as employing a former RL/RRL researcher, using near-annual IRE member directories between 1942 and 1963 (note: no data available for 1943-1945, 1947, 1949, and 1957).

Figure 5: Share of TRAM-listed firms by radar industry segment, 1947-1956



Notes: Figure shows the share of radar industry participants in each edition of the Thomas Register of Manufacturers (TRAM) between 1947 and 1956 which we classify as providers of radar systems, components, and services, based on the product/service descriptions provided in the TRAM directory listings. Firms can be classified into multiple categories (e.g., component manufacturing to customer specifications as both component and service). Firms without product descriptions classified as unknown.

Table 1: Top 10 manufacturers of radar systems in World War II

Firm	WW2 value (2022 $, BBs)	Pct. of WW2 total	Listed in TRAM? 1947	1950	1953	1956	1959
Western Electric Co.	20.281	39.9%					
General Electric Co.	6.247	12.3%	Y	Y	Y		
Philco Corp.	4.283	8.4%	Y	Y	Y	Y	Y
Raytheon Mfg. Co.	3.741	7.4%	Y	Y	Y	Y	Y
Westinghouse Electric Corp.	3.657	7.2%	Y	Y	Y	Y	Y
Radio Corp. of America	2.150	4.2%		Y	Y	Y	Y
Hazeltine Corp.	1.913	3.8%					
Stewart-Warner Corp.	1.050	2.1%					
Belmont Radio Corp.	1.033	2.0%	n.a.	n.a.	n.a.	n.a.	n.a.
Sperry Gyroscope Co.	0.863	1.7%	Y	Y	Y	Y	Y

Notes: Table lists the top 10 World War II radar suppliers (by value), based on Guerlac (1987), with values inflated from 1940s levels using a composite wartime adjustment, weighting annual inflation factors by each year's share of radar deliveries. It then indicates whether each firm was listed as a radar supplier in postwar editions of the Thomas Register of American Manufacturers (TRAM). Though not found in TRAM, Western Electric is known via archival records to have been active in radar. Belmont Radio Corp. was acquired by Raytheon in 1945 and is not separately listed thereafter.

Table 2: RL/RRL share of patents in principal radar patent classes and components, 1943-1946

USPC or Component/System	Pct. of patents from RL/RRL, 1943-1946	Govt. funded share of patents	RL/RRL rank among assignees
Panel (A): Share of patents in radar-related classes			
343 (Radio wave antennas)	15.5%	59.2%	1
342 (Directive radio wave systems/devices (radar))	10.8%	58.2%	2
333 (Wave transmission lines and networks)	10.4%	51.4%	2
327 (Electrical devices, circuits, and systems)	7.9%	58.9%	2
315 (Electric lamp and discharge device systems)	5.5%	28.9%	3
708 (Electrical computers: processing)	5.4%	39.1%	4
Panel (B): Share of radar-related patents in specific measurable components			
Radar systems	15.2%	68.5%	1
Antennas	14.3%	58.8%	1
Waveguides	10.9%	55.3%	3
Magnetrons	9.2%	37.3%	3

Notes: Panel (A) lists the top patent classes (USPCs) with Rad Lab/RRL patents between 1943 and 1946 (when nearly all Rad Lab/RRL patents were filed). Columns report (i) the Rad Lab/RRL share of patents, (ii) the government-funded share of patents, and (iii) the Rad Lab/RRL rank against all class assignees. Panel (B) lists radar systems and components which are identifiable using CPC codes (see Section 4), and reports the same statistics among patents associated with these systems/components.

Table 3: Changes in research orientation of Rad Lab/RRL inventors: tendency to produce patents in radar classes

	Fraction in Radar USPCs			Any in Radar USPCs		
	(1)	(2)	(3)	(4)	(5)	(6)
	Pre-to-Mid	Mid-to-Post	Pre-to-Post	Pre-to-Mid	Mid-to-Post	Pre-to-Post
1(Is RL/RRL alum)	0.232	-0.100	0.091	0.597	-0.278	0.310
	(0.038)	(0.036)	(0.035)	(0.061)	(0.078)	(0.062)
N	76006	38866	58582	76006	38866	58582
R^2	0.71	0.71	0.61	0.73	0.71	0.64
Y mean	0.02	0.02	0.02	0.04	0.06	0.04

Notes: Table estimates differences in differences in the tendency of Rad Lab/RRL staff to invent in radar, relative to other inventors, as it changed across the pre-, mid-, and post-war periods. In each panel there are two outcomes: Columns (1) to (3) present intensive measures (the fraction of the inventor's patents of a given type), and Columns (4) to (6) intensive measures (any patents of a given type, conditional on patenting at all). The third and sixth columns are our preferred specifications, being indicative of lasting shifts in inventive behavior. Robust SEs in parentheses.

Table 4: Firms supplying wartime radar components and systems named in Guerlac (1987)

Firm	Systems	Components: Antenna	T-R Box	Crystal Mixer	Receiver	Indicator	CRT	Modulator	Transmitter	Beacons
Western Electric Co.	X	X	X	X	X			X	X	
General Electric Co.	X		X			X	X	X	X	X
Radio Corp. of America	X				X	X	X	X	X	X
Raytheon Manufacturing Co.	X	X			X	X		X	X	
Philco Radio Corp.	X	X						X	X	X
Sylvania Electric Products Co.	X		X					X	X	
Westinghouse Electric Corp.	X		X					X	X	
Galvin Manufacturing Co.	X	X								X
Sperry Gyroscope Co.	X			X					X	
Grinding Tool Co.	X	X								
F. J. Hagerty Co.	X	X								
Douglas Aircraft Co.	X	X								
Stromberg-Carlson Co.	X							X		
F. M. Link Co.	X							X		
Hallicrafters Co.	X									X
Gilfillan Brothers Co.	X									X
+ 15 firms producing only systems										
+ 2 firms producing only components										

Notes: Table identifies World War II suppliers of complete radar systems and of specific radar components explicitly named in Guerlac (1987), sorted in descending order by number of segments a firm is described as having been present in. Contemporary evidence suggests the complete wartime radar ecosystem included a wider set of firms than those noted by Guerlac, and a supply chain that ran several layers deep (a Fortune (1945) article on the emergent industry alleges "8,000 subcontractors", though this is potentially an overestimate).

Table 5: Differences in postwar use of Rad Lab/RL resources by radar firms as a function of whether they have an R&D presence near Cambridge

	Cites in a patent: (1) RL/RRL patent	(2) RL series	Employs (3) Any alum	Cites in a patent: (4) RL/RRL patent	(5) RL series	Employs (6) Any alum
Presence in Middlesex, MA	0.101	0.106	0.446	0.044	0.034	0.117
	(0.085)	(0.061)	(0.081)	(0.076)	(0.061)	(0.048)
N	835	835	2562	801	801	2562
R^2	0.01	0.01	0.05	0.43	0.40	0.70
LHS mean	0.31	0.21	0.26	0.32	0.21	0.26
RHS mean	0.16	0.16	0.05	0.16	0.16	0.05
Firm FE				Y	Y	Y
Year FE				Y	Y	Y

Notes: Table relates firms' tendency to build on or use RL/RRL-developed resources to whether the firm has R&D operations in Cambridge, MA or its surrounding county (Middlesex). The results provide a test of whether a physical presence in or near Cambridge was needed to make use of these resources. Columns (1) and (2) estimate differences in firms' propensity to cite RL/RRL patents (Column 1) or the Rad Lab Series (Column 2) in radar-related patents (defined as patents classified in radar component and system CPCs with the word "radar" or "microwave" in the patent text). The outcome is measured at the firm-year level as an indicator for whether such a citation was made in a given year, conditional on the firm filing any radar-related patents, and the sample spans 1947 (when front-page citations begin) to 1965. Column (3) estimates differences in these firms' propensity to employ at least one former RL/RRL researcher, measured using near-annual IRE member directories between 1948 and 1963. In all cases, the independent variable measures whether the firm filed any radar-related patents in the prior year in Middlesex County, as an indicator for current R&D activity in the area. Columns (4) to (6) repeat these estimations adding firm and year fixed effects. SEs clustered by firm in parentheses.

Online Appendix

Coordinated R&D Programs and the Creation of New Industries

Daniel P. Gross and Maria P. Roche

Table of Contents

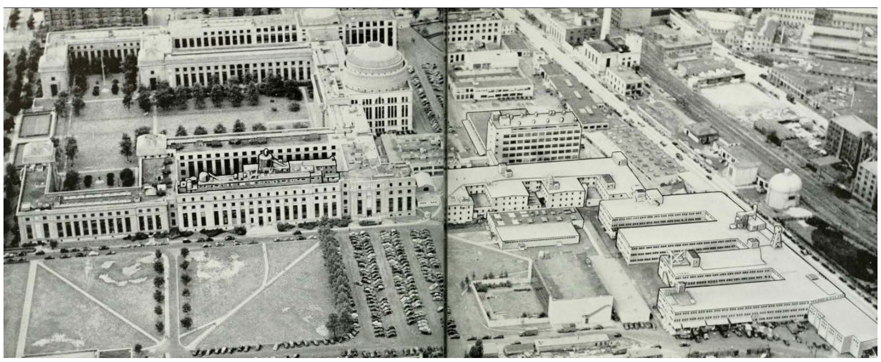
A Historical Appendix

A.1 Archival records: A glimpse into the Rad Lab

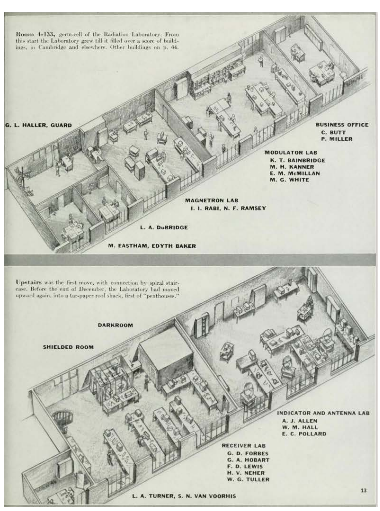
This appendix section provides additional contextual information on WWII radar program, particularly for the research organizations at the center of the wartime research effort: the MIT Radiation Laboratory (Rad Lab) and Harvard Radio Research Laboratory (RRL). Figure A.1 presents photos of the Rad Lab's facility. Tables A.1 and A.2 describe the Rad Lab's organizational structure—where many divisions and working groups map to specific radar components, and others map to (upstream) basic science and specific (downstream) applications. Figures A.2 and Figure A.3 provide org charts for the Rad Lab and RRL, respectively.

Figure A.1: Photographs, 1940-1945 (reproduced from MIT 1946)

Panel (A): Aerial photograph of Building 20 (Rad Lab building; on right, outlined)



Panel (B): Initial office schematic (1940)



Panel (C): Early research activity (1940)

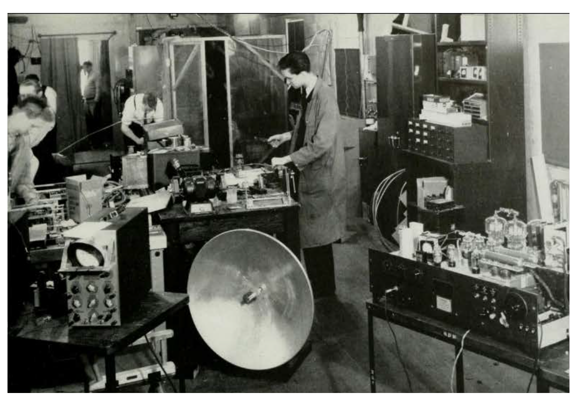


Table A.1: List of Rad Lab Divisions (reproduced from MIT 1946)

Division	Name	Chief	Known Staff
1	Business Office	T. F. O'Donnell	95
2	Buildings and Maintenance	J. G. Peter	4
3	Personnel and Shops	F. W. Loomis	51
4	Research	I. I. Rabi	73
5	Transmitter Components	J. R. Zacharias	235
6	Receiver Components	L. J. Haworth	158
7	Beacons	L. A. Turner	46
8	Fire Control and Army Ground Forces	I. A. Getting	81
9	Airborne Systems	M. G. White	78
10	Ground and Ship	J. C. Street	95
11	Navigation	J. A. Pierce	24
12	Field Service	J. G. Trump	13

Notes: Table lists Rad Lab divisions, division heads, and staff counts we are able to identify in each. Divisions 4 to 11 were the principal technical divisions.

Table A.2: List of Rad Lab R&D Working Groups (reproduced from MIT 1946)

Division	Division name	Group	Group name	Group chief
4	Research	41	Fundamental Development	E. M. Purcel
4	Research	42	Propagation	D. E. Kerr
4	Research	43	Theory	G. E. Uhlenbeck
4	Research	44	Experimental Systems	J. L. Lawson
4	Research	45	Special Dielectrics	O. Halpern
5	Transmitter Components	51	Modulators	H. D. Doolittle
5	Transmitter Components	52	Transmitters	G. B. Collins
5	Transmitter Components	53	Radio Frequency	A. G. Hill
5	Transmitter Components	54	Antennas	L. C. Van Atta
5	Transmitter Components	55	Test Equipment	F. J. Gaffney
5	Transmitter Components	56	Component Engineering	M. M. Hubbard
5	Transmitter Components	57	Special Problems	J. C. Slater
6	Receiver Components	61	Receivers	S. N. Van Voorhis
6	Receiver Components	62	Indicators	C. Sherwin & J. Soller
6	Receiver Components	63	Precision	B. Chance
6	Receiver Components	64	Trainers	R. L. Garman
6	Receiver Components	65	Moving Target Indication	R. A. McConnell
7	Beacons	71	Racons	A. Roberts
7	Beacons	72	Identification	M. D. O'Day
8	Fire Control and Army Ground Forces	81	Systems	L. L. Davenport
8	Fire Control and Army Ground Forces	82	Systems	R. P. Scott
8	Fire Control and Army Ground Forces	83	Servos	N. B. Nichols
8	Fire Control and Army Ground Forces	84	Theory	R. S. Phillips
8	Fire Control and Army Ground Forces	85	Design	J. S. White
9	Airborne Systems	91	(none)	T. W. Bonner
9	Airborne Systems	92	(none)	M. G. White
9	Airborne Systems	93	(none)	W. M. Cady
10	Ground and Ship	101	Mechanical Engineering	M. B. Karelitz
10	Ground and Ship	102	Ship Applications	J. S. Hall & R. E. Meagher
10	Ground and Ship	103	Special Applications	R. M. Emberson
10	Ground and Ship	104	Ground Applications	E. G. Schneider
11	Navigation	111	Laboratory	A. J. Pote
11	Navigation	112	Loran Operational Research	J. A. Pierce
11	Navigation	113	Field Engineering and Procurement	W. L. Tierney

Figure A.2: Rad Lab Organization Chart (source: MIT 1946)

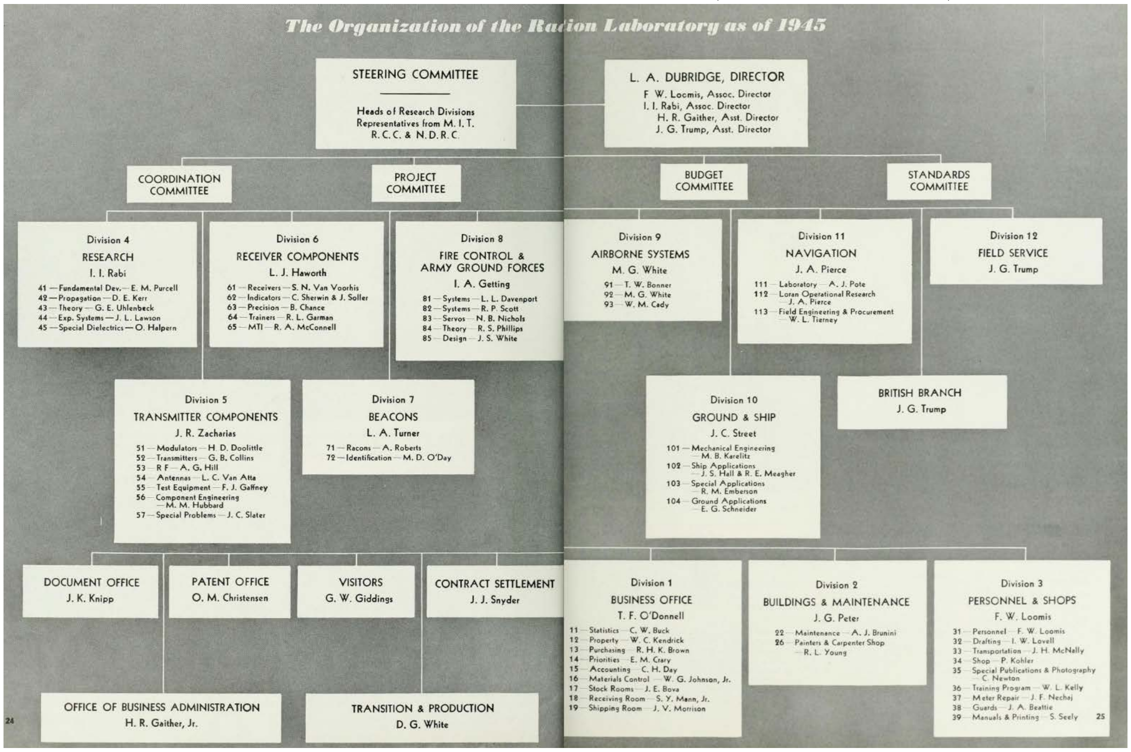
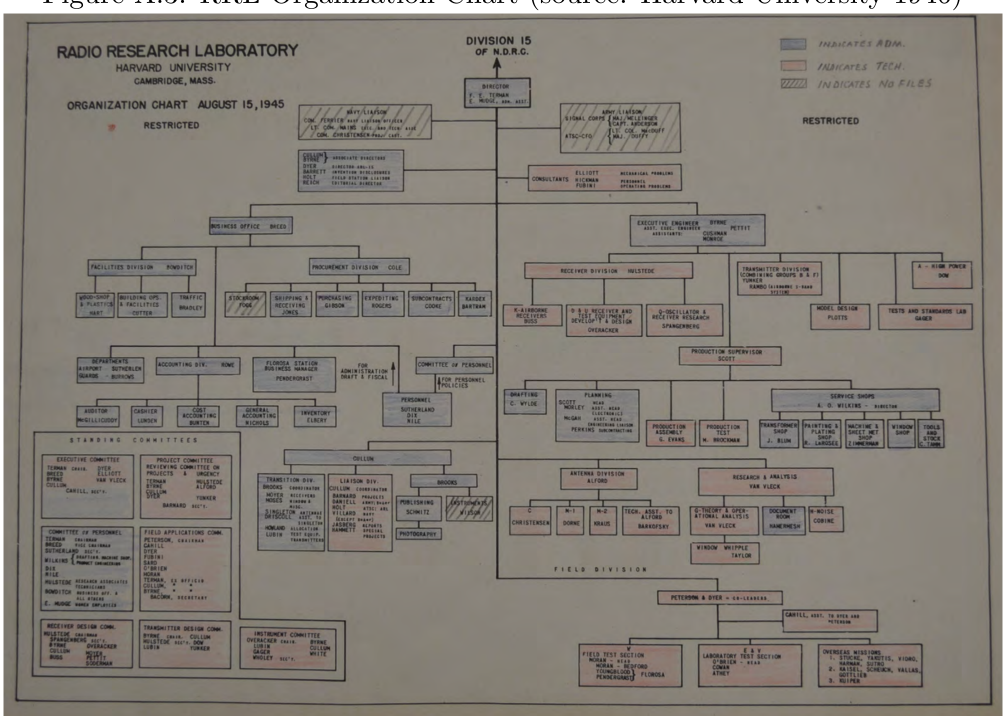


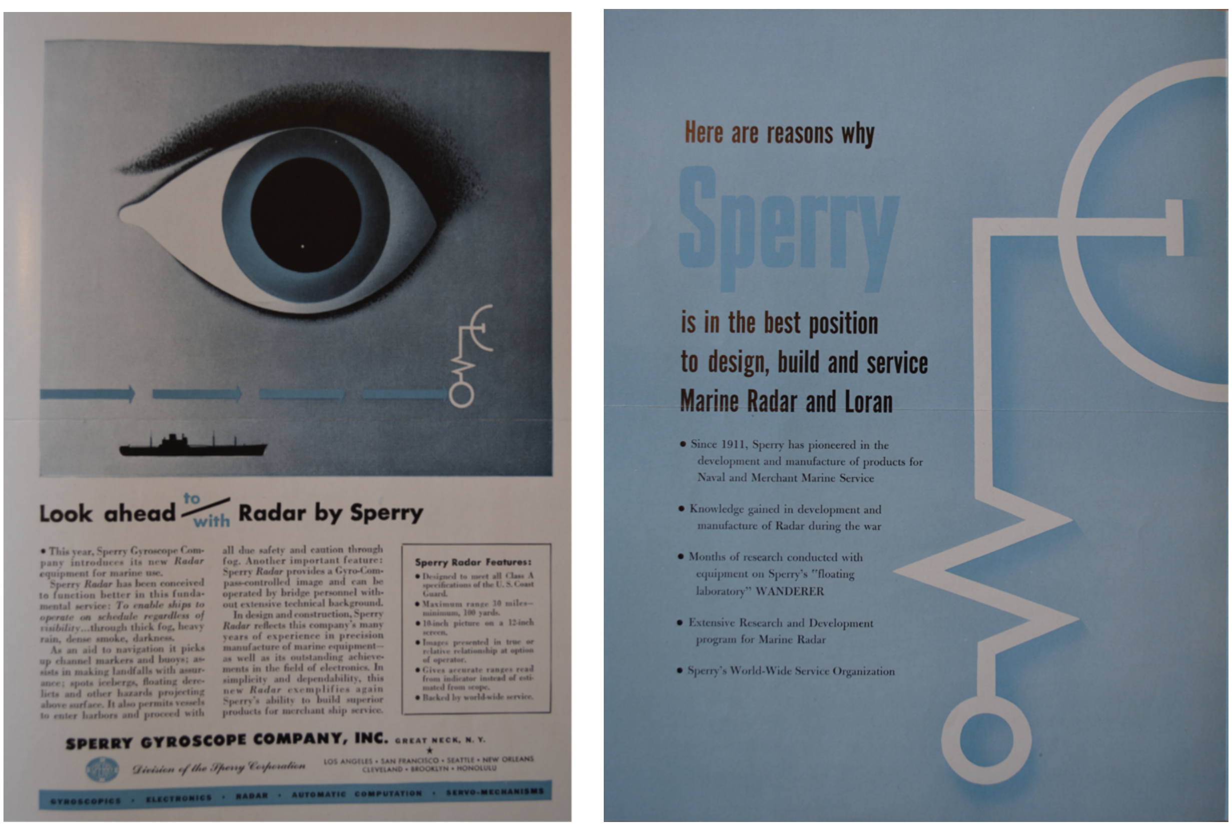
Figure A.3: RRL Organization Chart (source: Harvard University 1946)



A.2 Supplementary material on World War II suppliers

Figures A.4 to A.6 provide examples of postwar commercial promotional materials for Sperry Gyroscope, Western Electric, and Westinghouse obtained from corporate archives. Both advertise commercial applications of radar while emphasizing each firm's wartime work: Figure A.4 (Sperry) markets commercial marine radar and refers to its "knowledge gained in development and manufacture of radar during the war," Figure A.5 (Western Electric) markets radar "for air and sea commerce" and highlights that it supplied "approximately 50% of the dollar volume of all [wartime] radar," including airborne, shipborne, and ground systems. Figure A.6 (Westinghouse) similarly markets both air and sea radar and references its wartime experience. Figures A.7 and A.8 provide internal and public reports of new product development and testing for Sperry's commercial marine radar, from the firm's archival records. Table A.8 reproduces Sperry's internal accounting records reporting the profitability and growth of its marine radar business.

Figure A.4: Promotional material for Sperry Gyroscope marine radar (1946)

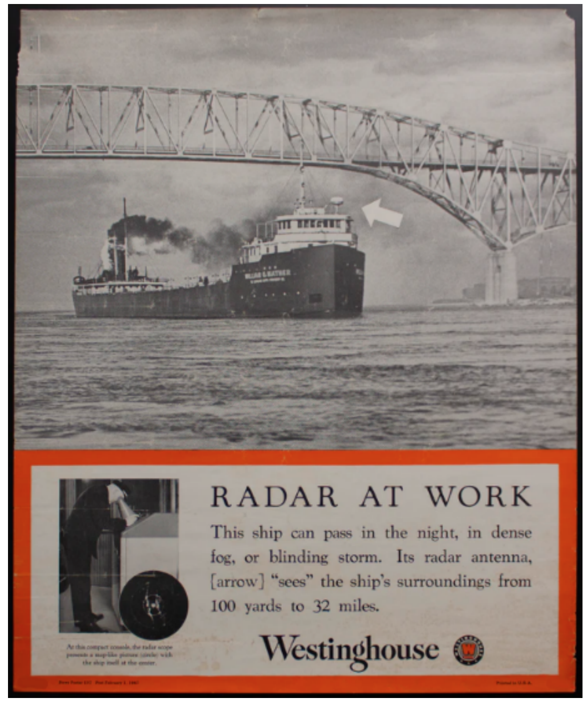


Source: Hagley Museum, Sperry Gyroscope Company collection, Box 5, Folder 332.

Figure A.5: Promotional material for Western Electric radar (1946)

Source: AT&T Archives and History Center, Western Electric collection, location 89-08-84-05.

Figure A.6: Promotional material for Westinghouse radar (1946-1947)



Source: Images obtained from Golden Age Posters.

Figure A.7: Sperry Radar River Trials: Internal report

REPORT ON SPERRY RIVER RADAR TRIALS

I. INTRODUCTION:

On November 22, 1946, the Sperry Gyroscope Company installed an experimental Marine Radar aboard the M/V TRI-STATE of the Ashland Oil & Refining Company at Pittsburgh, Pa. The purpose of this installation was two-fold.

1. To see if Marine Radar could be applied to river operations.
2. If so, to carry out an organized program designed to develop a practical River Radar.

From early observations, it was clear that Marine Radar could be a practical instrument for river use. It was also clear that the conditions under which river tows are navigated differed from any other marine operation. This dictated that Radar equipment be developed that could cope with the specific problems encountered in river navigation. We felt the quickest, surest, and most reliable procedure for developing this type equipment was through operational research. Such a program has been in progress for the past six months aboard the M/V TRI-STATE, the S/S SOHIO FLEETWING, and our Marine Laboratory, the M/V WANDERER.

The purpose of this report, then, is to supply information gained from these trials and outline preliminary requisites for a River Radar.

Notes: Figure provides excerpt from a 1946 Sperry Gyroscope report on pilot tests of radar-based river navigation. Source: Hagley Museum, Sperry Gyroscope Company collection, Box 5, Folder 433.

Figure A.8: Radar for harbor traffic control: Newspaper reporting, 1946-1949

MARINE ENGINEERING & SHIPPING REVIEW

June 1946

Operation of Commercial Radar and Loran Demonstrated

Blind Navigation

Sperry Equipped Floating Laboratory Yacht Wanderer Makes Spectacular Blacked-Out Entrance Into Bridgeport Harbor.

Tug Navigates Fog With Ease By Using Radar

POPULAR SCIENCE - October '49

1 **Radar tower** and pilot station landmark outer harbor at Long Beach, Calif. Scanner is located on top of the 122-foot steel structure.

2 **Position of an incoming ship** is being plotted on a harbor-area chart. The port makes no extra charge for the radar-piloting service.

3 **Long Beach Harbor** is shown on a radar viewing scope. Line across bottom is breakwater. Elongated pips are ships; dots are buoys.

Radar Talks Ships into Port

TAKING a tip from aviation, the Port of Long Beach, Calif., has installed a radar system to guide ships safely into and out of the harbor in even the foggiest weather. It works much like the Ground Control Approach radar system by which an airplane pilot is "talked down" to an airport runway.

The harbor pilot is radar-guided to a ship, which he then boards and maneuvers in, obeying instructions sent from a shore station where the ship's course is constantly followed on a radar scope. The new system, first in America, makes it possible to locate ships 30 miles away. The electronic equipment was supplied by Sperry Gyroscope.

Notes: Figure shows newspapers headlines on early radar trials from 1946-1949. Articles from *Marine Engineering & Shipping Review* (1946), *Marine Progress* (1946), *New York Herald Tribune* (1947), and *Popular Science* (1949). Source: Hagley Museum, Sperry Gyroscope Company collection, Box 36, Folder 2 and Box 37, Folders 14 and 17.

Table A.3: Example: Sperry Gyroscope Co. Marine Radar sales, 1946-1954

			Share of sales			
Year	Sales (000s, $)	Gross margin	Gov't	Commercial	Export	Internal
1946	$0	(n.a.)	(n.a.)	(n.a.)	(n.a.)	(n.a.)
1947	$579	2.6%	0%	81%	19%	0%
1948	$2,712	13.7%	3%	60%	36%	0%
1949	$1,236	19.5%	1%	52%	46%	0%
1950	$1,070	16.5%	2%	36%	62%	0%
1951	$1,304	14.9%	1%	37%	49%	13%
1952	$2,075	10.5%	1%	23%	43%	33%
1953	$1,027	12.8%	1%	32%	34%	32%
1954	$565	25.4%	1%	30%	23%	46%

Notes: Table presents Sperry Gyroscope Co. marine radar sales and profitability in the first postwar decade. Data from the Sperry Gyroscope Co. archival records at the Hagley Museum (Box 53, Folder 18, "Product Sales and Margins"). "Internal" sales represent radar systems incorporated into other Sperry-manufactured products.

B Data Appendix

B.1 Data on Rad Lab and RRL staff

Information on Rad Lab and RRL technical staff was also obtained from their respective archival records. Our starting point was the records of the Rad Lab maintained at MIT. These records include a roster of staff members who worked at the Cambridge laboratory, with a biography accompanying each employee that lists their (i) field, (ii) degree year, level, institution, and subject for all degrees, (iii) work at the Rad Lab, and (iv) postwar place of employment or study (Radiation Laboratory 1946a). A second book provides staff members' mailing addresses, though it is unclear for what time period (Radiation Laboratory 1946b). A third book extends data on postwar placements (Radiation Laboratory 1946c). The RRL archival records at Harvard provide similar, albeit less comprehensive, data on its staff, providing a list of names and addresses only. Figures B.1 to B.3 show samples from each of these data sources. We expand these lists to include individuals named in the publication "Five Years at the Radiation Laboratory" (MIT 1946), a yearbook that lists staff members' division and working group inside the Rad Lab.

The sets of names in each of these data sources are partly but not fully overlapping. The Rad Lab staff roster, address list, and placement list contain 1362, 1353, and 942 names, respectively. We believe the staff roster covers most of the Rad Lab's technical staff: as Appendix Figure B.1 shows, the individuals in this list are nearly all scientists and engineers, though it should be noted that the precise sampling process is not known. Of the individuals in this roster, we have addresses for 99% and postwar job placement for 68%; 70% could also be found in the yearbook. By comparison, the RRL directory lists 1043 staff members, but it likely includes more non-technical staff, given that we know the RRL was younger and smaller. Thirty-four individuals appear in the staff lists of both labs, reflecting the intrinsic links between them. An additional 2027 individuals not found elsewhere are incorporated in our data through the yearbook.

Portions of our analysis (primarily appearing in this appendix, and incorporated by reference into the main text) make use of linked Rad Lab/RRL–patent inventor samples. We link Rad Lab and RRL staff members to patent inventors in three ways:

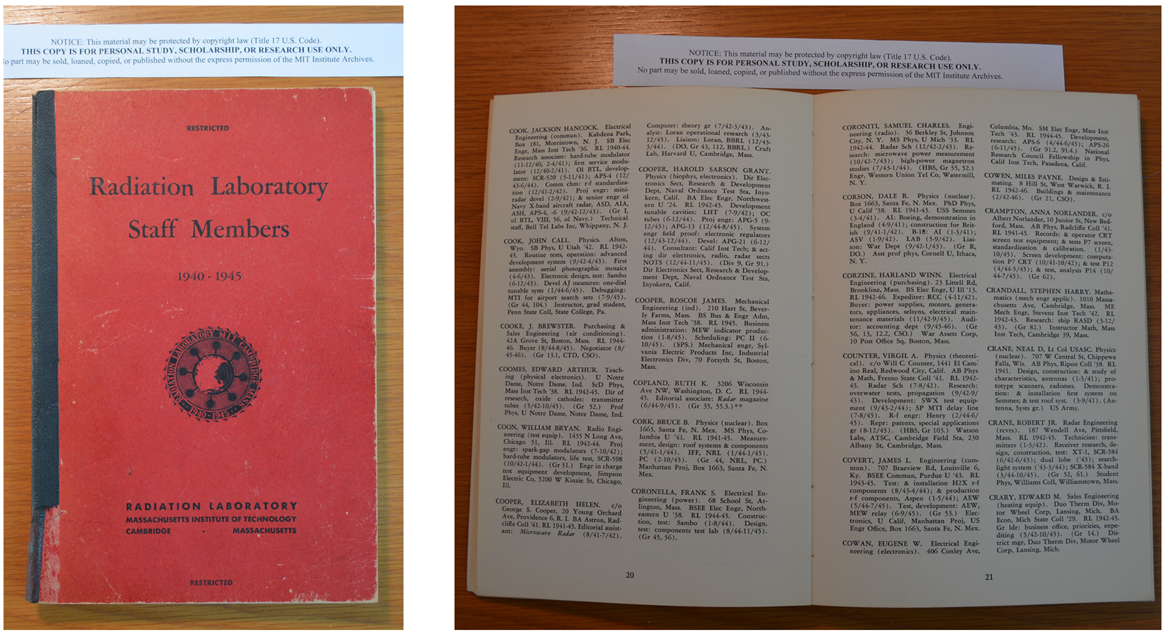
1. In our first approach, we start by identifying all inventors on Rad Lab/RRL patents and manually crosswalk them to Rad Lab/RRL staff rosters. We apply the resulting crosswalk to the complete patent record, including to non-RL/RRL patents. This sample by design limits the set of identified Rad Lab/RRL alumni inventors in the patent record to those with ≥ 1 patent produced and reported under Rad Lab/RRL contracts.

2. Our second approach works in reverse: we take Rad Lab and RRL roster names and manually search for them in the patent record. This sample will expand the set of Rad Lab/RRL staff members linked to the patent record, because it begins with the full staff roster rather than the subset of staff members with Rad Lab/RRL patents.

3. In a third approach, we programmatically make links between all patent inventors and all known Rad Lab staff members by matching exactly on first name, last name, and middle initial (where provided). The risk of false positives increases.

Each of these approaches comes with tradeoffs between precision and recall, and we strike this balance by making the middle approach our preferred one—though results throughout the paper are robust to the other approaches to record linking.[1]

Figure B.1: Rad Lab staff roster, compiled June 1946 (MIT Institute Archives)



[1] A distinct challenge in linking these two sources is inventor disambiguation (Li et al. 2014). In most cases, the names from our lab rosters are sufficiently distinctive that we can make links with high confidence, but common names increase the risk of false links. This measurement error would likely only attenuate our results (i.e., a conservative bias), as it would result in our mixing untreated individuals with treated ones. In robustness checks, we remove individuals with common names from our sample, which we define as those whose first name and surname ranked in the top 100 and 500 of those in the 1940 census, and obtain similar results.

Figure B.2: Rad Lab staff placement, compiled January 1946 (MIT Institute Archives)

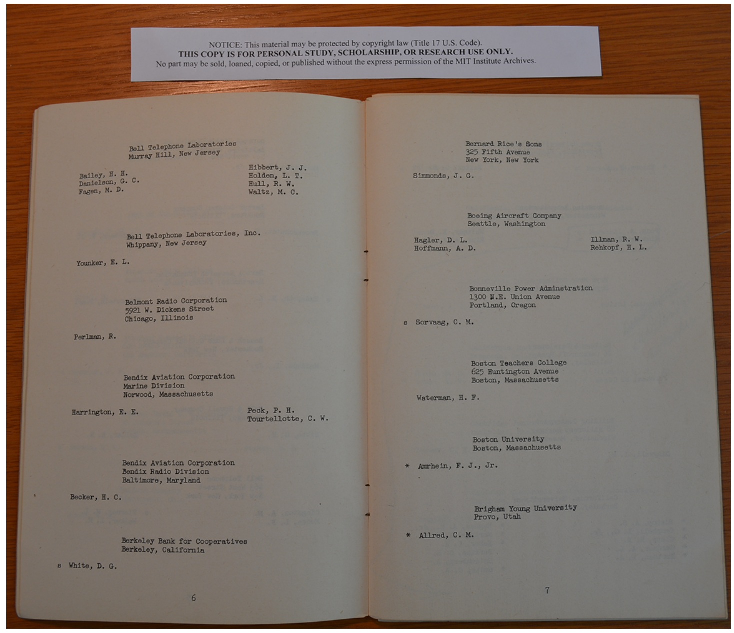
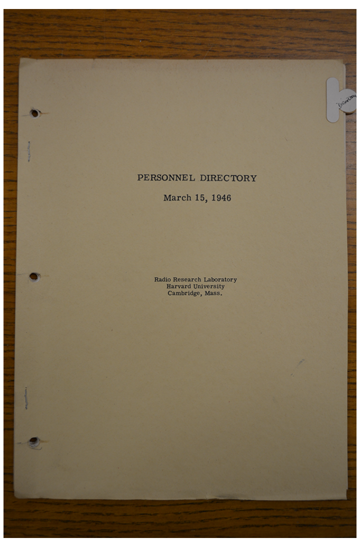
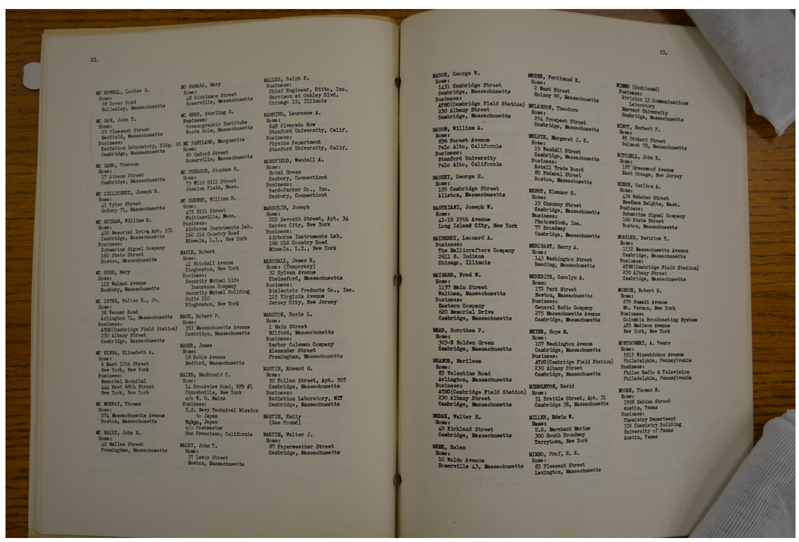


Figure B.3: RRL personnel directory, compiled March 1946 (Harvard University Archives)





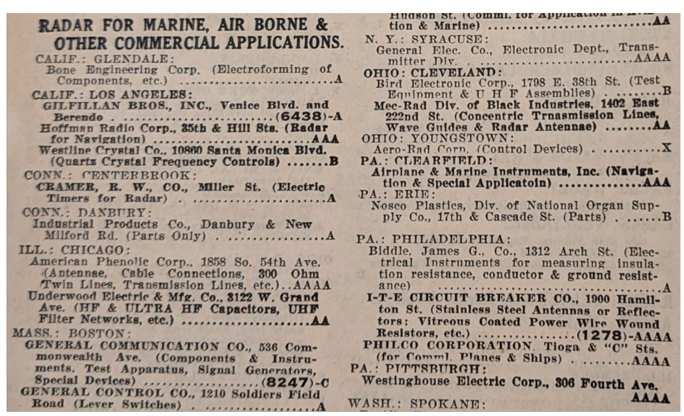
B.2 Thomas Register of Manufacturers

In parts of the paper, we draw on firm listings in the Thomas Register of Manufacturers (TRAM) to identify participants in the postwar radar industry. In doing so, we follow a long tradition in the industry studies literature of using TRAM to evaluate industry evolution (e.g., Gort and Klepper 1982, Klepper and Graddy 1990, Agarwal and Gort 1996).

Figure B.4 provides a sample from the 1947 edition, showing firm listings under the "Radar for Marine, Airborne & Other Commercial Applications" heading. Each listing provides a firm's name, address, an indicator of what it supplies, and firm size code. As can be seen from this example, the radar category in TRAM included firms supplying systems and specific components. Despite this, we think this list is likely to provide an incomplete accounting of the full set of firms related to radar production, if only for the reason that many radar input suppliers might be classified under other categories, and/or may not be recognized as related to radar by the publisher. In this sense, measuring the boundaries of the radar industry through TRAM may itself be subject to error. Even so, we find TRAM's list to be a useful starting point for evaluating the scale and scope of the radar industry, and in the paper we use it towards this end.

TRAM was published trienially over the period we study. We obtained copies of the 1941 to 1959 editions and extracted both (i) firms under radar headings and (ii) the full index to each edition, to distinguish existing firms (which appear in previous TRAM editions) and new firms. Note that we mainly use the TRAM sample to evaluate the commercial industry's growth over time, and to consider which of these firms were World War II radar program participants or suppliers, existing firms which entered from adjacent industries, and new firms. Elsewhere in the paper we separately measure firms which were actively producing radar-related invention—an approach which provides a distinct window into the industry, emphasizing R&D-performing firms—in order to evaluate how they made use of Rad Lab and RRL-developed resources.

Figure B.4: Sample from Thomas Register of American Manufacturers, 1947 ed.



RADAR FOR MARINE, AIR BORNE & OTHER COMMERCIAL APPLICATIONS.

CALIF.: GLENDALE:
Bone Engineering Corp. (Electroforming of Components, etc.) ....A
CALIF.: LOS ANGELES:
GILFILLAN BROS., INC., Venice Blvd. and Berendo ....(6438)-A
Hoffman Radio Corp., 35th & Hill Sts. (Radar for Navigation) ....AAA
Westline Crystal Co., 10860 Santa Monica Blvd. (Quartz Crystal Frequency Controls) ....B
CONN.: CENTERBROOK:
CRAMER, R. W., CO., Miller St. (Electric Timers for Radar) ....A
CONN.: DANBURY:
Industrial Products Co., Danbury & New Milford Rd. (Parts Only) ....A
ILL.: CHICAGO:
American Phenolic Corp., 1858 So. 54th Ave. (Antennae, Cable Connections, 300 Ohm Twin Lines, Transmission Lines, etc.)..AAAA
Underwood Electric & Mfg. Co., 3122 W. Grand Ave. (HF & ULTRA HF Capacitors, UHF Filter Networks, etc.) ....AA
MASS.: BOSTON:
GENERAL COMMUNICATION CO., 536 Commonwealth Ave. (Components & Instruments, Test Apparatus, Signal Generators, Special Devices) ....(8247)-C
GENERAL CONTROL CO., 1210 Soldiers Field Road (Lever Switches) ....A

... tion & Marine) ....AA
N. Y.: SYRACUSE:
General Elec. Co., Electronic Dept., Transmitter Div. ....AAAA
OHIO: CLEVELAND:
Bird Electronic Corp., 1798 E. 38th St. (Test Equipment & U H F Assemblies) ....B
Mec-Rad Div. of Black Industries, 1402 East 222nd St. (Concentric Trnasmission Lines, Wave Guides & Radar Antennae) ....AA
OHIO: YOUNGSTOWN:
Aero-Rad Corp. (Control Devices) X
PA.: CLEARFIELD:
Airplane & Marine Instruments, Inc. (Navigation & Special Applicatoin) ....AAA
PA.: ERIE:
Nosco Plastics, Div. of National Organ Supply Co., 17th & Cascade St. (Parts) ....B
PA.: PHILADELPHIA:
Biddle, James G., Co., 1312 Arch St. (Electrical Instruments for measuring insulation resistance, conductor & ground resistance) ....A
I-T-E CIRCUIT BREAKER CO., 1900 Hamilton St. (Stainless Steel Antennas or Reflectors; Vitreous Coated Power Wire Wound Resistors, etc.) ....(1278)-AAAA
PHILCO CORPORATION, Tioga & "C" Sts. (for Comml. Planes & Ships) ....AAAA
PA.: PITTSBURGH:
Westinghouse Electric Corp., 306 Fourth Ave. AAAA
WASH.: SPOKANE:

Though TRAM is the broadest manufacturer directory we are familiar with from this era (in terms of the range of products covered), and has been relatively frequently used in research on industry evolution, other publishers also circulated national manufacturer listings—especially for a more focused set of subscribers. The Institute of Radio Engineers (IRE), a membership society for radio and electronic engineers, is one such source: IRE began publishing a list of firms and products appended to its annual directory in its 1946 edition (we describe the IRE, and its annual directory, in more detail in Section B.4). Though in some years, these firm listings complement and may even expand on the TRAM sample, the IRE firm lists have several shortcomings which make them unusable for our purposes. The most important shortcoming is that the product classification changes with every edition. In 1946, there was a heading for "Radar"; in 1948, one for "Radar Equipment and Associated Apparatus"; in 1949 and 1950, no explicit radar-related heading; in 1951 and 1955-1959, headings for radar receivers and transmitters; in 1952-1954, headings for radar antennas, receivers, transmitters, and waveguides; in 1960; one heading for "Radar Equipment"; and so on. This variation makes consistent longitudinal analysis difficult. Relative to TRAM, IRE also provides less information about each firm (only name and location), while suffering a similar issue of it being difficult to identify all firms that might be considered part of the broader fold of the radar industry, given that they may be classified under specific component categories like vacuum tubes, antennas, crystal rectifiers, and so on. Due to strengths of TRAM relative to this alternative data source, and the track record of prior scholars with TRAM-based studies, we prioritize TRAM as the principal firm directory for measuring industry participation.

B.3 Construction of U.S. patent datasets

B.3.1 Base data

The construction of the patent datasets used in this paper begins with the USPTO historical master file (Marco et al. 2015), which provides a master list of utility patents with grant dates, patent class/subclass (USPC), and two-digit NBER category (Hall et al. 2001). In building this paper's dataset, we restrict the sample to patents granted between January 1, 1920 and December 31, 1979—although most of the paper invokes only a subset of these, emphasizing the sample of patents filed between 1930 and 1960. For all granted patents in this set, we obtain additional patent characteristics from the following sources:

- FreePatentsOnline.com (FPO): serial numbers, filing dates, and the network of forward and backward citations (front-page citations only)
- Clarivate Derwent Innovation database (DI): assignee names[2]
- Google Patents: titles, top terms, word embedding vectors

The DI assignee names are (mostly) standardized and were later found to match those in Google Patents data, which are freely available through Google BigQuery. These data are mostly complete, but a small number of patents are missing filing dates and assignees. Table B.1 shows the number patents with missing data, by decade of grant. For the period sampled in this paper, approximately 2.5% of patents are missing a filing date and 2.5% missing an assignee.

Table B.1: Number of patents with missing data, by decade

		No filing date		No assignee data	
Decade of grant	Patents	Number	Percent	Number	Percent
1920-1929	414901	25738	6.2%	25918	6.2%
1930-1939	442842	11102	2.5%	11221	2.5%
1940-1949	307630	5470	1.8%	5546	1.8%
1950-1959	425985	12461	2.9%	12661	3.0%
1960-1969	567761	11203	2.0%	11363	2.0%
1970-1979	689027	2	0.0%	73	0.0%
Total	2848146	65976	2.3%	66782	2.3%

Patented, OSRD-funded inventions are identified in the OSRD archival records by the serial number of the patent application. It is thus critical to have accurate data on serial numbers. We manually reviewed and validated the application-level data (serials and filing dates) from FPO for the period around World War II by checking patents with serial numbers or filing dates which are out of

[2] Note that serial numbers, filing dates, and the network of patent citations were also retrieved from the Derwent database for comparison against the FPO data, as a validation exercise. The two data sources overwhelmingly agreed, and where they disagreed, spot checks revealed that FPO was consistently the more accurate of the two, and when there was an error in the FPO data, it typically reflected the occasional typographical error on the printed patent publication itself, such as two flipped digits, or a digit one unit off the correct value. Given their reliability, the data for this paper thus use serial numbers, filing dates, and citations from FPO.

sequence. The important feature of the USPTO's application numbering system for our purposes here is that applications are organized into application "series", which span several years, and identified by a serial number within that series, generally issued in the order in which patent applications arrive at the USPTO, with serial numbers never exceeding six digits. Application series increment, and serial numbers reset, at the beginning of a year in which the serial numbers from the previous series are expected to surpass 1,000,000. Series 2 begins January 1, 1935 and ends December, 1947 and is the focus of this data cleaning effort. We take all patents identified by FPO as belonging to Series 2 and sort these patents by serial. We then look for patents where the previous and next serial have the same filing date but the given patent has a different filing date, and then manually validate the serial and filing date for these patents. Out of over 370,000 patents in Series 2, corrections were made to 279 serials and 188 filing dates. Although these corrections are valuable for matching patents to serials in OSRD records, the low error rate for this sample also indicates that such errors are not widespread in the data.

B.3.2 Harmonizing assignee names

Although the assignee names from DI are largely already standardized, closer examination reveals that there are still variants on individual assignee names (e.g., BELL TELEPHONE LABOR INC with >10,000 patents, and BELL TELPHONE LAB INC, BELL TEL PHONE LAB INC, and BELL TEIEPHONE LAB INC with 1 patent each). We undertake several procedures to further harmonize assignee names. We begin by sorting a list of assignees in alphabetical order, and for each assignee recording other nearby assignees up to 9 positions before/after in the sorted list. We then calculate the edit distance between the given assignee name and each of these nearby assignee names. When this edit distance is less than 25% of the length of the longer name in each pair, We flag that pair as a candidate for manual review. We then review all such matches for several categories of assignees, and standardize names when a match is found:

- Assignees with ≥15 patents between 1930 and 1960
- Assignees which were OSRD contractors
- Assignees identified as government agencies (see next section)
- Assignees identified as universities or hospitals (see next section)
- Assignees which were synthetic rubber manufacturers
- Assignees which were spinouts from Standard Oil

This process is repeated (because each round of harmonization may bring new assignees into the set with ≥15 patents between 1930 and 1960) until no new matches are found.

This harmonization is neither perfect nor exhaustive, but it is believed to be effective for the purposes of this paper. It is also worth noting that for the vast majority of assignee names which were standardized by this procedure, there was clearly a primary spelling for that assignee in the original DI data, with hundreds or thousands of associated patents in the case of large assignees, and at worst a handful of secondary spellings with one or two associated patents—such that the actual effects of both (i) performing this harmonization for the priority assignees above, and of (ii) not performing it for non-priority assignees, are likely minimal.

B.3.3 Determining assignee types

Assignees are then classified into four categories—firms, universities and hospitals, government agencies, and individuals—through a combination of rule-based and manual classification. We begin by classifying assignees as firms when the assignee name includes any of roughly 120 words which indicate firms (e.g., CO, CORP, INC, LTD, SPA, GMBH, etc., as well as technical words such as AERO, AUTO, CHEM, ENG, MACHINE, OIL, PROD, TECH, WORKS; full list available on request). We then manually classify remaining assignees with ≥ 15 patents between 1930 and 1960, as well as assignees whose name includes any of the following strings:

- COLLEGE, INST, UNIV, HOSP, RES FOUND
- US, CANADA, UK, FRANCE, GERMANY, SWITZERLAND, AUSTRALIA, JAPAN, ISRAEL, and assorted other countries
- ATOM (to identify international atomic energy commissions)

Assignees with >200 patents in the 1920-1979 period which are thus far unclassified are then classified as firms. Any remaining unclassified assignees are classified as individuals.

This procedure was developed over several years, and although—like the name harmonization—it is neither perfect nor exhaustive, random spot checks suggest it is overwhelmingly effective at categorizing assignees into the right bins. In total, 60.1% of patents with an assignee in the 1920-1979 sample are assigned to a firm, 0.2% to a university, 0.8% to a government agency, and 39.1% to an individual (numbers sum to >100% because 5% of patents have multiple assignees, and 0.2% have assignees in multiple categories). Using administrative data, we will see below that the fraction we measure through names as assigned to a government entity is an undercount, primarily because the DI data sometimes undermeasure patent assignment.

B.3.4 Identifying Rad Lab and RRL patents

We use the OSRD archival data collected by Gross and Sampat (2023) to identify Rad Lab and RRL patents. Archival records include an index of OSRD contracts and of inventions developed under these contracts, which contractors were required to disclose. We are able to identify the individual OSRD contracts under which the Rad Lab and RRL operated, and in turn all associated inventions, patent applications, and granted patents.[3] Out of all 3,134 patents generated by OSRD-

[3]For completeness, in Gross and Sampat (2023) we also search for continuations, divisions, and continuations-in-part of OSRD patent applications, extending this set by a handful of patents.

funded research that granted by 1980, a total of 588 (i.e., about 20%) were produced by the Rad Lab and RRL (472 and 116 from each lab, respectively).

B.3.5 Identifying other government-funded patents

We use additional archival data obtained from historical USPTO records to measure government-funded invention broadly. See Gross and Sampat (2025) for further details.

B.3.6 Identifying radar-related patents

As with most technology classification problems, the boundaries of radar innovation are intrinsically ill-defined. Core innovations or inventions specifically designed for use in radio detection may be more easily identified by the appearance of the word “radar” in the patent title or specification, but as the paper explains, radar includes many components which are widely used in other electronic and communications devices, from antennas to vacuum tubes. There is an even wider range of innovation which is relevant to radar art. We use multiple criteria to identify “radar patents” and associated invention which will be become a focus of analysis at points in the paper, at times using more relaxed or stringent criteria, depending on our particular aims.

Our first approach identifies broad radar-related classes and inventors who were active in them. To do so, we rank-order the most common USPC codes of Rad Lab and RRL patents, and focus on the six most common codes, which account for 70% of these patents:

USPC	Brief description	Patents	Cum. pct.
342	Communications: directive radio wave systems	130	22%
343	Communications: radio wave antennas	78	35%
333	Wave transmission lines and networks	75	48%
315	Electric lamp and discharge devices: systems	65	59%
327	Misc. active electrical nonlinear devices, circuits, systems	44	67%
331	Oscillators	30	72%

We then consider an inventor active in a radar-related field if they file a patent in one of these classes, and evaluate how their propensity to do so changes over time. This approach identifies inventors in areas related to radar art; we can expand or contract the list of relevant codes and the results in the paper would be qualitatively and statistically the same.

Our second approach focuses on inventions explicitly related to the development of specific radar components and systems. We use this to examine firms’ postwar R&D in radar and the resources it drew on. We begin by identifying patents in specific CPC codes:

CPC	Brief description	System/component
G01S13	Radar detection using reflected radio waves	Radar systems
G01S7	Details of systems described in G01S13	Radar systems
H01J25	Microwave vacuum tubes like magnetrons, klystrons	Magnetrons
H01J23	Details of vacuum tubes described in H01J25	Magnetrons
H01P	Waveguides and waveguide-based components	Waveguides
H01Q	Antennas for transmitting or receiving electromagnetic waves	Antennas

We consider these CPC codes to be indicative of patents covering potential radar component and system inventions. For patents classified to at one of these CPCs, we then process the patent text and count the number of occurrences of the word "radar" and "microwave". If radar appears at least twice or microwave at least once in the text, we consider it a radar-related patent. We then retrieve assignees and other metadata for these patents. A small number of firms in this sample (<10) experienced M&A during our sample period, according to official merger statistics from the Federal Trade Commission (U.S. Federal Trade Commission 1980); for these firms, we dynamically reassign their patents to ultimate owners in any post-acquisition years. We then use this information to create a firm-year panel of radar patent assignees, which we also link to information on firms' employment of Rad Lab and RRL alumni, as described next.

B.4 IRE membership directories

Though Rad Lab records provide information in staff members' immediate postwar job placements (Radiation Laboratory 1946c), they give us little visibility into where these researchers worked before the war or how their careers evolved after. For this paper, we are particularly interested to identify firms that subsequently employed individuals involved in the radar program.

To do so, we use digitized membership directories from the (near) annual yearbook of the Institute for Radio Engineers (IRE) between 1926 and 1963.[4] The IRE was a professional society for radio, electronic, and other electrical engineering professions and the predecessor to the modern Institute of Electrical and Electronics Engineers (IEEE). IRE's membership spanned a large swath of the early electronic engineering profession, including in the government, university, and industrial sectors. Most importantly for our purposes, its yearbook included a directory of its members, providing their employer, title, and address (see Figure B.5 for sample).

This directory was published annually from 1926-1932, intermittently over the next 15 years (in 1937 and 1942), and nearly annually from 1946 onwards (every year except 1947 and 1957); Figure B.6 shows the numbers of members listed in each edition. We develop an LLM-assisted data pipeline to link Rad Lab and RRL staff members to IRE directories and extract their employers. Though we only have names to link on, linking is relatively precise and unambiguous due to the specificity of both the input and the target datasets (staff rosters and IRE members).

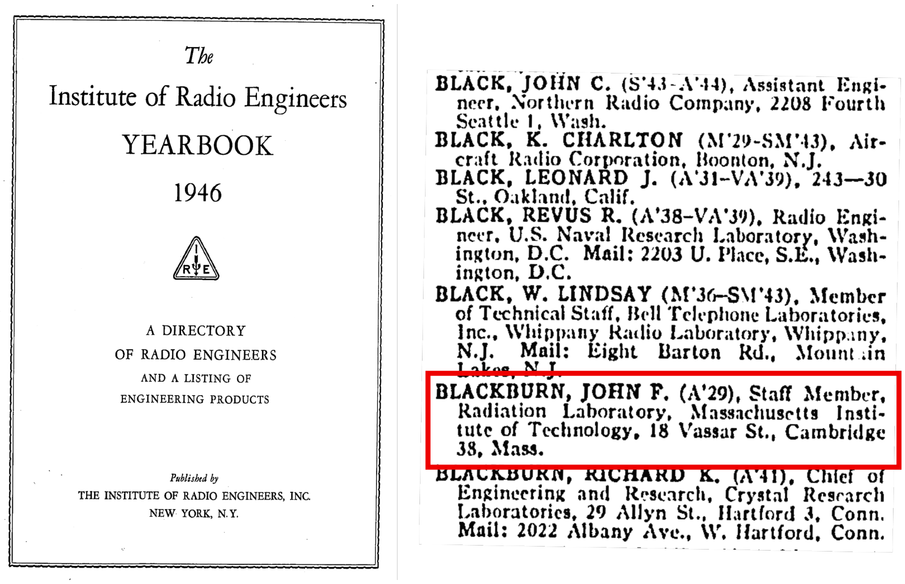
[4]We thank Jingyuan Zeng for producing and generously sharing these data.

We make links as follows. We first extract last names, first names, and middle initials from both the Rad Lab and RRL staff directories and from IRE directories, based on delimiters. We prepare all IRE directory editions in this manner except 1949, where the source PDF scans were too poor to successfully digitize, and where the electronic output is as a result mostly illegible. We then join individual staff members to all IRE entries that share the same last name and first initial. We treat first names as agreeing if they are identical, are very similar (edit distance of leq1 character or bigram similarity of $>$60% and edit distance $\leq$3 characters), or one is contained in the other. Links where first names are longer than one character and disagree, or where middle initials are present and disagree, are discarded. We then create a scoring system to assess remaining candidate links, assigning points when (i) first names match exactly or sound similar (based on soundex), (ii) middle initials are non-missing and agree, (iii) the other first names similarity conditions described above are met. For each Rad Lab/RRL staff member, we link them to the IRE directory entry in each directory year with the most points. Where ambiguities remain (i.e., when multiple links survive this filter), flag these cases as ambiguous. Most links that we make are made this way, but for completeness, we perform this procedure a second time applying the same rules in reverse for first and last names, in order to pick up as many likely links as possible.

Manual review of these links suggests that precision is extremely high. Our main concern, then, is that there are potential links we may have missed, particularly due to digitization errors. We therefore undertake additional efforts to improve this linkage. The main one is to attempt to fill gaps: we identify individuals who were linked to multiple years of the IRE yearbook but had gaps in between, and manually search for these individuals in the gap years. We manually review roughly 1,000 person-years that meet this condition, and find roughly 470 further links.

We successfully link 824 researchers to at least one IRE directory (531 RL members, 290 RRL members, and 3 members of both, out of a risk set of roughly 2400 individuals extracted from Rad Lab and RRL staff rosters), and 801 to at least one postwar edition, with a total of nearly 9,000 person-year observations. Of these, roughly 8,500 are linked unambiguously and we believe can be used confidently in our analysis; ambiguous links are typically individuals with very common names (e.g., "Robert Davis"). For all linked IRE members identified up to this point, we then retrieve their full IRE entries and use OpenAI's GPT 4.1 to extract the employer, which we then manually clean and harmonize. As a final step, we then manually link these employers to patent assignees in our radar patent sample (see paper), in order to determine which of these firms employed Rad Lab and RRL alumni, how many alumni they employed, and when.

Figure B.5: Sample from Institute for Radio Engineers (IRE) 1946 membership directory


The
Institute of Radio Engineers
YEARBOOK
1946

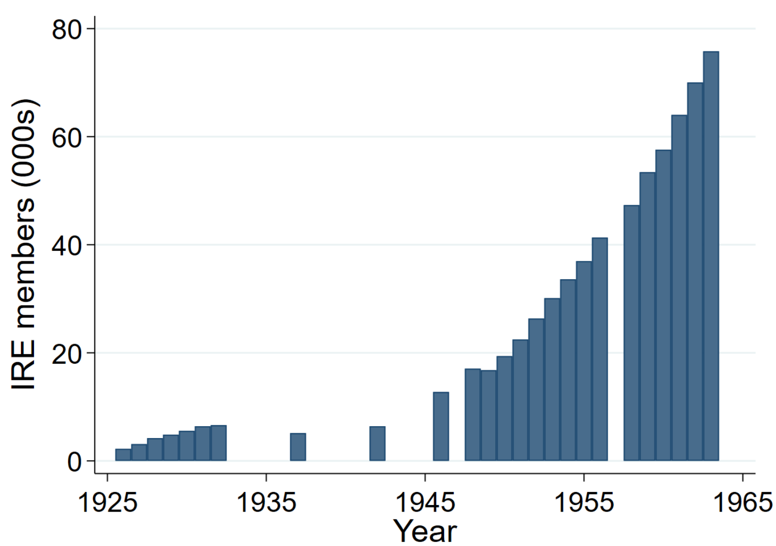
A DIRECTORY
OF RADIO ENGINEERS
AND A LISTING OF
ENGINEERING PRODUCTS

Published by
THE INSTITUTE OF RADIO ENGINEERS, INC.
NEW YORK, N.Y.

BLACK, JOHN C. (S'43-A'44), Assistant Engineer, Northern Radio Company, 2208 Fourth Seattle 1, Wash.
BLACK, K. CHARLTON (M'29-SM'43), Aircraft Radio Corporation, Boonton, N.J.
BLACK, LEONARD J. (A'31-VA'39), 243—30 St., Oakland, Calif.
BLACK, REVUS R. (A'38-VA'39), Radio Engineer, U.S. Naval Research Laboratory, Washington, D.C. Mail: 2203 U. Place, S.E., Washington, D.C.
BLACK, W. LINDSAY (M'36-SM'43), Member of Technical Staff, Bell Telephone Laboratories, Inc., Whippany Radio Laboratory, Whippany, N.J. Mail: Eight Barton Rd., Mountain Lakes, N.J.
BLACKBURN, JOHN F. (A'29), Staff Member, Radiation Laboratory, Massachusetts Institute of Technology, 18 Vassar St., Cambridge 38, Mass.
BLACKBURN, RICHARD K. (A'41), Chief of Engineering and Research, Crystal Research Laboratories, 29 Allyn St., Hartford 3, Conn. Mail: 2022 Albany Ave., W. Hartford, Conn.

Notes: Figure shows a sample subset of listings of Institute for Radio Engineers (IRE) members from IRE's 1946 membership directory. Highlighted in red is an example Rad Lab staff member (John Francis Blackburn), whom we also find in Rad Lab records. Blackburn can be found in earlier editions of the IRE directory employed at CalTech as a research fellow and in later editions employed at MIT as a research engineer, at Raytheon as an assistant to the vice president for research and engineering, and at Aerospace Corporation as a staff consultant. The (random) sample of individuals listed immediately before and after worked at Bell Labs, the Naval Research Laboratory, and various radio or electronics companies.

Figure B.6: Numbers of members in Institute for Radio Engineers (IRE) directories, by year



Notes: Figure shows members listed in each annual edition of the Institute of Radio Engineers (IRE) yearbook in our sample.

C Supplementary Results: Wartime R&D

C.1 Characteristics of Rad Lab researchers

We first use our data to document several characteristics of the MIT Radiation Laboratory (Rad Lab) and its spinout Harvard Radio Research Laboratory (RRL), examining both their operations and and their output. Table C.1, provides descriptive statistics for the 1,362 Rad Lab staff listed in the technical roster presented in Appendix B. Nearly half of this staff consisted of physical scientists, and one third engineers. Over a quarter had a PhD, whereas half had a bachelor's degree—including a large number of recent college graduates and graduate students who effectively worked as applied research assistants. One-sixth of this roster (216 of 1,362) produced a patented, Rad Lab invention. Though we lack comparable biographical data for the RRL, contemporary records indicate it was smaller but similar in composition and productivity. Table C.2 lists the top 10 postwar industry employers of Rad Lab and RRL researchers.

Table C.1: Descriptive statistics for Rad Lab staff and Rad Lab/RRL patents

Variable	N	Mean	P10	P25	P50	P75	P90
Physical Scientist	1362	0.49	0	0	0	1	1
Engineer	1362	0.34	0	0	0	1	1
Highest degree: PhD	1122	0.28	0	0	0	1	1
Highest degree: MA	1122	0.17	0	0	0	0	1
Highest degree: BA	1122	0.56	0	0	1	1	1
Degree year	1122	1937.36	1929	1935	1940	1942	1943
Has Rad Lab patent	1362	0.16	0	0	0	0	1
Num. Rad Lab patents, if any	216	2.38	1	1	1	3	6
RL/RRL patents' filing year	588	1944.98	1944	1945	1945	1945	1946
RL/RRL patents' forward citations	588	6.01	0	2	4	8	13

Notes: Table provides summary statistics for assorted characteristics of the Rad Lab staff in our data (top rows) and for Rad Lab/RRL patents (bottom rows).

Table C.2: Top 10 industry employers of Rad Lab/RRL alumni (according to lab records)

Rad Lab (MIT)		RRL (Harvard)	
	Count		Count
IBM Watson Laboratories	33	Airborne Instrument Laboratory	26
General Precision	20	Columbia Broadcasting System	15
General Electric	13	Raytheon Mfg. Co.	9
Bell Telephone Labs	12	Submarine Signal Co.	8
Self-Employed	12	General Electric	7
DuMont Laboratories	10	Bell Telephone Labs	6
Philco Corp.	10	Holtzer-Cabot Electric Co.	5
Eastman Kodak Co.	9	General Radio Co.	5
Airborne Instrument Laboratory	9	Radio Corp. of America	4
Sperry Gyroscope	8	Photoswitch, Inc.	4

Notes: Table lists the top 10 industry employers of Rad Lab and RRL staff, where known, based on each lab's respective records.

C.2 Characteristics of Rad Lab/RRL invention

Table C.3 compares Rad Lab and RRL patents to others in the same classes and filing years. We first evaluate novelty, measuring the maximal similarity of each wartime patent to the pre-war patent stock, and comparing that of RL/RRL patents to contemporary patents in the same classes. We do so with both text- and citation-based similarity. To simplify interpretation we standardize units. Columns (1) and (2) indicate that RL/RRL patents were 0.15-0.2 standard deviations less similar to the pre-war patent stock (that is, more novel) than others in the same classes and years. RL/RRL patents were also more likely to be collaborative (Column 3) and were subsequently more heavily-cited relative to contemporaries (Columns 4 to 7). The magnitudes of these differences are large enough to be economically meaningful: RL/RRL patents were roughly 30% more likely to involve multiple inventors (against the mean) and 20% more heavily-cited.

Table C.3: Distinctiveness and impact of Rad Lab/RRL patents

	Std(Maximal similarity)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Text-based	Citation-based	Mult. inventors	Num. citations	≥5 citations	≥10 citations	≥20 citations
1(Is RL/RRL patent)	-0.210	-0.156	0.048	0.754	0.056	0.027	0.011
	(0.037)	(0.038)	(0.018)	(0.301)	(0.022)	(0.016)	(0.009)
N	137861	103256	137660	137862	137862	137862	137862
R^2	0.23	0.09	0.08	0.08	0.06	0.05	0.03
Class-year FEs	Y	Y	Y	Y	Y	Y	Y
Y mean	0.00	0.00	0.17	4.18	0.32	0.10	0.02

Notes: Table estimates differences in assorted characteristics of Rad Lab/RRL patents relative to others in the same patent class and filing year. Observations are U.S. patents filed between 1943 and 1946. The outcome variables in Columns (1) and (2) are measures of each patent's maximal similarity to any 1930s patent in the same broader NBER technology category (Hall et al. 2001); when these measures decrease, it indicates the patent was distinctive relative to the pre-1940 stock. The text-based pairwise similarity measure is calculated from word embedding vectors provided in the Google Patents Research dataset (available via Google BigQuery; see Appendix), which are in turn produced from patent text. The citation-based measure is calculated as the proportion of forward citations received by two patents that they share in common, reflecting their proximity in technology space. Both measures are standardized prior to estimation, such that coefficients can be interpreted in units of standard deviations. The outcome in Column (3) is an indicator for whether a patent has multiple inventors; in Column (4), the patent's number of forward citations; in Columns (5) to (7), indicators for whether the patent achieved a given threshold of forward citations. All columns are estimated by OLS and include patent class x filing year fixed effects. Robust SEs in parentheses.

Table C.4 explores whether Rad Lab/RRL patents had more or less technologically diverse inventor teams than contemporary collaborative patents. Our estimation sample consists of co-inventor pairs on multi-inventor patents filed in the same years as Rad Lab/RRL patents (1943-1946), where both inventors in the pair also had pre-war patents, which we use to characterize prior inventive activity. We measure homophily in three ways. In Panel (A) we measure the similarity of co-inventors with respect to their pre-war patent classes, calculated as the fraction of the patent classes of their 1930s patents that they share in common. In Panel (B) we analogously measure similarity with respect to pre-war patent keywords.[5] Finally, in Panel (C) we measure shared industry experience, vis-à-vis

[5] We use Google BigQuery to retrieve the "top terms" associated with each patent (according to Google, "the top 10 salient terms extracted from the patent's title, abstract, claims, and description"), and identify the ten most frequent such terms for each inventor. Most inventors have at most only a few patents, and they are typically concentrated in technology space, making it easier to measure each inventor's positioning.

pre-war patents with a firm assignee. We estimate large reductions in inventor homophily on Rad Lab/RRL patents, roughly equal to the mean value in the full sample.

Table C.4: Similarity of co-inventors on Rad Lab/RRL patents vs. others

Panel A: Similarity of principal pre-war patent classes

	(1)	(2)	(3)	(4)
1(Is RL/RRL patent)	-0.065	-0.058	-0.053	-0.047
	(0.002)	(0.003)	(0.006)	(0.008)
N	19177	19177	19160	19024
R^2	0.00	0.01	0.07	0.13
Filing year FEs		Y		
Class FEs			Y	
Class-year FEs				Y
Y mean	0.07	0.07	0.07	0.07

Panel B: Similarity of principal words in pre-war patents

	(1)	(2)	(3)	(4)
1(Is RL/RRL patent)	-0.078	-0.070	-0.067	-0.057
	(0.003)	(0.003)	(0.007)	(0.008)
N	19168	19168	19151	19015
R^2	0.00	0.01	0.09	0.16
Filing year FEs		Y		
Class FEs			Y	
Class-year FEs				Y
Y mean	0.09	0.09	0.09	0.09

Panel C: Similarity vis-à-vis pre-war industry experience

	(1)	(2)	(3)	(4)
1(Is RL/RRL patent)	-0.230	-0.214	-0.206	-0.189
	(0.018)	(0.019)	(0.022)	(0.026)
N	25125	25125	25117	24989
R^2	0.00	0.02	0.06	0.12
Filing year FEs		Y		
Class FEs			Y	
Class-year FEs				Y
Y mean	0.28	0.28	0.28	0.28

Notes: Table estimates differences in the similarity of co-inventors on Rad Lab/ RRL patents relative to others. Observations are pairs of co-inventors on U.S. patents filed between 1943 and 1946. Panel (A) measures the similarity of co-inventors with respect to their pre-war patent classes, calculated as the fraction of the patent classes of their 1930s patents that they share in common. Panel (B) measures similarity with respect to pre-war patent keywords, calculated as the fraction of the keywords of their 1930s patents that they share in common. Panel (C) measures similarity with respect to industry experience, calculated as having any 1930s patent with a firm assignee. SEs clustered by patent in parentheses.

Table C.5 provides contextual evidence suggesting implications of this result, estimating the relationship between patents' forward citations and co-inventor homophily across this sample (patents filed between 1943 and 1946 with multiple inventors with pre-war patents). The table shows that more dissimilar co-inventors produce more highly-cited patents, particularly when the homophily of the pair is measured on their technological backgrounds.

Table C.5: Quality of patents produced by diverse inventor teams

Panel A: Similarity of principal pre-war patent classes

	(1) Num. citations	(2) Any citations	(3) ≥5 citations	(4) ≥10 citations	(5) ≥20 citations
Similarity	-1.093	-0.067	-0.072	-0.047	-0.020
	(0.271)	(0.019)	(0.024)	(0.015)	(0.007)
N	15803	15803	15803	15803	15803
R^2	0.14	0.11	0.12	0.11	0.09
Class-year FEs	Y	Y	Y	Y	Y
Y mean	4.67	0.85	0.36	0.13	0.03

Panel B: Similarity of principal words in pre-war patents

	(1) Num. citations	(2) Any citations	(3) ≥5 citations	(4) ≥10 citations	(5) ≥20 citations
Similarity	-0.796	-0.087	-0.066	-0.035	-0.010
	(0.282)	(0.019)	(0.023)	(0.015)	(0.008)
N	15797	15797	15797	15797	15797
R^2	0.14	0.11	0.12	0.11	0.09
Class-year FEs	Y	Y	Y	Y	Y
Y mean	4.67	0.85	0.36	0.13	0.03

Panel C: Similarity vis-à-vis pre-war industry experience

	(1) Num. citations	(2) Any citations	(3) ≥5 citations	(4) ≥10 citations	(5) ≥20 citations
Similarity	0.004	-0.009	-0.000	-0.002	-0.001
	(0.100)	(0.006)	(0.008)	(0.006)	(0.003)
N	20312	20312	20312	20312	20312
R^2	0.12	0.10	0.11	0.09	0.07
Class-year FEs	Y	Y	Y	Y	Y
Y mean	4.62	0.85	0.36	0.12	0.02

Notes: Table estimates differences in forward citations of patents with more versus less similar co-inventors. Observations are pairs of co-inventors on U.S. patents filed between 1943 and 1946. Panel (A) measures the similarity of co-inventors with respect to their pre-war patent classes, calculated as the fraction of the patent classes of their 1930s patents that they share in common. Panel (B) measures similarity with respect to pre-war patent keywords, calculated as the fraction of the keywords of their 1930s patents that they share in common. Panel (C) measures similarity with respect to industry experience, calculated as having any 1930s patent with a firm assignee. SEs clustered by patent in parentheses.

C.3 Impacts of Rad Lab/RRL experience

The patent record lends itself to systematic tests of changes in both the extensive and intensive margin of human capital deepening in the radar field). Table C.6 first examines Rad Lab staff members' propensity to patent in radar-related technology classes over time, which we interpret as a test of the extensive margin—i.e., whether wartime work drew new researchers into the field. Our sample for this exercise consists of Rad Lab staff members crosswalked to the set of all patent inventors who are observed with patents before (1933-1940), during (1941-1948), and after the war (1949-1956), indicating they were actively inventing in all three eras. We estimate difference-in-differences in these propensities for Rad Lab/RRL inventors versus other inventors in the pre- to mid-war, mid- to post-war, and pre- to post-war periods. Columns (1) to (3) present intensive measures (the fraction of an inventor's patents in radar classes), and Columns (4) to (6) extensive measures (an indicator for any radar patents, conditional on patenting at all). Table C.6 shows that Rad Lab/RRL staff were far more likely to continue patenting in radar after the war ended, with the magnitude of the effect many multiples of the sample mean.

Table C.6: Changes in research orientation of Rad Lab/RRL inventors: tendency to produce patents in radar classes

	Fraction in Radar USPCs			Any in Radar USPCs		
	(1)	(2)	(3)	(4)	(5)	(6)
	Pre-to-Mid	Mid-to-Post	Pre-to-Post	Pre-to-Mid	Mid-to-Post	Pre-to-Post
1(Is RL/RRL alum)	0.232	-0.100	0.091	0.597	-0.278	0.310
	(0.038)	(0.036)	(0.035)	(0.061)	(0.078)	(0.062)
N	76006	38866	58582	76006	38866	58582
R^2	0.71	0.71	0.61	0.73	0.71	0.64
Y mean	0.02	0.02	0.02	0.04	0.06	0.04

Notes: Table estimates differences in differences in the tendency of Rad Lab/RRL staff to invent in radar, relative to other inventors, as it changed across the pre-, mid-, and post-war periods. In each panel there are two outcomes: Columns (1) to (3) present intensive measures (the fraction of the inventor's patents of a given type), and Columns (4) to (6) intensive measures (any patents of a given type, conditional on patenting at all). The third and sixth columns are our preferred specifications, being indicative of lasting shifts in inventive behavior. Robust SEs in parentheses.

Table C.7 asks whether Rad Lab/RRL inventors' postwar invention grew more impactful than their pre-war invention, as reflected in forward citations, as a measure of intensive margin effects of the Rad Lab on cultivating R&D talent. Here our analysis is conducted at the patent level, restricting to patents filed 1930-1939 (pre-war) and 1947-1960 (post-war). Panel (A) estimates differences in forward citations to pre-war patents of Rad Lab/RRL inventors vs. others, accounting for class-year fixed effects, and find no statistical differences. In Panel (B), we make this comparison for postwar patents and find much larger, statistically significant differences.

Table C.7: Impact of patents with Rad Lab/RRL inventors

Panel A: Citation rates of pre-war patents

	(1) # citations	(2) ≥5 citations	(3) ≥10 citations	(4) ≥20 citations
Any RL/RRL inventors	0.074	0.010	0.013	-0.001
	(0.166)	(0.018)	(0.011)	(0.004)
N	396687	396687	396687	396687
R^2	0.08	0.06	0.04	0.03
Class-year FEs	Y	Y	Y	Y
Y mean	3.02	0.22	0.06	0.01

Panel B: Citation rates of post-war patents

	(1) # citations	(2) ≥5 citations	(3) ≥10 citations	(4) ≥20 citations
Any RL/RRL inventors	0.676	0.034	0.031	0.012
	(0.155)	(0.011)	(0.008)	(0.004)
N	577633	577633	577633	577633
R^2	0.08	0.06	0.05	0.03
Class-year FEs	Y	Y	Y	Y
Y mean	3.77	0.29	0.08	0.01

Notes: Table estimates differences in the forward citations of patents with Rad Lab/ RRL inventors, relative to others in the same patent class and filing year. Panel (A) does so for patents filed between 1930 and 1940; Panel (B), for patents filed in 1946 to 1960. In Column (4), the patent's number of forward citations; in Columns (5) to (7), indicators for whether the patent achieved a given threshold of forward citations. All columns are estimated by OLS and include patent class x filing year fixed effects. Robust SEs in parentheses.

D Supplementary Results

D.1 The WW2 Radar Ecosystem: Additional Statistics from the Rad Lab Archives

Tables D.1 and D.2 provide data on World War II radar system production from archival records, by type (overall) and by manufacturer (Rad Lab-designed systems only).

Table D.1: Radar system production through July 1, 1945, by type

	Units (1000s)			Value (2022 $, BBs)		
Type	Total value	Share of value	RL-designed share	Total value	Share of value	RL-designed share
Airborne	288.6	66%	20%	16.7	41%	73%
Ground	12.9	3%	35%	13.7	34%	36%
Shipborne	27.8	6%	53%	8.0	20%	57%
Beacons	31.1	7%	33%	1.0	3%	50%
Loran	71.8	16%	100%	1.1	3%	100%
Trainers	3.1	1%	87%	0.2	0%	78%
Total	435.3	100%		40.8	100%	

Notes: Table presents total production of radar through July 1, 1945, by type (application). Data from Rad Lab archival records, acquired from the U.S. National Archives and Records Administration, Record Group 227, NAID 894515, MIT Radiation Laboratory Project Committee Series 1: Project Administration Records, 1941-1945, Box 7.

Table D.2: Top producers of RL-designed radar systems through July 1, 1945 (2022 $, BBs)

Firm	Airborne	Ground	Shipborne	Beacons	Loran	Trainers	Total	Share
Western Electric Co.	8.04						8.04	34.3%
General Electric Co.	0.53	2.11	0.61	0.00	0.09		3.35	14.3%
Raytheon Mfg. Co.		0.14	3.03				3.17	13.5%
Philco Corp.	2.24			0.10	0.57	0.00	2.91	12.4%
Westinghouse Electric Corp.	0.35	1.82					2.17	9.2%
Submarine Signal Co.			0.82				0.82	3.5%
Sperry Gyroscope Co.	0.78						0.78	3.3%
Galvin Mfg. Corp.	0.05			0.35			0.40	1.7%
Radio Corp. of America			0.06		0.18		0.23	1.0%
Gilfillan Bros., Inc.		0.19		0.00		0.01	0.20	0.9%
Bendix Aviation Corp.		0.19					0.19	0.8%
Radiation Laboratory	0.01	0.11	0.03	0.01	0.02	0.00	0.17	0.7%
Research Construction Corp.	0.04	0.03	0.03	0.02	0.02	0.02	0.15	0.7%
Crosley Corp.		0.15					0.15	0.6%
Emerson Radio and Phonograph Corp.					0.12	0.02	0.14	0.6%
Federal Telephone & Radio Corp.		0.12					0.12	0.5%
Fada Radio & Electric Co.					0.08	0.01	0.09	0.4%
Zenith Radio Corp.	0.07	0.00					0.07	0.3%
Other	0.14	0.02		0.03	0.05	0.08	0.32	1.4%
Total	12.24	4.88	4.57	0.51	1.13	0.14	23.48	

Notes: Table lists the principal manufacturers of Rad Lab-designed radar in World War II, with sales by type of radar (airborne, shipborne, etc.), with values inflated from 1940s levels using a composite wartime adjustment (see notes to Table 1). Several of these firms were actively producing internally-designed systems in multiple categories of radar as well. Data from Rad Lab archival records, acquired from the U.S. National Archives and Records Administration, Record Group 227, NAID 5019146, MIT Radiation Laboratory Office of the Director – Transition Office, Records Relating to Expediting Production of Equipment, Box 70.

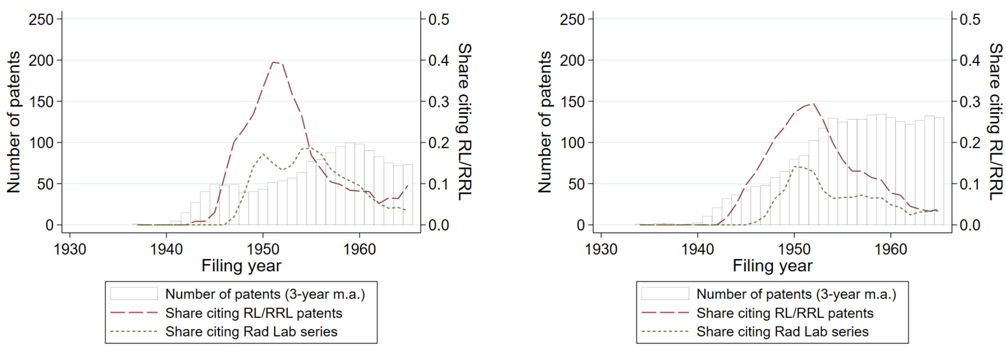
D.2 Postwar Industry Development

Figures D.1 and D.2 present additional statistics on postwar radar patent linkages to wartime science and technology, with the former reporting citations to Rad Lab/RRL patents and science by systems versus component inventions, and the latter reporting sustained linkages in successive generations of radar technology. Figure D.3 reports the frequency of words in TRAM-listed firms' descriptions directly indicative of their segment/positioning choices.

Figure D.1: Annual share of radar system and component patents citing Rad Lab/RRL patents and science, 1930-1965

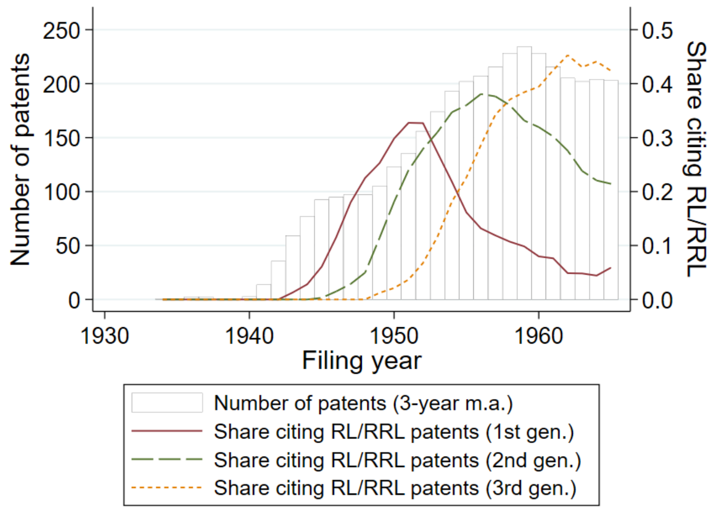
Panel (A): Systems patents

Panel (B): Components patents



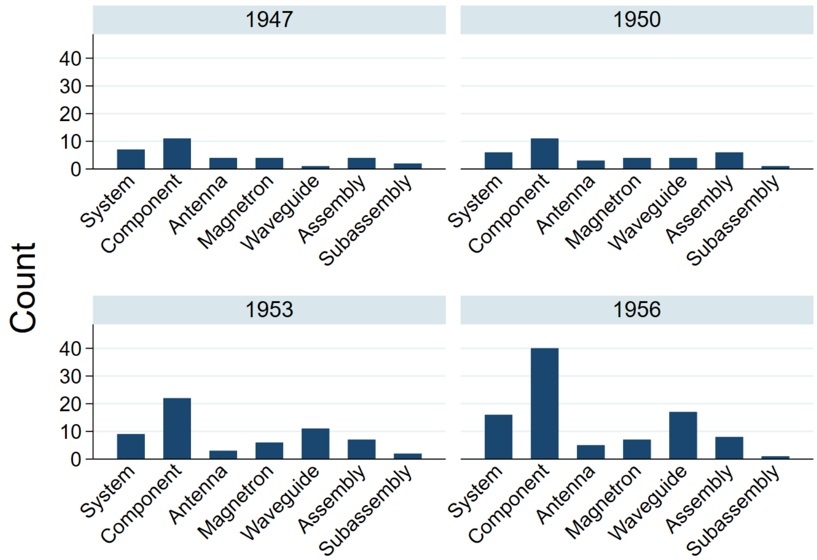
Notes: Figure shows the annual number of patents on radar systems and components (gray bars; see Appendix B.3) and the annual share of these patents which cite Rad Lab/RRL patents (in red) or the Radiation Laboratory Series (in green). Data reported by filing year and in three-year moving averages to smooth annual fluctuations.

Figure D.2: Annual share of radar patents with 1st-, 2nd-, and 3rd-degree linkages to Rad Lab/RRL invention through patent citations, 1930-1965



Notes: Figure shows the annual number of radar-related patents (patents on radar systems and components, in gray bars; see Appendix B.3) and the annual share of these patents with a patent citation chain which traces back to Rad Lab/RRL inventions. "1st generation" citations (in red) are patents which cites RL/RRL patents; "2nd generation" (in green), those which cite patents which cites RL/RRL patents, and so on. Data reported in three-year moving averages to smooth annual fluctuations. Figure illustrates that as technology advanced, a large share remained traceable (via patent citations) to World War II innovation.

Figure D.3: Frequency of select words in TRAM business descriptions, 1947-1956



Notes: Figure shows the number of radar industry participants in each edition of the Thomas Register of Manufacturers (TRAM) between 1947 and 1956 with select words in their business description which indicate component or system production. All terms are singularized prior to tabulation, and stop words (e.g., and, for, to, etc.) are removed from the sample. The most common word in firms' descriptions is "Component", followed by "Equipment", "Radar", "Part", "Waveguide", and "Microwave".

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