EARLY ACADEMIC SCIENCE AND THE BIRTH OF INDUSTRIAL RESEARCH LABORATORIES IN THE US PHARMACEUTICAL INDUSTRY

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ABSTRACT

The establishment and growth of industrial research laboratories is one of the key organizational innovations affecting technological progress in the United States in the 20th century. In this paper, we investigate the rise of industrial research laboratories in the U.S. pharmaceutical industry between 1927 and 1946. Our evidence suggests that institutional factors, namely the presence of universities dedicated to research, played a crucial role in the establishment and diffusion of private pharmaceutical research laboratories. Specifically, we document that the establishment and growth of industrial pharmaceutical laboratories between 1927 and 1946 is positively and significantly correlated with the existence, size, and growth of local university research (as measured by the number of PhDs, and while controlling for other factors likely to influence the geographic distribution of industrial research). We also demonstrate firm-level analyses documenting that the likelihood of firms' adopting industrial laboratories varies positively with the number of PhDs granted in the local area. Supplementing these core results, we examine the nature of these early relationships and the mechanisms by which university-industry collaboration emerged. In particular, we review a number of case histories illustrative of early university-industry interaction, investigate the determinants of university-industry research cooperation, and present evidence from patent counts that suggests the existence of spillovers arising from university research. Overall, our results paint a detailed picture of the importance of universities in the development of industrial research laboratories in the U.S. pharmaceutical industry and explicate a number of the mechanisms that contributed to the birth of industrial research labs.

I. Introduction

The establishment and growth of industrial research laboratories is one of the key organizational innovations affecting technological progress in the United States in the 20th century (Mowery, 1990). We investigate in this paper the rise of industrial research laboratories in the U.S. pharmaceutical industry between 1927 and 1946. Our evidence documents that universities played a crucial role in the establishment and diffusion and industrial research laboratories in the U.S. pharmaceutical industry in the interwar period. The foundation of our analysis is the demonstration that the emergence and growth of private pharmaceutical research laboratories depends upon the presence, strength, and growth of nearby academic science. We clarify the role of universities in affecting the birth of industrial research laboratories by elucidating some of the mechanisms by which universities and industry interacted during this period. We are also alert to the fact that this relationship was not unidirectional, and explore as well the influence of the local industrial base on the character of universities during this period.

The proposition that universities exerted a significant influence on the establishment of a new organizational form in industry is likely less controversial in the early 21st century than it would have been 100 years before. Hand-in-glove relationships between firm laboratories and universities in the life sciences have become the norm by the early 2000s, but were not commonplace a century ago. Indeed, many academic scientists and academic bodies, viewed industry with extreme skepticism or overt antipathy. Quoting a 1915 report of the Committee of the Board of Trustees of the American Medical Association, Parascandola (1985) illustrates the contempt held by medical scientists for industry, “It is only from laboratories free from any relations with manufacturers that real advances can be expected."[1] Though a fictional tale, Sinclair Lewis's novel *Arrowsmith* is more severe but also representative of the attitude of the time: Reacting to the news of famed biologist Max Gottlieb's decision to join the research laboratories of a private firm, colleagues grieved. In one lab, "sorrowing men wailed, 'How could old Max have gone over to that damned pill peddler?,'" while in other places colleagues lamented, "Of all the people in the world! I wouldn't have believed it! Max Gottlieb falling for those crooks!," and "I wish HE hadn't gone wrong!" (Lewis, 1925, p. 52).[2] It is, then, somewhat surprising that an environment that harbored such scorn for industry would, ultimately, be actively involved in planting the seed corn for the development of industrial research laboratories.

History demonstrates, however, that Prof. Gottlieb's decision to work with the pill peddlers signifies the growing ties between university scientists and private firms in the U.S. pharmaceutical and chemical industries. The increasing relevance of academic science for industrial purposes in the late 19th and early 20th centuries is an underlying force that enabled collaborations between universities and industry to be potentially fruitful (Mowery and Rosenberg, 1998; Murmann, 2003). We argue, then, that the specific form and nature of universities animated the potential for interaction between academic scientists and pharmaceutical firms in the U.S. interwar period. Further, we examine the early mechanisms through which universities affected research in the pharmaceutical and chemical industries, devoting particular attention to the labor market for trained researchers, collaborative research and consulting agreements, and contract

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[1] This quote appears in the *Journal of the American Medical Association* (1915) "Special Report of the Work of the Council on Pharmacy and Chemistry," *65*, p. 69.

[2] This quote is used commonly among historians of the U.S. pharmaceutical industry to reflect the attitudes of the time. See, for example, Parascandola (1985), Swann (1990), and Liebenau et al. (1990).

research arrangements. While our primary aim is to ascertain the extent of university influence on the development of industrial research laboratories, we reiterate that university researchers and their institutions benefited from and were also importantly changed by their interactions with industry. Though focusing on the influence of universities on the development of industrial research laboratories, we devote attention as well to the impact of private firms on university science. In the same way that proximity to established centers of academic science reduced the costs of innovation for the early industrial labs, we argue that proximity to established industrial innovators influenced the direction of scientific research in nearby developing universities.

Our principal analysis assess the importance of universities for the establishment of pharmaceutical research laboratories by estimating the impact of the presence of universities and the count of their PhD graduates on the likelihood and count of laboratories established in geographically proximate areas. We set the stage for this analysis by reviewing case histories of early U.S. pharmaceutical firms and describing the nature of relationships between academic scientists and pharmaceutical firms. Our empirical analysis investigates four competing hypotheses explaining the growth of U.S. pharmaceutical laboratories during the interwar period: (a) that the growth of these laboratories followed a random pattern, (b) that the distribution of laboratories followed a pattern of convergence, according to which those areas initially lacking in laboratories added labs at a rate greater than that of other regions, (c) that the distribution of laboratories followed a pattern of divergence, according to which those areas with the highest initial endowment of laboratories added labs at a rate greater than that of other regions, or (d) that the growth of laboratories was principally determined by the institutional influence of universities. Our results demonstrate that the principal effect in the data is the influence of local universities and the count of science PhD graduates on the establishment of research laboratories.

Our analyses of supplementary data elaborate on the role of universities in the birth of pharmaceutical research laboratories. In particular, records from the rosters of *Who's Who in Chemistry (1928),* demonstrate the activity of adopting firms in the labor market for graduating PhD's. Additional analysis also demonstrate that collaborative arrangements between academic scientists and industry and, occasionally, contract research agreements were both important pre-cursors and complements to firms developing their own laboratories. We find that the likelihood of collaboration between universities and industry covaries with the number of local PhD graduates and that productivity spillovers (measured in terms of firm patents in 1938) vary positively with both the number of local chemistry PhDs and collaboration with academic scientists.

Overall, our results paint a picture in which the role of universities in the development of industrial research laboratories is central and multifarious. In addition to serving as the launching pad for the careers of individuals who found employment in private firm laboratories, U.S. universities played an active role in the creation of such laboratories, via collaborative research and consulting, and in their developing expanded research capabilities over time. Equally so, though, universities appear to have been altered as a consequence of their interactions. In a very direct way, university researchers claim to have benefited from their interactions with industrial research. On occasion, firms provided important financing for research; however, university scientists, including prominent researchers, such as Nobel Prize winner Selman Waksman of Rutgers

University and the famed Roger Adams of Illinois, also claim to have benefited from collaboration with industrial research facilities in ways that were not limited to funding. By both providing financial support for university research laboratories and a market for future trained labor, firms supported the growth of scientific capabilities at local universities. The relationships between Merck and Rutgers and Dupont and the University of Delaware are illustrative of the bi-directional impact of the relationship between universities and industry.

The remainder of the paper proceeds in the following way: Section 2 introduces background research on university-industry interaction and reviews the origins of industrial research laboratories. Section 3 reviews historical interactions between the u.s. pharmaceutical industry and academic science. Section 4 presents our core dataset. Section 5 evaluates the importance of universities in influencing the growth of pharmaceutical research laboratories. Section 6 assesses the mechanisms of interaction between universities and pharmaceutical firms in greater detail. Section 7 concludes, discussing the implications of the results and speculating regarding related, future research.

II. University-Industry Interaction and the Origin of Industrial Research Laboratories

In this section, we lay the groundwork for our argument that U.S. universities contributed to the establishment, growth, and of industrial research laboratories. In particular, we review research that describes the growth of the U.S. universities in the late 1800s and early 1900s, suggests the importance of universities to the U.S.'s emerging industrial leadership, documents the importance of proximity and specific institutional arrangements in university-industry interaction.

II.1 The emergence of U.S. universities and the nature of university-industry interaction

Goldin and Katz (1999) identify the period of 1890-1940 as the "formative years" of American higher education. States dramatically increased their support of higher education during this period and the U.S. research university emerged in a form similar to that which exists today. These years were also formative for university-industry collaboration and the rise of industrial research laboratories in the United States. Figures 1-3 display the number of public universities, private universities, and industrial research labs by founding date, beginning in 1830. They reveal that the largest number of universities were founded in the late 19th century than in any other period. In large part, the rise of universities coincided with the Morrill Act of 1862, which established the land-grant universities, and the Hatch Act of 1887, which provided aid for the study of scientific agriculture. The boom in founding of industrial research labs came somewhat later, in the 1920s and 1930s.[3] The boom during this period was, however, quite substantial, so substantial in fact that university-industry interaction reached its highest point in the period between World War I and World War II. As Mowery and Rosenberg (1998) note, "university-industry research linkages…were well-established before World

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[3] It should be taken into account that these graphs are snapshots taken at two different points in time: the university data was compiled in 1924 and the industrial research lab survey was conducted in 1946. As a result, firms that were founded prior to1946 but did not survive to that date are not counted.

War II. Indeed, the share of university research expenditures financed by industry appears to have declined throughout much of the postwar period."[4]

Rosenberg, Mowery, Nelson and a number of co-authors have argued that the research universities that emerged during this period – and, in particular, the emergence of academic science responsive to the needs of industry – was been one of the main sources of American technological leadership in the twentieth century.[5] These authors note a number of examples of commercially important early inventions that originated in universities, including the Babcock test (which improved the way dairy producers tested the butterfat content of milk); Edwin Armstrong's research on vacuum tubes at Columbia University (which influenced the development of radio technology); and the development of hybrid corn at agricultural experiment stations. Further, the University of Akron supplied local rubber producers with skilled employees, and its scientists conducted research in the processing of rubber and, later, polymer chemistry.[6] Other examples include the University of Oklahoma's research in the field of petroleum, the University of Kentucky's and the University of North Carolina's focus on the processing of tobacco, and the University of lllinois and Purdue University's work on railroad technologies.[7] Noting the important influence on innovation in the later part of the 20th century, these authors further acknowledge the seminal contributions of university research on the development of computers and lasers.[8]

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[4] Mowery and Rosenberg, p. 37. Also, Swann (1988) argues that post-war increases in federal funding for university research in the health sciences reduced collaboration between universities and the pharmaceutical industry.

[5] See Nelson and Wright (1992), Rosenberg and Nelson (1994), Mowery and Rosenberg (1998), Rosenberg (2000), Mowery, Nelson, Ziedonis and Sampat, (2003).

[6] Mowery et al (2003), p. 1.

[7] Nelson and Rosenberg (1994).

[8] Rosenberg and Nelson (1994), Mowery et al. (2003), p. 1.

The role of proximity in facilitating university-industry is central in our investigation of the factors that led to the rise of industrial research laboratories. Existing empirical studies of contemporary university-industry research linkages suggest that research conducted in universities has a significant and geographically focused effect on innovation. Jaffe (1989) provides evidence that corporate patenting in certain industries is positively associated with state-level spending on university research in related academic disciplines. Acs, Audretsch and Feldman (1992) substitute innovation counts for patent data and find even stronger evidence for spillovers from university research. Jaffe, Trajtenberg, and Henderson (1993) find that knowledge spillovers from university research, as measured by patent citations, are geographically concentrated.[9] In a study of the biotechnology industry, Zucker, Darby and Brewer (1998) show that biotechnology firms tend to locate near universities in order to take advantage of the areas' higher levels of "intellectual capital". In both the qualitative and quantitative evidence we review, geographic proximity plays an important role in facilitating interactions between universities and pharmaceutical firms.

The nature of university-firm interactions is informed by research that examines the organizational locus of innovative activity. Specifically, a set of recent papers examine whether innovative activity takes place in divisions of the corporation or in entrepreneurial firms that transact in the market for technology. Teece (1988) explains how transaction costs can dictate the organizational form in which innovation takes place. Arora, Fosfuri and Gambardella (2001) document the growth in technology trade in the late twentieth century, led by high-tech industries like software, chemicals, semi-

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[9] Patent citations are references in the patent document to other patented technologies that bear a similarity to the invention or that influenced the inventor.

conductors and electronics. Arora, Fosfuri and Gambardella (2003) model the division of “inventive labor” under different conditions. Stern and Gans (2003) focus on how several aspects of the “commercialization environment” affect the innovative start-up’s optimal choice of co-operation or competition with incumbent firms. Peretto (1998) develops a model that explains the transition from independent inventors to corporate R&D labs in the late 19th/early 20th centuries as a product of the “interaction of market structure and technological change.” The results discussed in the following sections of this paper contribute to the literature on the organization of R&D by focusing on a specific institution – the university – that contributed to the diffusion of in-house R&D labs in industry. While demonstrating the influence of universities on this organizational innovation, we highlight how universities were affected in the process.

II.2 The origins of industrial research

The first organized industrial research laboratories appeared in Germany in the 1870s, in firms that sought to commercialize inventions based on recent breakthroughs in organic chemistry.[10] Murmann (2003) describes the co-evolution of the dye industry and academic research in chemistry in nineteenth-century Germany, and argues that spillovers from universities to the dye industry and vice versa led Germany to dominate the international dye industry in the 19th century. Mowery and Rosenberg argue that it was not scientific developments alone which led to the growth of in-house research in the United States, but also the strength of U.S. anti-trust policy following the Sherman Act (which triggered a search for alternative sources of market power through industrial innovation) and stronger protection of intellectual property rights through the patent

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[10] Mowery and Rosenberg (1998), p. 13.

system. However, as Mowery points out, "a weak antitrust climate in other nations, such as Germany, was associated with growth in industrial research, making it difficult to assert a direct cause-and-effect relationship between anti-trust policy and the growth of intrafirm R&D".[11] It could also be argued that the increasing strength of intellectual property rights in the late 19th and early 20th centuries would seem to promote greater specialization in innovation and vertical *dis*-integration rather than a shift in innovative activity from the realm of the independent inventor to within the boundaries of the corporation. Indeed, Lamoreaux and Sokoloff argue that, in the nineteenth century,

> "the U.S. patent system created a framework that supported trade in technology, and that the patent agents and lawyers who serviced this system often took on the functions of intermediaries, matching inventors seeking capital with investors seeking profitable outlets for their funds and also inventors seeking to sell new technological ideas with buyers eager to develop and commercialize them."[12]

Lamoreaux and Sokoloff document a well-functioning market for technology in the late nineteenth century United States. In 1870-71, 72% of all patents that were assigned to a party other than the inventor were assigned after issue. By 1910-11, this number was halved (36.5%).[13] Fisk (1998) explains that, prior to the 1890s, courts almost always favored the rights of the inventor in cases where the ownership of an employee's invention was contested by an employer. Starting in the 1890s, Fisk documents the emergence of the "shop right" patent doctrine, which favored the employer in intellectual property disputes. This change in intellectual property doctrine no doubt made it much more attractive for firms to establish in-house research labs.

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[11] Mowery (1990), p. 346.
[12] Lamoreaux and Sokoloff (2002), p. 5-6.
[13] Lamoreaux and Sokoloff, (1996), p. 12689.

Mowery and Rosenberg also emphasize the importance to industrial innovation of science conducted in universities. In this paper, we argue that the unique form taken by American universities in the late nineteenth and early twentieth centuries helped promote the adoption of industrial research laboratories within the boundaries of firms. Whereas during the nineteenth century, "most industrialists believed the manufacturer's job was to manufacture; new ideas to improve manufacturing could be purchased or otherwise appropriated … managers offered little support for research until they had evidence that a worker's results indicated likely commercial application,"[14] the institutionalization of scientific research in universities facilitated the adoption of scientific research in industry. The scientific research undertaken in universities reduced the cost to firms of acquiring scientific knowledge, and this led firms located near universities to engage in research. Furthermore, the trend towards specialization and professionalization in science increased the supply of qualified workers with easily identifiable skills. Once firms could access a pool of potential research workers whose academic credentials reduced the uncertainty associated with hiring them, firms could establish labs to engage in long-term research projects.

Several inter-related historical forces combined to favor the organization of invention within the firm. Changes in the nature of technology, in the extent to which firms could claim intellectual property rights over their employees' inventions, and in the enforcement of anti-trust rules led firms to seek to adopt of in-house industrial research facilities. In order for firms to respond to these forces by organizing invention within firm boundaries, they needed skilled R&D workers and scientific expertise. Universities

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[14] Swann (1988), p. 13.

provided these inputs to production of new technology through consulting relationships and by providing certification for the skills of potential R&D employees.

III. Historical Interactions between the U.S. Pharmaceutical Industry and Academic Science

In order to characterize the relationship between academic science and the early industrial research labs, we exploit the fact that geographic proximity promotes interaction between people and organizations. We argue that firms located near research universities were more likely to adopt in-house R&D facilities because local universities provided both part-time faculty consultants with highly specialized knowledge and scientifically-trained university graduates who could be employed as full-time research employees. Because long-distance collaboration was more difficult in the first half of the twentieth century than it is today, firms were more likely to focus their search for scientific expertise on nearby institutions.

The early histories of two late 19th century pharmaceutical firms, Mulford and Sterling are illustrative of the potential influence of local university science on firm-specific investments in innovation.[15] Founded by two graduates of the Philadelphia College of Pharmacy, the H.K. Mulford Company commenced operations in Philadelphia in 1891 when H.K. Mulford and Milton Campbell purchased the "Old Simes" drugstore. After initial successes in improving pill-making technologies, the founders undertook the more ambitious challenge for which they themselves were by no means sufficiently trained – the synthesis of diphtheria antitoxin. Bacteriological illness had become increasingly problematic for urban areas as a result of the increased density of city life.

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[15] Furman (2003) reviews the relationship between local resources and the strategic orientation of Mulford and Sterling.

This problem was of particular concern to the Municipal Health Department in Philadelphia, which was the third largest city in the country at the time. Philadelphia's Health Department, like that of New York, was especially active in promoting efforts to address bacteriological illnesses. Long known as the "Cradle of Pharmacy" (Mahoney, 1959; Feldman and Schreuder, 1996), Philadelphia was the home to some of the most advanced biomedical research institutions in North America. In addition to the Philadelphia College of Pharmacy, several other institutions were pursuing bacteriological research, including the University of Pennsylvania, Medico-Chirurgical College, and Pepper Clinical Laboratories of the University Hospital. Together with the Municipal Health Department, these institutions were engaged in research on diphtheria in response to "public clamor" for a diphtheria antitoxin.[16] Galambos argues that Mulford "recognized the opportunities embodied in the "clamor" for diphtheria antitoxin" and set out to produce a commercially viable drug.[17] In 1894, the firm hired Dr. Joseph McFarland, who was on faculty at the University of Pennsylvania's Medical Department and the Philadelphia Polyclinic and College for Graduates in Medicine and had trained in bacteriology in Heidelberg and Vienna, and created for him a laboratory in which he could concentrate on developing diphtheria antitoxin (Galambos, 1995). In his efforts, McFarland benefited greatly from interactions with the New York City Health Department and the Laboratory for Hygiene at the University of Pennsylvania. By 1895, Mulford was able to become the first commercial provider of a diphtheria anti-toxin. The firm's success with McFarland led them to hire Professor Leonard Pearson from Penn's

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[16] Galambos (1995), p. 13.
[17] Ibid., p. 13.

Veterinary School and to establish a full-fledged laboratory in 1896 in Glenoden, PA dedicated to biological, veterinary, and vaccine research (Galambos, 1995).

Although Sterling was founded under circumstances similar to those of Mulford and around the same point in time, it pursued a very different trajectory with respect its orientation towards research. After graduating from the Philadelphia College of Pharmacy William E. Weiss returned to his hometown of Wheeling, West Virginia to found the company that became Sterling with his childhood friend Albert Diebold. The firm succeeded at marketing and distributing patent medicines, products of questionable medical validity which were often alcohol- or narcotic-based, and by 1912 had a value of $4 million (Mann and Plummer, 1991). Sterling ultimately acquired the assets of the Bayer Company following World War I. That the fact that Sterling was able to raise the funds required for this acquisition demonstrates a triumph of marketing and distribution capabilities over technical aptitudes: Sterling's drug-making competence was so limited that it was forced to solicit substantial guidance from Bayer in order to understand how to manufacture the basic products it won at auction. Both demand and supply side factors appear to have had an influence on Sterling's choice of organizing strategies. Serving the mainly rural populations of West Virginia and central and western Pennsylvania, Sterling did not confront the same demand for medicines to fight the bacteriological illnesses towards whose cures academic science had begun to work. Even if such demand had existed, however, Sterling did not have ready access to trained individuals who could have contributed to effectively to drug discovery; at the very least, the comparative advantage of Sterling's West Virginia location was not research-driven.

The early history of Detroit's Parke-Davis, another one of the first chemical firms to establish science-based industrial research, resonates with that of Mulford.[18] Similar to its Philadelphia counterpart, Parke-Davis began serious research efforts with the aim of making diphtheria anti-toxin. To do so, it hired Elijah M. Houghton, a research assistant at the University of Michigan in 1895 and Charles McClintock, a research assistant in bacteriology, in 1896. Parke-Davis established a research lab in biology, and succeeded in producing diphtheria anti-toxin within a few months.[19] McClintock then turned his efforts to other biological research, which dominated the firm until the 1920s when a separate department for chemical research was established.[20]

These early examples of the importance of local labor markets in diffusing biomedical research knowledge are typical of the experience of U.S. firms in the 1920s and 1930s. Firms located near universities appear to have had greater ease in recruiting scholars for their research efforts. The differences in the strength and relevance of the science bases in Philadelphia, PA and Wheeling, WV during the formative years of Mulford and Sterling are quite stark. The "Cradle of Pharmacy," Philadelphia was home to numerous universities with departments dedicated to biomedical sciences, including the University of Pennsylvania (which was founded 1740, and offered its first doctorate in 1871), as well as the Philadelphia College of Pharmacy (founded 1821), the Medical College of Pennyslvania (1850), Jefferson Medical College (1825), Hahnemann Medical College (1848), Temple University (1884), and the Drexel Institute of Technology (1892). The University of Pennsylvania was one of the country's leading biomedical institutions, and had granted, on its own, 919 doctorates by 1925. By contrast, Sterling's

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[18] Swann (1988), p. 20.
[19] Ibid, p. 21.
[20] Ibid., p. 21.

hometown, Wheeling, WV was 50 miles from the nearest university. The closest significant universities to its home base were in Pittsburgh (59 miles from away), Morgantown, WV (79 miles away), and Penn State (198 mi away). Though not nearby, Pittsburgh was an emerging center of university life at the turn of the century, offering the University of Pittsburgh (which was founded in 1786 and granted its first doctorate in 1886), the Carnegie Institute of Technology (1905), and Duquesne University (1878). Even if Sterling had opened facilities in Pittsburgh, these growing universities would not, however, have been able to offer research services comparable to those of Philadelphia – by 1925, the city's largest university, the University of Pittsburgh, had only granted 86 PhDs, and Carnegie and Duquesne did not grant any PhDs until the 1920s.

The potentially prohibitive cost of long-distance collaboration is illustrated as well by the agreement struck between Du Pont and consulting chemist Roger Adams, a professor at the University of Illinois. Du Pont offered Adams $5,000 a year, which was substantially more than half his university salary, to entice him to make a monthly trip from Urbana to Wilmington, and to visit for a month or so during the summers. Adams negotiated a deal in which he received $3,000 annually (plus travel expenses) for a visit every other month, along with $750 for each summer month spent at Du Pont.[21] While Du Pont, one of the first and most successful companies to adopt in-house research, had access to the funds required to invest in long-distance relationships with consultants (and had little choice, given the absence of a major research university in the vicinity of Wilmington), younger and smaller firms did not. Table 1 lists the industrial labs in the NRC data that in 1938 listed the names of the universities at which they funded

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[21] Hounshell and Smith (1988), p. 297. While a consultant for Du Pont, Adams told a colleague, "I feel that I get quite as much out of the contact from the chemical standpoint as they do" (Ibid, p. 298).

consultants or research fellows.[22] Local universities, where they exist, predominate. While other more distant universities were supported by firms with larger research efforts (like Merck, with a research staff of 111), even these firms continue to be associated with nearby universities.

Universities, in addition to providing consulting services, fed the labs with a supply of skilled labor. We have seen that Mulford and Parke-Davis both hired graduates of local universities (the University of Pennsylvania and the University of Michigan, respectively) to form two of the first in-house research labs in the United States. We draw evidence on the geographic mobility of university graduates from the *Chemical Who's Who*, a directory published in 1928 that contains biographical sketches of executives and researchers in the chemical industry. For a sample of the thirty largest labs in the National Research Council (NRC) volume of 1927, we collected information on the educational background and location of first employment of executives listed in the *Who's Who*. Many of the executives, whether directly involved in research or not, came from scientific backgrounds, and the biographical information on the location of an individual's alma mater and post-graduate employment is instructive whether or not the individual joined the company immediately upon graduation. The information we collected revealed that the first employment after graduation from a university was very often in the same city as the university, and that many firms seemed to hire graduates of nearby universities. While the extent of this practice varied by firm, the firms that did hire from nearby universities ("nearby" defined loosely to include universities within 100 or 200 miles of the lab) tended to hire almost exclusively from those universities. For

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[22] In the NRC publication, this is described as "grants to university labs for research projects in support of program of association."

example, at Sharp and Dohme of Baltimore, one of the two directors of pharmaceutical research listed in the *Who's Who* in 1928 was J.C. Krantz, a former professor at the University of Maryland and a former lecturer at Johns Hopkins. The other director of pharmaceutical research graduated from the Philadelphia College of Pharmacy and worked at Mulford and Co. in Philadelphia before joining Sharp and Dohme. One laboratory superintendent (C.Neal) was a graduate of the University of Maryland department of Pharmacy, and another superintendent (E. Miller) earned a doctorate from Johns Hopkins. Of the nine employees and executives whose educational credentials are described in the *Who's Who*, six joined after studying or working at Johns Hopkins or the University of Maryland. Three were graduates of the Philadelphia College of Pharmacy (two of whom came to Sharp & Dohme after initial employment at Mulford & Co) and one came to Sharp & Dohme after working as a professor at the University of Vermont.

Another example of localization in early research collaborations, Eli Lilly & Co., of Indianapolis, Indiana, engaged in collaborative research with Purdue University. Lilly hired Purdue grads, like director of research development H.W. Rhodehamel, chief pharmacist F.E. Bibbins, and assistant chief engineer J.C. Siegesmund. Pharmaceutical research scientist E.H. Stuart was a graduate of Indiana University. The majority of Lilly employees whose credentials are listed in the Who's Who were graduates of Indiana universities. Of the ten listed university-educated employees of Eli Lilly & Co. of Indianapolis, four were graduates of Purdue University (62 miles away in West Lafayette) who joined Lilly upon graduation. Two attended other universities in Indiana (DePauw and Indiana University), one came from the U.S. Industrial Alcohol Co. in New Orleans after graduating from Louisiana State University, and the others studied at

Trinity College and the Philadelphia College of Pharmacy. As we discuss in some more detail below, Lilly also provides an interesting example of early firms' abilities to work with distant researchers.

At Abbott Labs of Chicago, the president, Alfred Burdick, was a former professor at the Illinois Medical College; consulting scientist Roger Adams was chair of the department of Chemistry at the University of Illinois Urbana-Champaign. Adams' former student Henry Volwiler, chief chemist in 1928 (he was later to become president and chairman of the board), was a graduate of the University of Illinois, as was Floyd Thayer, a former research chemist who was in 1928 manager of the chemical sales department. Of the eight people listed, six joined the firm after graduating from or working at an Illinois university. Swann notes that several of Adams' students went on to join Abbott.

In contrast to these examples, there are fifty-five individuals listed as employees of Du Pont, and the list of universities is almost as long. It is clear that not every firm in the industry hired graduates of local universities – mainly because it was not always the case that local universities produced graduates with the skills required during this period. Although the *Who's Who* was published in 1928, most of the individuals who appear in it had been with the firms for many years, most of them having been hired in the previous decade or earlier.

The example of Alfred Newton Richards' work for Merck shows how academics played key roles in the establishment of in-house R&D labs. Richards essentially acted as a head-hunter and recruiter when Merck set up its in-house facilities starting in 1930. Richards was professor of pharmacology and vice-president of medical affairs at the University of Pennsylvania. As Swann notes, "The University of Pennsylvania was a logical site for Merck to establish connections for biomedical research and clinical investigations of its drugs. Pennsylvania was a major research institution with access to extensive clinical facilities; the university was conveniently located not far from Rahway; and most important, Merck had close contact with one of the faculty whom the university community esteemed – Newton Richards."[23] Richards acted as a liaison between Merck and the academic community, helping not just in recruiting but also in the organization of collaborative projects. Students and clinicians at Penn carried out the investigation and testing of methylcholine, a vasodilator eventually marketed by Merck as Mecholyl Chloride. Pharmacologists at Penn also helped develop Vinethene, an anaesthetic originally discovered by a pharmacologist at the University of California Medical School. Merck "did not feel that it would be advantageous to spend a great deal of money for the pharmacological study of vinyl ether in California. The distance was so great that a true cooperation could not be obtained."[24] Instead, the work was undertaken by clinical faculty at the more geographically proximate University of Pennsylvania.

While firms with larger R&D budgets often engaged academic consultants at more distant universities who were specialists in a specific field, younger firms were more likely to collaborate with local academics. Starting in 1925, Northwestern University chemist Arthur Tatum did routine testing a few times a year for the small Chicago firm Cook Laboratories. Tatum had no unique knowledge of the drugs he tested, and Swann notes that "Cook probably engaged Tatum simply because of his proximity to the firm."[25] Selman Waksman worked part-time at nearby Cutter Laboratories while a

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[23] Swann (1988), p. 74-75.
[24] Letter from Merck scientist R.T. Major to A.N. Richards, quoted to Swann (1988), p. 77.
[25] Swann (1988), p. 103.

graduate student at UC Berkeley, and at Takamine Labs of New Jersey while a young assistant professor at Rutgers.[26]

Geographic proximity was likely to matter most for (a) labs at early stages of development, or (b) relatively informal or occasional consulting contracts on general scientific matters, but not large-scale research projects requiring specialized scientific knowledge. For example, Lilly had 4 general consultants at nearby universities by 1943: an organic chemist from U Chicago ($2000/yr), chemical engineer from Purdue ($600/yr), biochemist from U Illinois ($600/yr), organic chemist from U Indiana ($2,400/yr).[27] However, Lilly's large-scale collaborative research projects were undertaken with researchers at more distant universities, for example their collaboration with Banting and Best's work on synthesizing insulin at the University of Toronto, and with scientists at Harvard and the University of Rochester on the treatment of pernicious anemia in the 1920s.[28]

Companies like Du Pont, established in 1802 on the banks of the Brandywine river (the location was attractive for its easy access to waterpower and the abundant supply of willow trees that could be used to produce charcoal) were founded long before chemical research was widespread in American universities, and as a result proximity to universities did not influence the choice of location. Although we focus in this paper on the impact of universities on research efforts in private firms, we acknowledge that universities were particularly affected by their interactions with industry, as well, often in ways that were not anticipated by the universities. Examining such firms and their

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[26] Israel, P. (2004) "Waksman – Biography," http://www.scc.rutgers.edu/njh/SciANDTech/Waksman/biog.htm (July, 16 2004).

[27] Swann (1988), p. 52.

[28] Swann (1988), Chapter 5.

interactions with universities can help shed light on the contributions of firms to the evolution of universities in their era.

The relationships between Merck and Rutgers University and DuPont and the University of Delaware are illustrative. Merck's choice of Rahway, NJ as the location for the plant it built in 1899 was influenced by a board member who owned land in the community.[29] This decision proved propitious for nearby Rutgers University. In the 1930s, Merck developed a relationship with microbiologist Selman Waksman of the College of Agriculture at Rutgers.[30] Starting in 1939, Merck agreed to supply assistance for antibiotics developed by Waksman, who would assign all ensuing patents to Merck in exchange for a 2.5% royalty to be paid to Rutgers. In 1943 Waksman developed streptomycin, a new blockbuster antibiotic that was at once less toxic and more effective (particularly in treating tuberculosis) than existing alternatives. Motivated by fear of a public outcry over the monopolization of such an important drug, Waksman and Rutgers convinced Merck to relinquish their rights to Waksman's patents to the Rutgers Research and Endowment Fund, which licensed the patent to several competing companies. The Fund collected $12 million in royalties from Waksman's discoveries over the next forty years.[31] Swann quotes Waksman as suggesting that he owed more to support from Merck than from Rutgers for the discoveries.[32]

Rutgers was not the only university to benefit from an association with a nearby firm. Du Pont played an important role in the development of science research at the

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[29] Feldman and Schreuder, p. 856.

[30] Waksman went on to win the Nobel Prize for Medicine in 1952.

[31] Swann (1988), p. 90.

[32] Ibid., p. 90. Waskman stated that, "Without the help…of an industrial organization that took over a major part of the pharmacological evaluation of the antibiotic [streptomycin] and large-scale production our contribution would have never attained its goal."

University of Delaware, through a number of significant gifts from the Du Pont family and others associated with Du Pont. In 1924, the first physics professor was brought to Delaware with the help of Lammot Du Pont, who contributed $2,000 for equipment and pledged an additional $600 a year for five years, half for research equipment and half to top off the new professor's salary.[33] The university's chemical laboratory was established between 1935 and 1937 with a $300,000 gift from Fletcher Brown, a former Du Pont Vice President. Brown also made a donation to supplement the salary of Allan Colburn, a Du Pont engineer who became the first professor of Chemical Engineering at Delaware in April 1938.[34] Chemical Engineering quickly became the most active field of research at the university.[35]

IV. Data on Universities and Pharmaceutical Research Laboratories, 1920-1946

In order to answer the question of whether the early industrial research labs were more likely to locate near universities, we employ data on the number of research labs by city over several years from the publication *Industrial Research Laboratories of the United States*. The National Research Council began to send out surveys in 1920 containing questions about firms' industrial research activities. While the term "industrial research" was interpreted broadly to include development and product improvement, the term "laboratory" was restricted to apply only to those departments of companies that had "separate and permanently established research staff and equipment", excluding "firms that indicated they only occasionally carry out research, using teams temporarily

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[33] Munroe, Ch. 9.

[34] Ibid.

[35] Ibid, ch. 10. Monroe notes: "possibly excepting the agricultural experiment station".

recruited for the purpose or assembled from their operating staffs."[36] Government and university laboratories were excluded, as were labs that conducted testing and analysis but no research.

These publications contain information on the characteristics of industrial research labs in nineteen years between 1920 and 1985.[37] In the earliest years in which the series was published, these characteristics include the firm's address, the number of its research employees, and a brief description of its activities. In later years, the surveys list the labs' founding dates, number of scientific and other personnel by type (i.e.: biologists, chemists, etc.), the names of important researchers, scientific journals published by the lab, and their partners in collaborative research. Starting in 1950, the volumes also contain indices of universities that participate in collaborative research, indicating whether or not the university possesses "facilities for research in practically all fields of science", its facilities are limited to specific fields, or it has particular capabilities in certain areas.

We have combined this data with information on American universities drawn from the *Bulletin of the Office of Higher Education (Biennial of Education)* and the American Council on Education's serial publication *American Universities and Colleges* for the years before 1965 and from the National Center for Education Statistics for the years following 1965.[38] These have been combined with county-level population data from the US censuses of population for 1920-1970 and counts of the number of

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[36] *Industrial Research Laboratories of the United States* (1956), p. 2 of introduction.

[37] The years in which volumes were published are: 1920, 1927, 1931, 1933, 1938, 1940, 1946, 1948, 1950, 1956, 1960, 1965, 1970, 1975, 1977, 1979, 1982, 1983, and 1985.

[38] We thank Claudia Goldin for making the *Biennial* data available.

manufacturing establishments per county from the US censuses of manufacturing for 1920-1972.

Figures 4, 5, and 6 plot the industrial research labs, universities, and manufacturing establishments, by county on maps of the United States, respectively.[39] The figures suggest that manufacturing and industrial research were more concentrated (particularly in the manufacturing belt of the Northeast/Midwest) than were population and universities and colleges. Table 2 provides summary statistics from the dataset. It shows that counties with more Ph.D.-granting universities tend to have a much larger number of chemical/pharmaceutical industrial research labs per capita, in each year of the sample. We restrict ourselves to data on the number of labs per county in the years 1927, 1938, and 1946.[40] .

V. Evaluating the Role of Universities as a Determinant of Pharmaceutical Laboratory Growth

Table 3 contains results from a panel regression in which the dependent variable is the number of pharmaceutical industrial research labs by county and year. Ordinary Least Squares (OLS) on logged variables is used in Columns 1-3, to facilitate the interpretation of the coefficients on the lagged variables and as elasticities. Because the dependent variable is a non-negative integer truncated at zero (a count), Columns 4-6 contain robustness checks using econometric methods (Negative Binomial regressions[41]) designed to account for these characteristics of the data.[42]

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[39] Manufacturing and population are plotted only for those counties above the median for the country.

[41] A likelihood ratio test for over-dispersion of the conditional mean rejected the Poisson model.

[42] In columns 1-4 the dependent variable is the log of the number of labs + 1, and in columns 5-7 it is the number of labs. In columns 1-4, the number of chemistry PhDs is in logs (with 1 added to the variable before taking logs), and in columns 5-7 it is in levels.

In the first column of Table 3, the number of pharmaceutical labs in a county is modeled as a function of that county's population, the number of manufacturing establishments in the county, the number of Chemistry PhDs granted by universities in the county (all in logs), and year and county fixed effects. The number of Chemistry PhDs awarded by a university is used as a proxy for the extent to which the university engages in relevant research.[43] The coefficient associated with the number of Chemistry PhDs in the county is positive and significant at the 5% level, and implies that, holding constant any time-invariant characteristics of counties that lead labs and universities to be located there, an increase of 10% in the number of Chemistry PhDs granted by nearby universities is associated with a 0.8% increase in the number of labs in the county.

Column 2 introduces the lagged pharmaceutical labs (in logs) on the right hand side, and of necessity focuses on the latter two years of the sample. The coefficient on this variable is 0.453, which is significantly less than 1. That means that the change in laboratories in a county in 1938 and 1946 is *decreasing* in the research located there in 1927. That is, counties with more pharmaceutical labs in 1927 had slower rates of growth in labs up to 1938 and 1946. This coefficient on research employment in a county in 1927 remains significantly different from 1 in all specifications. In column 3, the number of Chemistry PhDs in 1927 is included, and is significantly different from zero. When the contemporaneous number of PhDs is included, as in column 4, the latter variable is significantly different from zero, but the former is not. These two columns show that, while the original distribution of academic science (ie: the number of science PhDs

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[43] We also obtained data on the universities' research expenditures for certain years. While this variable comes closer to the effect we are trying to estimate, it is not available for every university in every year. As a result, we use number of PhD degrees awarded, which is perhaps noisier but we would argue a reasonable proxy for the research effort of the university.

awarded by universities in a county in 1927) is positively and significantly related to the number of pharmaceutical research laboratories in the county in later years, it becomes insignificant once the contemporaneous number of PhDs is included in the regression. That is, while the geographic distribution of academic science in 1927 is correlated with the distribution of pharmaceutical research in 1938 and 1946, this correlation appears to be picking up the strong autocorrelation in the number of PhDs. Columns 5 and 6 are Conditional Fixed Effects Negative Binomial regressions of the pharmaceutical research labs and employment respectively in a county for all years (1927, 1938 and 1946), including county fixed effects. Similar findings with respect to the coefficient on science PhDs are obtained from a negative binomial model. These results demonstrate that, despite the strong autocorrelation in PhDs, increases in the number of PhDs within a county over time are associated with increases in pharmaceutical research. Columns 7-9 use both labs and employment as the dependent variable in Negative Binomial regressions similar to the OLS regressions found in columns 2-4, and the coefficient on contemporaneous Chemistry PhDs remains positive and significant at the 5% level.

It should be noted here that the data on research labs may not be exhaustive of all the labs in existence for the early years during which it was collected. The Appendix to this paper reproduces an excerpt from the 1927 issue of the survey. It explains that members of the main scientific and engineering associations were consulted in order to establish a list of firms known to have in-house research labs, and the published information is based on surveys were sent to these firms. This sample is obviously not random. It is important to determine what effect this sampling bias might have on the results, that is, whether the correlation between labs and universities per county could be an artifact of the way the sample was constructed. If, for example, key members of the scientific and engineering associations were university professors, they would be more likely to know of the existence of research labs in the surrounding community. Improvements in the survey methodology might actually explain the decline in the correlation between university research and the number of labs in a county if surveyors became less reliant on scientific societies for information.

In Table 4, we estimate the probability of adopting an in-house R&D lab among the corporate members of the American Chemical Society as of 1927. The American Chemical Society (ACS) was one of the societies used by the NRC to collect information on research laboratories. By restricting ourselves to companies that were clearly known to the secretaries of every branch of the ACS (the directory of members distributed by the ACS listed corporate members on the first few pages), we can be confident that the sampling error is random because the NRC almost certainly sent questionnaires to all the corporate members of the ACS. The probability of adopting in-house research is modeled as a function of the number of PhDs awarded by universities within 100 miles, the age of the company (proxied by the date it joined the ACS), whether or not there is a College of Pharmacy in the county, whether the local branch of the ACS is headquartered in the county, manufacturing, population, and regional fixed effects. The dependent variable is equal to 1 if the company had a research facility (that is, if the company is listed in the NRC volume for 1927), and 0 otherwise, and we estimate the parameters via Logit.

When university research enters the model on its own, its coefficient equals 0.029 and is not significantly different from zero. However, when we control for the age of the firm and interact age with research, the latter coefficient increases to 0.760 and is significant at the 5% level. The coefficient on the interaction term is negative and significant, implying that university research had less bearing on the decisions of older firms to establish industrial research labs. Chi-squared test statistics for the test of joint significance of ln(PhDs within 100 mi) and that variable interacted with the log of age are found at the bottom of the table, and indicate joint significance at the 5% level for all specifications. The coefficient on the number of industrial research labs in the county is positive and significant, implying that the probability of adopting industrial research for an individual firm is increasing in the total number of research labs nearby. This may be picking up the effect of an omitted variable operating at the county level to promote the adoption of industrial research. It may also indicate that the presence of prior adopters of industrial research made nearby firms more likely to establish a lab (since this variable is significant after controlling for other things we should expect to influence adoption). Firms located in a county with a college of pharmacy were not significantly more likely to establish an in-house research facility. It should be noted that in other specifications not included here, the indicator of the presence of a college of pharmacy in the county has a positive and significant coefficient when the regional fixed effects and the number of research labs in a county are excluded. The coefficient on the variable measuring whether there is an ACS branch headquarters in the county is not significant.

VI. The mechanisms of university-industry interaction: Labor Markets, Collaboration, and Productivity

We look closer at the role played by proximity to academic science in Table 5, in which the firm's decision to collaborate with academic scientists is modeled as a function of the extent of research undertaken at nearby universities. In contrast to previous results, the number of PhDs within 100 miles does not explain collaboration as well as the number of PhDs in Chemistry awarded by local universities. Firms with larger numbers of researchers were more likely to engage in cooperative research, but the firm's age is not significantly associated with the probability of collaborating with academic scientists, nor are the manufacturing or population intensities of the county. To test the hypothesis that collaboration with local academic scientists was more important for younger, smaller firms, we include interaction effects of local chemistry research with age and size in columns 4 and 5. The coefficient on the interaction of age and nearby PhDs in Chemistry is negative and significant at the 5% level, implying that the influence of nearby chemistry research was more important for younger firms. The effect of local academic chemistry research does not appear to vary according to firm size, however, since the interaction of firm size and chemistry PhDs is not significant at the 5% level. Columns 6 and 7 present the regressions with the firms divided by founding date. The decision of whether or not to collaborate is not significantly affected by local academic research in chemistry for labs founded before 1920 (the median founding date in the sample). However, as column 7 shows, local chemistry research is positively and significantly associated with the probability of engaging in university-industry collaboration for labs founded after 1920 (and the coefficient is twice as large as in column 6). That is, while young and old laboratories were approximately equally likely to engage in collaboration with universities, the laboratories founded after 1920 were more likely to collaborate if there was a university nearby. This finding is consistent with the results based on the data on members of the American Chemical Society presented in Table 4, which show that the presence of local academic science only influenced the adoption of industrial research facilities for younger firms. Another interpretation of these results is that small, newly-founded laboratories lacked the funds or the reputations required to convince consultants from distant universities to travel to the laboratory. Young laboratories may have sought out university scientists for general services like the advice on hiring provided by Richards when Merck opened its research facility in Rahway, or the routine testing performed for Cook laboratories by Tatum at the University of Chicago. Established laboratories could convince scientists to participate in more specialized research projects like Lilly's collaboration with the University of Toronto on penicillin.

In an attempt to assess more directly whether firms in the pre-war period benefited from spillovers from university research, we test whether the pharmaceutical firms listed in the NRC survey of 1938 and 1946[44] were granted significantly more patents per lab employee if they were located near a university or if they engaged in research collaboration with a university. This analysis is based on information in Table 6, which contains results of a Negative Binomial regression in which the dependent variable is the number of patents granted to the firm by year and the right-hand side variables include the size (employment) of the research lab[45], a dummy variable equal to 1 if the firm engages in cooperative research with a university,[46] the number of Chemistry PhDs granted by universities in the county, and year and regional dummies.

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[44] These were the only two years in which information on cooperative research is available.

[45] Some firms had laboratories at more than one location. Each lab is treated as a separate observation, and standard errors are clustered by firm. A small minority of firms had no information on the number of researchers employed in the lab, and for these firms we made employment equal to 1 and included a dummy variable equal to 1 for those observations.

[46] In the NRC publication, this is described as "grants to university labs for research projects in support of program of association".

The coefficient estimates in Table 6 show that local university research in chemistry (as proxied by the number of PhDs in Chemistry awarded by universities in the county) is positively correlated with patents per employee (research productivity) among firms that engage in cooperative research with universities.[47] However, there appears to be no benefit to firms that do not engage in collaborative research – in fact, labs that were located near academic chemistry departments but did not collaborate with universities had significantly fewer patents per R&D worker than non-collaborative firms located far from a university. The results show that firms that collaborated with universities in 1938 were granted significantly more patents per R&D worker – approximately 3 times as many. However, the number of PhDs in Chemistry granted by nearby universities is *negatively* associated with R&D productivity, except for firms that cooperate with universities. In column (3), the interaction of the number of chemistry PhDs awarded and the indicator for research cooperation is positive (0.248) and significantly different from zero at the 1% level. An F-test for the joint significance of the cooperation variable and the interaction term has a statistic of 67.3, which is significant at the 1% level.

The message of Table 6 is that the research productivity of early pharmaceutical labs was positively associated with the scale of academic chemical research nearby, but only for labs that had formal cooperative relationships with universities. Again, the question arises: did the firms generate more inventions because they benefited from spillovers from academic research? Or did chemistry departments located near research-active firms expand to meet the demand for graduate students to work on cooperative projects?

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[47] The number of patents is regressed on the ln(university research expenditures + 1), and a dummy variable is included for counties where research expenditures equal 0.

Table 7 brings some evidence to bear in response to this question. It displays the results of a logit regression at the level of the university in which the dependent variable equals 1 if the university established a department of chemical engineering between 1937 and 1948. This variable is regressed on a measure of pharmaceutical research in industry in the county in 1938, the population and number of manufacturing establishments in the county in 1938, and the growth of population, manufacturing, and industrial research in pharmaceuticals during the period. The results show that universities located in counties that were centers of employment in the pharmaceutical industries in 1938 were significantly more likely to establish a department of chemical engineering between that year and 1946, even after controlling for the growth of the industry during that period. This appears to be evidence of a feedback effect in which the presence a nearby firms influenced the programs offered by universities. We intend to focus on quantifying these feedback effects as work on this paper continues.

VII. Discussion

The 1920s, 30s and 40s saw the diffusion of an organizational innovation in the form of the in-house R&D laboratory. Also during this period, the modern research university developed and collaborative linkages between industrial and academic researchers were formed. We argue that universities played an important role in the emergence of industrial research situated within the boundaries of the firm, and we present evidence that R&D labs located near universities benefited from increased access to academic scientists and graduates. The preliminary results described in this paper characterize the relationship between universities and the pharmaceutical industry between 1920 and 1946. They demonstrate that industrial and academic research were co-located, and that proximity to university research made firms more likely to adopt industrial research facilities and collaborate with academic scientists. They also show that firms' patents per R&D worker were positively correlated with the amount of university research conducted nearby, but only when the firms engaged in collaborative research with nearby universities.

While most of the paper focuses on spillovers from universities to industry, it is surely the case that characteristics of local industry, and certain large firms, in particular, had a significant influence on the development of universities. We acknowledge a couple of cases in which the direction of academic research in developing universities was affected by key relationships with nearby firms. We also present preliminary results that demonstrate that universities located near larger numbers of industrial research labs in chemistry and pharmaceuticals as of 1938 were more likely to establish new programs of chemical engineering by 1946. These initial results, while, interesting and indicative of the phenomenon of industry influence on universities do not yet present a complete picture of the bi-directional, interactive nature of the relationship that shape the evolution of universities and industries. As this work progresses, we intend to examine more closely this other side of the university-industry relationship, and to investigate the mutual influence of these institutions on one another.

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Table 1: Pharmaceutical Research Labs and Academic Collaborators, 1938

Laboratory	**Location**	**University**
Bauer and Black	Chicago, IL	Northwestern, U Chicago, U Michigan
Breon and Company, Inc., George A.	Kansas City, MO	U Nebraska, U Kansas, U Cincinnati
Bristol-Meyers Company	Hillside, NJ	Carnegie Institute Technology, Rutgers, Stanford
Carbide and Carbon Chemicals Corporation	South Charleston, WV	Mellon Institute Industrial Research
Commerical Solvents Corporation	Terre Haute, IN	Purdue University
Drackett Company	Cincinnati, OH	Ohio State University
Emerson Drug Company	Baltimore, MD	U Maryland; U Illinois; Yale
Endo Products, Inc.	New York, NY	NYU
Harshaw Chemical Company	Cleveland, OH	Western Reserve University
Hynson, Westcott, and Dunning, Inc.	Baltimore, MD	John Hopkins University, U Maryland
Jergens Company, Andrew	Cincinnati, OH	University Cincinnati
Kessler Chemical Corporation	Philadelphia, PA	Philadelphia College Pharmacy and Science
LaMotte Chemical Products Company	Baltimore, MD	Western Reserve University
Merck and Company, Inc	Rahway, NJ	U California; John Hopkins; U Pennsylvania; Princeton; NYU; Tulane; MIT; Philadelphia College Pharmacy; Cornell, Rutgers
Monsanto Chemical Corporation	St. Louis, MO; Dayton, OH	U Cincinnati, U Illinois, Michigan U, U Nevada, U Wisconsin, and Princeton
National Oil Products Company, Inc.	Harrison, NJ	Harvard Medical School; U Iowa; Lehigh; Columbia
Sharp and Dohme, Inc	Glenoden, PA and Baltimore, MD	U Pennsylvania, Bryn Mawr College, Johns Hopkins Hospital, Philadelphia College Pharmacy and Science; U California, Yale, Northwestern, Rochester
U.S. Industrial Alcohol Company	Stamford, CT and Baltimore, MD	Kalamazoo College, Stanford, Temple, U Connecticut, U Chicago, U Detroit, U Michigan, U Tennessee

Source: *Industrial Research Laboratories of the United States, 1938*

Table 2: Pharmaceutical labs per 100,000 population

	Mean	Std. Dev.	Obs.
Counties without a PhD-granting university			
1927	0.130	1.050	2990
1938	0.027	0.309	3006
1946	0.059	0.565	3000
Counties with a PhD-granting university			
1927	0.514	1.392	92
1938	0.142	0.362	105
1946	1.472	3.948	111
Counties with a university granting PhDs in Chemistry			
1927	0.370	0. 629	49
1938	0.131	0.347	76
1946	1.672	4.169	98

Table 3: Location of pharmaceutical research 1927-46

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable:	Number of labs	Number of labs	Number of labs	Number of labs	Number of labs	Number of employees	Number of labs	Number of labs	Number of employees
Population in year t	0.004	0.008	0.008	0.008	0.068	0.418	0.240	0.232	0.596
	(0.003)	(0.002)**	(0.003)*	(0.003)**	(0.096)	(0.103)**	(0.040)**	(0.044)**	(0.443)
Manufacturing in year t	-0.012	0.007	-0.002	-0.002	-0.312	0.090	0.607	0.568	0.460
	(0.004)**	(0.002)**	(0.003)	(0.003)	(0.131)*	(0.105)	(0.062)**	(0.244)*	(1.101)
Chemistry PhDs in year t	0.083	0.120		0.108	0.014	0.044	0.031	0.020	0.067
	(0.010)**	(0.019)**		(0.023)**	(0.006)*	(0.010)**	(0.014)*	(0.010)*	(0.033)*
Labs in 1927		0.453	0.460	0.449			0.166	0.171	1.570
		(0.035)**	(0.036)**	(0.035)**			(0.052)**	(0.043)**	(0.411)**
Chemistry in 1927			0.142	0.025				0.040	-0.655
			(0.033)**	(0.038)				(0.031)	(0.483)
Population in 1930			-0.001	-0.000				-0.107	1.215
			(0.009)	(0.008)				(0.063)	(1.045)
Manufacturing in 1930			0.013	0.011				0.117	-0.147
			(0.005)*	(0.005)*				(0.277)	(0.058)*
Constant	0.042	-0.074	-0.075	-0.079	4.243	-5.016	-7.305	-7.317	-16.663
	(0.028)	(0.016)**	(0.051)	(0.047)	(1.631)**	(0.879)**	(0.400)**	(0.646)**	(3.398)**
Observations	9246	6154	6146	6146	831	831	6154	6146	6154
R-squared	0.04	0.47	0.45	0.47					

Robust standard errors in parentheses. * significant at 5%; ** significant at 1%
(1) Fixed-effects OLS, log-log specification on all years (1927, 38, 46), year and county fixed effects included
(2)-(4) OLS, log-log specification on 1938 & 1946, year and region fixed effects.
(5)-(6) Conditional Fixed Effects Negative binomial regression on all years, county and year fixed effects included.
(7)-(9) Negative binomial regression on 1938 & 1946, year and region fixed effects included

Table 4 : Determinants of adoption of in-house research among members of the American Chemical Society, 1927

Logit model, y = 1 if company is listed in NRC volume, 0 otherwise.

ln(PhDs within 100 mi)	0.029	0.028	0.760	0.758	0.616	0.639
	(0.064)	(0.064)	(0.283)**	(0.282)**	(0.279)*	(0.280)*
ln(Age)		0.441	1.770	1.783	1.622	1.638
		(0.237)	(0.594)**	(0.585)**	(0.557)**	(0.557)**
ln(Age) x ln(PhDs)			-0.365	-0.371	-0.352	-0.358
			(0.140)**	(0.140)**	(0.134)**	(0.135)**
ln(ACS Branch)				0.267	-0.175	
				(0.253)	(0.302)	
ln(Other IR labs)					0.329	0.249
					(0.129)**	(0.115)*
D(College of Pharmacy)						0.217
						(0.302)
Constant	0.377	-0.515	-3.059	-3.213	-3.309	-3.312
	(0.302)	(0.563)	(1.174)**	(1.162)**	(1.096)**	(1.093)**
Chi-sq test statistic for joint significance of PhD coeffs			7.22*	7.25*	7.93*	7.83*
Log likelihood	-217.61	-225.60	-221.225	-220.647	-217.614	-217.179
Observations	343	340	340	340	340	340

Regional fixed effects included.
Robust standard errors in parentheses
* significant at 5% level; ** significant at 1% level

PhDs within 100 mi = number of PhD degrees awarded by universities within 100 miles.
Age = Actually a proxy for age = 1927 – year the company joined the American Chemical Society.
D(ACS Branch)= 1 if the regional branch of the ACS is located in the county.
D(College of Pharmacy) = 1 if there is a college of pharmacy in the county.
Manufacturing = Number of manufacturing establishments in the county.
Population= Population of the county.

Table 5: Determinants of cooperative research, 1938 and 1946

Logit, dependent variable =1 if the lab engages in cooperative research with a university in 1938 or 1946

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Chemistry PhDs	0.136	0.149	0.151	0.761	0.539	0.111	0.220
	(0.090)	(0.075)*	(0.075)*	(0.197)**	(0.216)*	(0.117)	(0.111)*
All PhDs within 100 mi	0.027						
	(0.092)						
R&D workers	0.861	0.864	0.872	0.930	1.075	1.100	0.675
	(0.217)**	(0.215)**	(0.206)**	(0.211)**	(0.229)**	(0.373)**	(0.249)**
Age			-0.043	0.340	-0.017	-0.643	-0.138
			(0.224)	(0.280)	(0.238)	(0.700)	(0.407)
Age X Chemistry PhDs				-0.210			
				(0.063)**			
R&D X Chem PhDs					-0.103		
					(0.054)		
Constant	-3.459	-3.361	-3.261	-4.498	-4.049	-2.147	-2.398
	(0.816)**	(0.752)**	(1.038)**	(1.283)**	(1.171)**	(3.040)	(1.199)*
Observations	543	543	543	543	543	206	317
Log likelihood	-161.082	-161.131	-161.109	-154.862	-159.163	-70.387	-84.941
F-test of joint significance				17.93**	23.17**		

* significant at 5%; ** significant at 1% All variables in logs. Robust standard errors (clustered by firm) in parentheses. Region and year fixed effects included

(1)-(5) All labs
(6) Labs founded before 1920
(7) Labs founded after 1920

Table 6: Research productivity of pharmaceutical firms

Negative binomial estimates, dependent variable
= number of patents granted in 1938 & 1948

	(1)	(2)	(3)
R&D staff	1.282	1.137	1.138
	(0.147)**	(0.123)**	(0.125)**
Chemistry PhDs in county	-0.375	-0.402	-0.440
	(0.065)**	(0.070)**	(0.084)**
D(Co-op)		1.128	0.678
		(0.377)**	(0.531)
Chem PhDs X D(Co-op)			0.248
			(0.118)*
Constant	-3.277	-3.259	-3.159
	(0.524)**	(0.450)**	(0.442)**
Observations	553	553	553

Robust standard errors (clustered by firm) in parentheses. Region and year fixed effects included.

* significant at 5%; ** significant at 1%

Table 7: New Chemical Engineering programs, 1938-46

Dependent variable = 1 if the university began offering degrees in chemical engineering between 1938 and 1946

	(1)	(2)	(3)
Pharma Employment in county 1938	0.316	0.366	0.396
	(0.148)*	(0.146)*	(0.133)**
Non-Pharma labs in county	0.225	0.362	
	(0.218)	(0.223)	
County population	0.012	0.013	0.103
	(0.101)	(0.096)	(0.087)
Manufacturing in county	0.025	-0.174	0.063
	(0.142)	(0.160)	(0.115)
Growth of county population, 1940-1950		2.835	2.345
		(1.186)*	(1.159)*
Growth of manufacturing, 1939-1947		-0.616	-0.385
		(0.737)	(0.786)
Growth of Pharma, 1938-1946			0.188
			(0.151)
Constant	-3.508	-3.192	-4.620
	(1.169)**	(1.222)**	(1.166)**
Observations	608	607	607

Robust standard errors in parentheses

* significant at 5%; ** significant at 1%

Figure 1: Founding Dates of Public Universities
(using data from 1924 Biennial of Education data Sample)

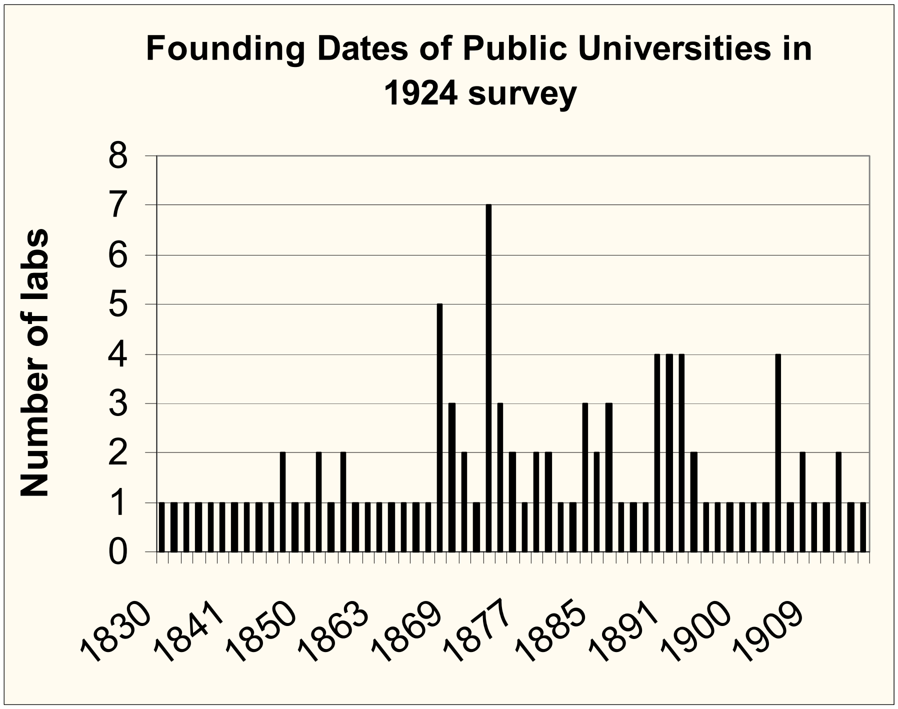


Figure 2: Founding Dates of Private Universities
(using data from 1924 Biennial of Education data Sample)

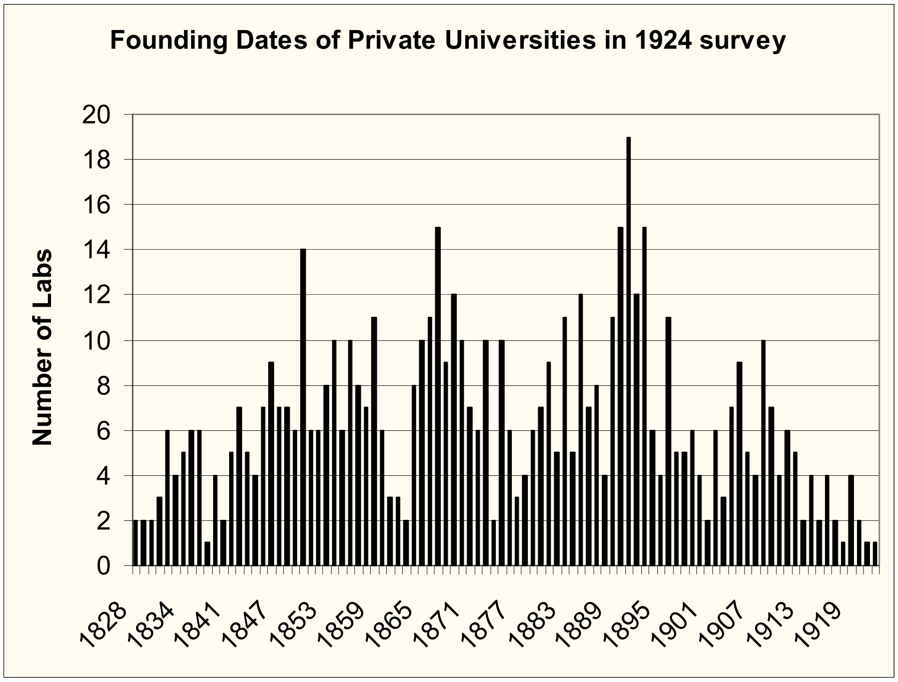


Figure 3: Founding Dates of Industrial Research Labs
(using data from 1946 National Research Council data Sample)

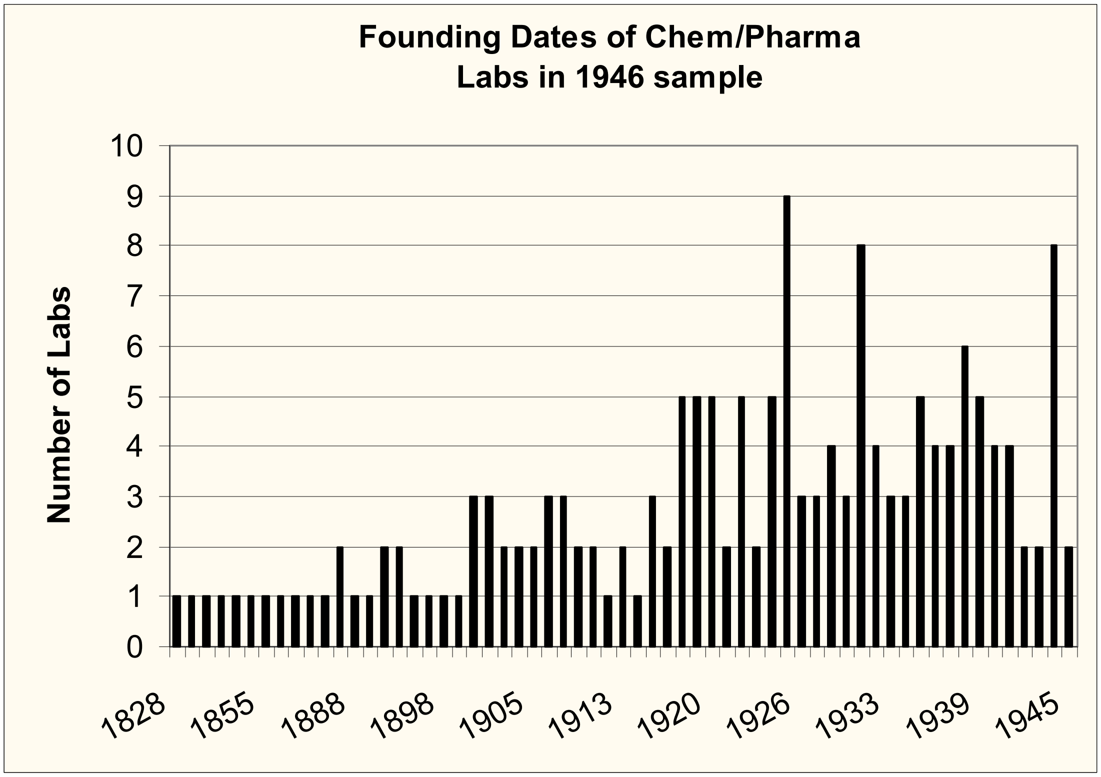


Figure 4: The Location of Industrial Research in the United States, 1927
(Sizes of circles indicate the number of labs in the city/town)

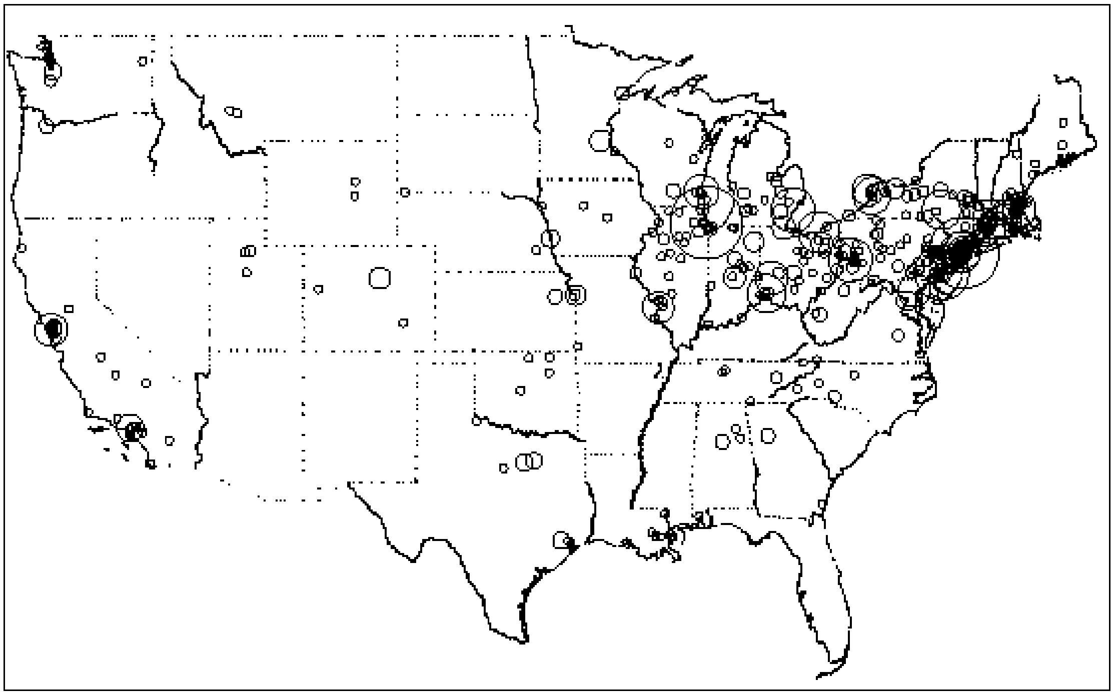


Figure 5: PhD-granting institutions, weighted by degrees granted, 1928-37

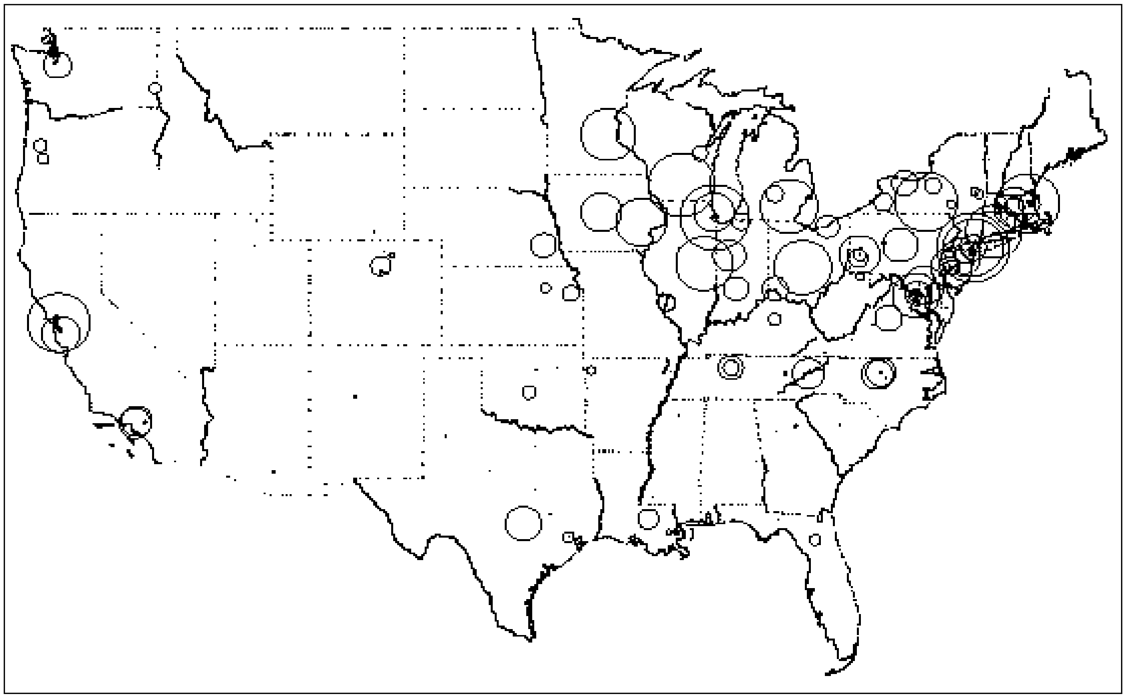
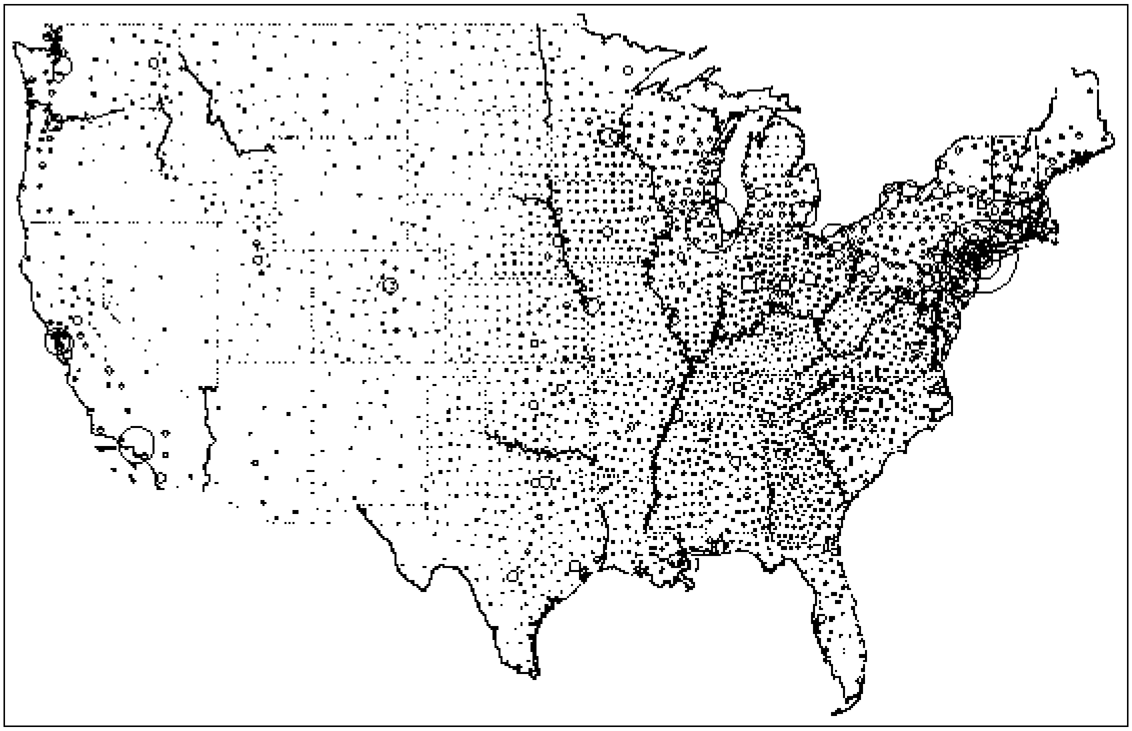


Figure 6: The Location of Manufacturing in the United States, 1929

(Sizes of circles indicate the number of establishments in the county)



Appendix: Introduction from the 1927 survey

"The continued demand for information regarding industrial research laboratories has made it seem advisable to issue a second revision of the list originally published in Number 2 and revised in Number 16 of the Bulletin of the National Research Council. The original publication, compiled in 1920 by Mr. Alfred D. Flinn, Secretary of the Engineering Foundation, listed about 300 industrial laboratories. The first revision prepared in August 1921, by Miss Ruth Cobb of the Research Information Service, listed 526 laboratories. The present revision contains data for 1,000 laboratories.

As in the earlier lists, all information given in this publication has been obtained directly by correspondence and statements are based upon information supplied by laboratories….In preparing the mailing list of new companies to which questionnaires should be sent, the Research Information Service sought the cooperation of the secretaries of the local divisions of the American Chemical Society, the American Institute of Electrical Engineers, the American Society of Civil Engineers and the American Society of Mechanical Engineers; most of the secretaries supplied a list of the industrial laboratories in their community…"