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WHEN THE PILL PEDDLERS MET THE SCIENTISTS: the Antecedents and Implications of Early Collaborations between US Pharmaceutical Firms and Universities

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This paper examines rise of collaborations between for-profit pharmaceutical firms and academic scientists between 1927 and 1946, investigating (a) the historical and economic factors that led to such collaborations and (b) the implications of these early collaborations for the firms involved. The paper builds on a tradition of prior research in this area, which reviews case evidence in a detailed way. The paper supplements this evidence with additional historical analysis and by drawing on survey data on a population of research-active firms. The paper's analyses highlight the importance of geography in the collaborative efforts of the period and provide evidence that those firms that did collaborate with universities produced greater number of patented outputs and grew more quickly than those that did not. Overall, the findings provide useful evidence about the qualities that helped set the stage for the hand-in-glove relationships that characterize the interactions between modern universities and pharmaceutical firms in the United States.

"It is only from laboratories free from any relations with manufacturers that real advances can be expected." —American Medical Association, Board of Trustees, 1915, quoted in Parascandola (1985)

Close collaborations between industrial research facilities and academic scientists are a fundamental element of the modern pharmaceutical industry in the United States. Such relationships were not, however, commonplace at the dawn of the industry. Indeed, as Parascandola's quote from the 1915 AMA Board of Trustees' Committee report suggests, medical scientists regarded for-profit pharmaceutical firms more with hostility than appreciation, considering such firms as "pill peddlers" to be avoided rather than as potential funders and partners.[1] This attitude changed considerably between the 1910s and World War II. Referring to his 1943 discovery of streptomycin, Rutgers' Nobel Prize winner Selman Waksman claims, "Without the help…of an industrial organization [Merck] 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."[2]

Considering U.S. researchers' early contempt for private industry, the fact that hand-in-glove relationships between firm laboratories and academic scientists are commonplace in the early 2000s represents a surprising turnaround. Even more surprising, considering this early enmity, is the fact that university research played a significant and ostensibly causal role in the rise of industrial research in the pharmaceutical industry.[3] This development is surprising for another reason as well, namely that the state of U.S. academic science, particularly life science, was relatively primitive even in the few decades prior to the 1900s.

Indeed, early pharmaceutical concerns in the United States had little use for university-based knowledge, both because the structure of these institutions, which were principally focused on classical, humanities-based education, did not provide a useful entry point for collaboration and because the state of medical science was too primitive to provide useful guidance in the search for effective remedies. The nineteenth century witnessed substantial achievements in medical sciences, including Pasteur's germ theory of disease and technologies, which enabled the standardized preparation of medical treatments. Many of these advances occurred in the leading universities of Europe, such as the University of Berlin (whose Institute of Infection Diseases included such eminent scientists as Robert Koch, Emil von Behring, Paul Ehrlich, and Shibasaburo Kitasato). The increasing relevance of academic science for industrial purposes in the late nineteenth and early twentieth centuries was a principal underlying force that ultimately enabled fruitful collaborations between universities and industry.[4] Throughout the nineteenth century, however, the American system of higher education was substantially less developed than the European system. This changed during the early part of the new century, the period between 1890 and 1940, which Goldin and Katz describe as the "formative years" of U.S. higher education.[5] The analysis describes this transformation in the U.S. system of higher education that led American universities to become attractive partners for for-profit pharmaceutical concerns. This section also describes the early evolution of the U.S. pharmaceutical industry, whose early history included an assortment of organizations selling medical preparations, including street-corner pharmacies and bombastic charlatans, few of which could have taken useful advantage of academic science, however valuable, into an industry with increasingly sophisticated research capabilities and facilities.

This paper examines the antecedents and consequences of early collaborations between U.S. pharmaceutical firms and universities. It argues that the development of these collaborations rested in large part (a) on transformations in the nature and quality of U.S.

universities that took root in the 1800s and (b) on the emergence during the early part of the twentieth century of a more sophisticated U.S. pharmaceutical industry. In examining the rise of collaborations between academics and U.S. pharmaceutical firms, this research builds most closely on that of Liebenau, Parascandola, Swann, and Feldman, each of whom have chronicled examples of such collaborations and noted the importance of academic science in shaping pharmaceutical research efforts.[6] The analyses in this paper complement their rich, case-driven analyses of industry-university partnerships by supplementing case studies with analyses of data on the number and nature of early collaborative efforts. The paper provides descriptive evidence in support of the theory that firms that collaborated with universities in the 1930s and 1940s were more innovative and grew faster than non-collaborating firms. This paper complements other research on this topic.[7]

The analysis in this paper reviews illustrative case evidence on the nature of university-industry collaborative efforts and evaluates survey data on firm-university collaboration between the 1920s and 1940s. The data are drawn from the survey-based publication, *Industrial Research Laboratories of the United States*, which reports upon the research activities, locations, and collaborations of firms engaged in in-house R&D efforts. These analyses suggest that geographic location played an important role in early collaborative efforts in this industry, as firms located near universities appear to have been more likely to engage in collaborative research efforts with those universities. Although the data and approach do not support strong conclusions about causality, they do enable us to observe some of the implications of collaborating with universities: collaborating firms achieved a larger number of patents and grew more quickly than those firms that did not collaborate with university scientists. Since the sample is selected from a set of firms that operate industrial research facilities, the estimates of the association between collaboration and patenting and growth are likely to be conservative estimates of the underlying relationship. Overall, the analyses provide valuable quantitative evidence regarding the antecedents and implications of university-industry collaboration in the U.S. pharmaceutical industry during the first half of the twentieth century.

The Emergence of American Universities and Pharmaceutical Firms prior to 1920

Although a number of notable American universities, including Harvard, Yale, and the University of Pennsylvania, were founded prior to 1750, the United States' system of higher education was substantially underdeveloped in comparison to those of the industrializing nations of Europe. One factor in this slow development was the relative lack of government involvement in education.[8] While federal and state ministries played a significant role in the organization, certification, and budgeting in countries such as England and France, colleges in the United States grew without a national ministry of education and without a standardized model or structure.[9] With responsibility for secondary and post-secondary education residing at the state and local levels, American institutions of higher education evolved into diverse forms, based on a variety of conceptions of education.[10] Contrary as well to the European model, secondary and post-secondary education in the United States followed an egalitarian model; this led to a larger pool of students eligible for college but a smaller number of students trained at elite high schools. An early disadvantage of this system of relatively small and highly varied institutions is that few colleges achieved the necessary economies of scale and scope required for research leadership. In *The American Commonwealth*, James Bryce's classic 1888 volume of observations on American institutions and people, he comments that while the United States offers more than four hundred degree-granting institutions, only a very small number "answer to the modern conception of a university."[11] Indeed, the nation's first Ph.D.s were not granted until 1861 (at Yale) and no U.S. universities emulated the highly successful German model until Johns Hopkins, founded in 1876.

The emergence of American research universities was accelerated in the period following the Civil War. The Morrill Act of 1862, Hatch Act of 1887, and Second Morrill Act of 1890 expanded the scale of many universities, provided additional sources of funds, and created a set of institutions with an explicit emphasis on utility-oriented practical education, which helped focus resources on such activities as improving agriculture and mechanical arts in addition to teaching humanities, as did many older universities. Throughout the 1800s, however, undergraduate education remained the primary area of emphasis for American universities. Indeed, even as late as 1890, fewer than 3 percent of students in American colleges and universities were enrolled in graduate programs.[12] Although this was hardly a condition in which leading-edge scientific research could thrive, the investments and policy choices of the post-Civil War era did set the stage for the significant evolution of the US university system that followed.

Beginning in the 1890s, American universities were transformed in three fundamental ways that would set the stage for their becoming viable sources of research in the period between the two World Wars. Goldin and Katz (1998) highlight three fundamental changes: First, the size of universities increased; second, the scope of universities broadened to include a wider array of departments and professional schools; third, states began to provide financial support to universities after 1890, after most had neglected to do so in prior decades.

These changes and the related "academic boom of the 1890s"[13] coincided with increasing progress in science and technology and with increased specialization in scientific disciplines. Each of these developments increased the overall value of university products for industry. The demand for labor with specialized skills rose with industrial technical sophistication, and both the demand for and value of academic research to industry rose as well.[14] The associated rise in the number of faculty positions helped attract increasing numbers of researchers and students trained at elite European (often German) institutions,[15] often to Philadelphia, New York, and the region in between.[16] A number of research-oriented universities, including Clark (1887), Chicago (1890), and Stanford (1891) were founded during this period. To support research efforts, university presidents often turned to wealthy industrialists and to industry directly.[17]

The combined impact of these changes was significant and, indeed, transformational among American institutions of higher education. Thus, by the turn of the century, American universities had achieved significant growth and considerable specialization. In addition, a substantial number of institutions combined the generation of knowledge (via research) with the dissemination of knowledge (via teaching). Indeed, by the 1910s, economic historians and historians of education argue that the institutional form of American higher education had emerged.[18]

A review of the nineteenth century U.S. pharmaceutical industry provides a little hint that member firms would ally with academic researchers in the pursuit of efficacious medicines. The industry consisted principally of patent medicine makers, who distributed alcohol- or narcotic-based products of dubious medicinal value, and regional manufacturers, who prepared tinctures, ointments, and consumable chemicals based largely on centuries-old recipes.

Patent medicine-makers were generally fanciful entities that manufactured and distributed patent medicines. Few of these firms were transformed by the coming scientific revolutions into research-driven pharmaceutical firms. These firms are, however, significant in U.S. economic history for their colorful marketing, aggressive claims, significant investments in branding and creative branding strategies, and use of print media for advertising.[19] Few of these firms' products were of long-term therapeutic aid to consumers. Often, these products' active ingredients included opiates, cocaine, or alcohol; many were demonstrably dangerous.[20]

The decline of patent medicine makers and the rise of ethical pharmaceutical concerns began in the latter decades of the nineteenth century. Although numerous drivers contributed to the evolution of the industry, one of the most notable was the increased value of medical and scientific knowledge. Such knowledge was both in substantially greater demand and greater supply in the United States towards the turn of the century. Rapid population growth in urban environments led to ever greater dangers from bacteriological illnesses that flourish among populations living in close quarters. In order to help thwart the threats posed by contagious illnesses, including cholera, diphtheria, dysentery, and yellow fever, public health services in major American cities undertook substantial efforts at sanitary reform and made considerable investments at developing cures for bacteria-based diseases. For example, the public health services of New York City and Philadelphia, each of which had accumulated substantial experience (mostly failed) in dealing with public health crises in the 1800s, played leadership roles in developing diphtheria antitoxin.[21] At the same time that the characteristics of American cities increased the demand for medical knowledge, scientific breakthroughs (principally in Europe) vastly increased the supply of scientific knowledge of value to the pharmaceutical industry. For example, Koch's and Pasteur's work in the 1860s and 1870s substantiating the role of microorganisms in causing diseases (the "germ theory of disease") may be the single most crucial contribution of biological sciences to human health; further, the advances of Jenner and Pasteur in vaccination and immunology, as well as concomitant discoveries in organic chemistry and drug synthesis, played a foundational role in providing and demonstrating the value of medical knowledge for pharmaceutical preparations.[22]

In addition to these influences, government intervention and geopolitical circumstances also helped prime American pharmaceutical firms for collaboration with academic researchers. Key legislative actions, the Biologics Control Act of 1902 and Pure Food and Drug Act of 1906 (and 1912 Shirley Amendment), pushed the U.S. pharmaceutical industry away from the hucksterism of patent medicines toward more rationalized practices by providing the U.S. federal government with initial responsibilities for and power to regulate the industry. The Federal Food, Drug, and Cosmetic Act of 1938 expanded the government's dominion over the industry by requiring that all new drugs receive approval by the Food and Drug Administration (FDA) as a condition for market introduction. The shortage of imported medicines induced by the outbreak of World War I also played a significant role in driving U.S. pharmaceutical firms toward involvement with universities, as university scientists often possessed knowledge of preparation and manufacturing techniques that American firms had not yet developed. In addition, the value of collaborating with universities was enhanced both by the immigration of leading European scientists and by the seizure and auction of German intellectual property by the Office of the Alien Property Custodian.

Early Collaborations between Pharmaceutical Firms and University Scientists

The rise of American universities and the birth of an indigenous pharmaceutical industry with access to European and local medical knowledge helped sow the seeds for university-industry collaboration. The majority of these collaborations were negotiated between specific faculty members and growing firms and the early history of such collaborative efforts demonstrates the importance of local access to knowledge and the limitations of collaborating across distances. Furman and MacGarvie discuss a number of cases in which early pharmaceutical labs chose to collaborate with prominent nearby scientists. One example of this is Merck's collaboration with Alfred Newton Richards of the University of Pennsylvania. According to Swann, "The University of Pennsylvania was a logical site for Merck to establish connections for biomedical research and clinical investigations of its drugs…[as it]…was a major research institution with access to extensive clinical facilities…located not far from Rahway; and…[with]…close contact with one of the faculty whom the university community esteemed - Newton Richards." [23] Larger firms with larger research and development budgets were more likely to work with distant consultants than were smaller and younger firms. This appears to have afforded an early advantage to firms in the Philadelphia-New Jersey-New York corridor, as a result of the substantial resources available. This was particularly true for the Philadelphia area, which was the location of some of the most advanced biomedical research institutions in North America and was therefore described as the "Cradle of Pharmacy."[24] Galambos, L. with J. E. Sewell describes the case of H.K. Mulford, a predecessor of the modern Merck and a firm that benefited greatly from collaborations in its Philadelphia environment.[25] Founded by graduates of the Philadelphia College of Pharmacy, the firm developed relationships with and hired personnel from the University of Pennsylvania's Medical Department, the Philadelphia Polyclinic, and the Laboratory for Hygiene at the University of Pennsylvania, which were instrumental in its becoming the first private concern to develop and introduce a diphtheria antitoxin.

The evidence on early collaborations suggests that geographic propinquity was most important for smaller firms, firms whose research efforts were more nascent, and firms engaging in informal or occasional collaboration on general scientific matters. Interestingly, large-scale research projects requiring specialized scientific knowledge appear to function effectively across distances. Eli Lilly constitutes an interesting example. Eli Lilly had established general consulting relationships with researchers at four nearby universities by 1943, but more distant universities (like the University of Rochester and the University of Toronto), were, however, involved in the firm's large-scale collaborative projects, including the ground-breaking research on insulin at the University of Toronto.[26]

Sources of Quantitative Evidence on the Drivers and Consequences of University-Industry Collaboration

In order to investigate the drivers and consequences of early university-industry collaboration in the U.S. pharmaceutical industry, the paper employs data based primarily on information available in the publication, *Industrial Research Laboratories of the United States.* These volumes, published by the National Research Council, were compiled from intermittently administered national surveys of firms operating in technology- and science-oriented segments of the economy. The dataset incorporates all firms classified in the sector identified as "pharmaceutical/chemical" and includes data about their characteristics from the editions published in 1927, 1938, and 1946.[27] 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, research publications issued by the company, and their partners in collaborative research.

These data enable one to compile a picture of firms engaged in industrial research activities and to investigate the correlates of collaboration among those firms. It is, however, important to recognize that these data are limited, especially since they do not reflect the universe of all firms engaged in industrial research. Considering that the sample is self-selected from the set of firms that conduct industrial research, it seems reasonable to believe that the firms that respond to the NRC studies are among those most committed to in-house research activities. As a consequence, the paper's conclusions are likely to be conservative, in the sense that in-sample firms that do not collaborate with universities are probably more committed to industrial research than the remainder of firms in the population that did not respond to the NRC surveys.

To supplement the NRC data, information on the location of universities and their academic output during the 1920s, 1930s, and 1940s is provided. Although the data do not enable precisely measurement of the extent of academic science produced by all US universities in the first half of the twentieth century, the paper is able to employ a proxy measure for overall academic output: the number of Ph.D. graduates. These data appear in the *Bulletin of the Office of Higher Education (Biennial of Education)* and the American Council on Education's serial publication *American Universities and Colleges*).[28] As institutions that devote greater faculty resources to conducting academic research are more likely to have doctoral programs, institution-specific counts of Ph.D. graduates in science appear to be useful indicators of university scientific output.

Analyzing the Drivers and Implications of Collaborating with Universities

Table 1 lists a set of firms and their university collaborators based on information reported in the 1938 National Research Council (NRC) publication, *Industrial Research Laboratories of the United States.* The volume characterizes such collaborations as "grants to university labs for research projects in support of program of association."[29] Such grants could involve funding faculty research projects, consultant arrangements, or agreements to provide funding for university research fellows and graduate study. With few exceptions, nearly all pharmaceutical and chemical firms collaborating with academic scientists associate with a nearby university. Often, these collaborations involved distances of less than a few miles. For example, Baltimore's Hynson, Westcott, and Dunning (HWD) collaborated with Johns Hopkins University. This association turned out to be beneficial for HWD, enabling them to market and sell a merbromin, an antiseptic drug discovered by Johns Hopkins doctor Hugh Young.[30] New York City's Endo Products, whose product, Hydrin, was among the first FDA-approved antiobesity treatments,[31] affiliated with researchers at New York University. Other firms pursued within-state, though not within-city. For example, Terre Haute, Indiana's Commercial Solvents Corporation, which produced chemical products, such as synthetic methanol and acetone, as well as pharmaceutical products, including penicillin, worked with Purdue University, centered in West Lafayette, Indiana, just under 100 miles away.[32]

Table 1: Pharmaceutical/Chemical 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
Commercial 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 of 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.*

The examples above focus on firms that identified only one academic partner. Firms that associated with multiple partners, the majority of which are among the larger firms in the data, appear to be more likely to collaborate with universities from other states and other regions of the country. Nonetheless, nearly all of these maintained local collaborations, which were among their longest-lasting and deepest collaborative efforts. For example, Merck, which was based in Rahway, NJ and Philadelphia, PA, collaborated with the University of Pennsylvania, Princeton, Rutgers, and the Philadelphia College of Pharmacy, as well as NYU, Johns Hopkins University, Cornell, Tulane, and the University of California.

Table 2 conducts a more systematic analysis of the antecedents and implications of firm collaboration with universities. Table 2 also demonstrates differences between collaborating and non-collaborating firms in the pharmaceutical and chemical sectors in 1938 and 1946. Several interesting patterns emerge. First, among firms in the data (i.e., those that self-identified as conducting in-house R&D), a substantial fraction did engage in collaboration with universities during this period. Collaboration with universities was more common in the pharmaceutical sector than in chemicals, with 40.5 percent of pharmaceutical firms engaging in collaboration and only 24.5 percent of chemical firms participating.

Table 2: Firm size, patenting, growth, and collaboration with universities in 1938 and 1946, by industry segment

	Pharmaceuticals		Chemicals	
	Non-collaborators	Collaborators with universities	Non-collaborators	Collaborators with universities
Number of observations	138	94	166	54
Mean number of R&D workers	20.467	64.808	15.104	62.260
Mean number of patents	1.645	15.234	3.228	6.111
Mean patents per worker	0.046	0.129	0.164	0.126
Mean laboratory growth rate, 1938-46	-0.209	0.419	-0.183	0.180
T-statistic for difference in means of number of R&D workers:	-4.855***		-6.002***	
T-statistic for difference in means of number of patents:	-2.304**		-1.225	
T-statistic for difference in means of patents per worker:	-2.119**		0.417	
T-statistic for difference in means of T-test of laboratory growth:	-2.078**		-1.156	

Source: *Industrial Laboratories of the United States,* United States Patent and Trademark Office, and authors' calculations.
* significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level.

Collaborating firms in the sample differ from non-collaborators in size, patenting, output, and growth. Collaborator firms in both sectors employed significantly more R&D workers than those that did not. Pharmaceutical firms, which tended to have a larger total number of patents than chemical producers, also display a larger gap in terms of the number of patents when collaborators are compared with non-collaborators. Collaborating pharmaceutical firms achieved 15.2 patents on average, while those that did not obtained only 1.6 patents, and this difference is statistically significant at the 5 percent level. Chemical collaborators obtained more patents (6.1 versus 3.2); however, this difference is not statistically significant. Pharmaceutical companies collaborating with universities also achieved higher levels of research productivity, measured by patent output per R&D worker (0.129 patents per worker vs. 0.046 patents per worker, a difference that is statistically significant at the 5 percent level). Finally, the laboratories of collaborating pharmaceutical firms also grew significantly faster between 1938 and 1946 than those that did not.

These simple comparisons of means are of interest, but they do not account for the possibility that correlations between these variables may bias estimates of the impact of collaboration. However, a multivariate regression analysis contained in Furman and MacGarvie (2007b) examines the relationship between collaboration and patenting after controlling for variables such as the size of their R&D staff (a proxy for both firm size and R&D sophistication), firm age, and industry-wide changes over time. Consistent with historical evidence, the results suggest that those firms that cooperated with universities received larger number of patents than those that did not (after controlling for size and age). The results of an analysis of the growth of laboratories' R&D staff between 1938 and 1946 suggest that firms that engaged in collaborative research with universities in 1938 grew 60 percent faster than those that did not.

Economic and business historians have long recognized the importance of vibrant and complementary relationships between universities and industrial innovation in driving economic growth in the United States.[33] Further, since the passage of the Bayh-Dole Act in 1980, a wave of interest in university-industry relationships has emerged.[34] Nonetheless, substantially less research investigates the origins and implications of university-industry partnerships particularly with large scale data.[35] Historical research, including that of Liebenau, Parascandola, and Swann, provide detailed accounts of emerging relationships between academic researchers and private firms in the pharmaceutical industry during the first half of the Twentieth century. This paper builds on such research, discussing illustrative historical examples and bringing survey-based data to bear on questions associated with the drivers and consequences of university-firm collaborative efforts. The results provide evidence consistent with prior speculations that collaborations with universities were significant for the firms that participated. Even among a sample of research-active firms, those that collaborated with or supported academic work achieved greater patenting and growth than those that did not. It is important to note that available historical data do not enable us to draw causal conclusions from the analysis; nonetheless, these results seem illustrative of the factors affecting and resulting from university-industry collaboration during this period.

Collaborations between firms and academic scientists were integral elements that helped the U.S. pharmaceutical industry emerge from its relatively primitive state in the nineteenth century and evolve during the course of the twentieth century into one of the world's most innovative industries. More immediately, though, such collaborative efforts were essential in preparing U.S. pharmaceutical firms to develop and manufacture valuable new medicines, such as penicillin and antibiotics in the years during and following World War II. More generally, this paper's analyses clarify the transformative effect of academic science on American industry and respond to Rosenberg and Nelson's call to document and explain the early history of university-industry relationships in the United States.

NOTES

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1. The term "pill peddler," which refers derisively to pharmaceutical manufacturers, was popularized by the Sinclair Lewis novel *Arrowsmith,* in which academic scientists lament the choice of the fictional Max Gottlieb, a prominent researcher, to leave the academy to join a for-profit pharmaceutical concern: "How could old Max have gone over to that damned pill peddler?…Of all the people in the world! I wouldn't have believed it! Max Gottlieb falling for those crooks!" (Lewis, 1925, p. 52). This term appears regularly in research on pharmaceutical history, e.g., in the title of Liebenau's 1987 volume, *Pill Peddlers: Essays on the History of the Pharmaceutical Industry*.
2. Quoted in John P. Swann, *Academic Scientists and the Pharmaceutical Industry* (Baltimore: Johns Hopkins University Press, 1988), 90.
3. Jeffrey L. Furman and Megan MacGarvie, "Academic science and the birth of industrial research laboratories in the U.S. pharmaceutical industry," *Journal of Economic Behavior & Organization* 64, no. 4 (August 2007): 756-776.
4. David Mowery and Nathan Rosenberg, *Paths of Innovation: Technological Change in Twentieth-Century America* (Cambridge, UK: New York: Cambridge University Press, 1998); Johann Peter Murmann, *Knowledge and Competitive Advantage: The Coevolution of Firms, Technology, and National Institutions* (New York, NY: Cambridge University Press, 2003); and Johann Peter Murmann, "The coevolution of industries and academic disciplines," (working paper, 2003).
5. Claudia Goldin, and Lawrence F. Katz, "The Shaping of Higher Education: The Formative Years in the United States, 1890 to 1940," *Journal of Economic Perspectives* (Winter 1999): 37-62.
6. Jonathan Liebenau, "Industrial R&D in Pharmaceutical Firms in the Early Twentieth Century," *Business History* (1984): 330-346; Jonathan Liebenau, "Innovation in pharmaceuticals: industrial R&D in the early twentieth century," *Research Policy* (1985), 15; *Pill Peddlers: Essays on the History of the Pharmaceutical Industry,* ed. Jonathan Liebenau (Madison, WI: American Institute of the History of Pharmacy, 1990); John Parascandola, "Industrial Research Comes of Age: The American

Pharmaceutical Industry, 1920-1940," *Pharmacy in History* 27 (1985): 12-21; John Parascandola, "From germs to genes: trends in drug therapy, 1852-2002," *Pharmacy in History* 44 (2002): 3-11; John P. Swann, "Universities, Industry, and the Rise of Biomedical Collaboration in America," *Pill Peddlers: Essays on the History of the Pharmaceutical Industry,* ed. Jonathan Liebenau (Madison, WI: American Institute of the History of Pharmacy, 1990): 73-90; Maryann P. Feldman, "The Locational Dynamics of the US Biotech Industry: Knowledge Externalities and the Anchor Hypothesis," *Industry and Innovation* 10 (2003): 311 – 328; Maryann P. Feldman, and Pierre Desrochers, "Research universities and local economic development: Lessons from the history of the Johns Hopkins University," *Industry and Innovation* 10 (2003): 5-24; and Maryann P. Feldman. and Yda Schreuder, "Initial advantage: The origins of geographic concentration of the pharmaceutical industry in the Mid-Atlantic region," *Industrial and Corporate Change* 5 (1996): 839-862.

7. Jeffrey L. Furman and Megan MacGarvie, "Academic science and the birth of industrial research laboratories in the U.S. pharmaceutical industry," and Furman and MacGarvie, "Organizational innovation & academic collaboration: The role of universities in the emergence of U.S. pharmaceutical research laboratories" (working paper, 2007).
8. Hugh D Graham and Nancy Diamond, *The Rise of American Research Universities: Elites and Challengers in the Postwar Era* (Baltimore, MD: Johns Hopkins, 1997).
9. Contrary to the wishes of the first six Presidents of the United States, Congress refused to establish a national university, Graham and Diamond, *The Rise of American Research Universities,* 15.
10. Laurence Veysey, *The Emergence of the American University* (Chicago: University of Chicago Press, 1965).
11. Bryce (1888), quoted in Graham and Diamond, *The Rise of American Research Universities,* 10-11.
12. Robert L. Geiger, *To Advance Knowledge: The Growth of American Research Universities, 1900-1940* (New York, NY: Oxford University Press, 1986), 14-15.
13. Laurence Veysey, *The Emergence of the American University.*
14. Goldin and Katz, "The Shaping of Higher Education," also note that rising numbers of high school graduates played a particularly important role in driving higher education enrollments and the scale and scope of U.S. universities.
15. Robert L. Geiger, *To Advance Knowledge.*
16. Maryann P. Feldman. and Yda Schreuder, "Initial advantage: The origins of geographic concentration of the pharmaceutical industry in the Mid-Atlantic region," *Industrial and Corporate Change* 5 (1996): 839-862.
17. Robert L. Geiger, *To Advance Knowledge.*
18. Goldin and Katz, "The Shaping of Higher Education," 7.
19. James Harvey Young, "Patent Medicines: An Early Example of Competitive Marketing," *The Journal of Economic History* 20, no. 4 (December 1960): 648-656.
20. A number of these firms did prove successful, however, in adapting to the ethical pharmaceutical industry that evolved during the Twentieth century. One of the most famous of these is the firm Sterling, which began selling patent medicines throughout

West Virginia and western Pennsylvania.

21. Louis Galambos with Jane. E. Sewell, *Networks of Innovation: Vaccine Development at Merck, Sharp & Dohme, and Mulford, 1985-1995* (Cambridge, UK: Cambridge University Press, 1995).
22. John Parascandola, "From germs to genes: trends in drug therapy, 1852-2002," *Pharmacy in History* 44 (2002): 3-11.
23. John P. Swann, *Academic Scientist and the Pharmaceutical Industry: Cooperative Research in Twentieth Century America* (Baltimore, MD: Johns Hopkins University Press, 1988).
24. Thomas Mahoney, *The Merchants of Life* (New York, NY: Harper Brothers, 1959) and Feldman and Schreuder, "Initial advantage."
25. Louis Galambos with Jane. E. Sewell, *Networks of Innovation.*
26. Michael Bliss, *The Discovery of Insulin* (Chicago, IL: University of Chicago Press, 1982).
27. Other volumes published in the first half of the century include: 1920, 1927, 1931, 1933, 1938, 1940, 1946, and 1948.
28. We thank Claudia Goldin for making the *Biennial* data available.
29. National Research Council, *Industrial Research Laboratories of the United States* (Washington, D.C.: National Research Council, 1927-85).
30. Maryann P. Feldman, and Pierre Desrochers, "Research universities and local economic development: Lessons from the history of the Johns Hopkins University," *Industry and Innovation* 10, no. 1 (March 2003): 5-24.
31. Eric Colman, "Anorectics on trial: a half century of federal regulation of prescription appetite suppressants," *Annals of Internal Medicine* 143, no. 5 (September 2005): 380-385.
32. Commercial Solvents Corporation is perhaps most well-known for manufacturing acetone and butanol according to fermentation processes developed by and licensed from Chaim Weizmann.
33. Edwin Mansfield, "Academic research and industrial innovation," *Research Policy* 20 (1991): 1-12; Edwin Mansfield, "Academic research underlying industrial innovations: Sources, characteristics, and financing," *Review of Economics and Statistics* 7, no. 1 (February 1995): 55-65; Richard Nelson and Nathan Rosenberg, "American Universities and Technical Advance in Industry," *Research Policy*, 23 (1994): 323-348.; David Mowery and Nathan Rosenberg, *Paths of Innovation: Technological Change in Twentieth-Century America*; see also, Richard R. Nelson and Gavin Wright, "The Rise and Fall of American Technological Leadership," *Journal of Economic Literature* 30, no. 4 (December 1992): 1931-1964; Nathan Rosenberg, "America's University/Industry Interfaces, 1945-2000", unpublished manuscript, Stanford University, 2000; and David Mowery et al., *"Ivory Tower" and Industrial Innovation.*
34. See, e.g., Cohen, W. M., R. Florida, L. Randazzese, J. Walsh, "Industry and the academy: Uneasy partners in the cause of technological advance," *Challenges to Research Universities,* ed. Roger Noll (Washington, D.C.: The Brookings Institution, 1998); David Mowery and Bhaven Sampat, "The Bayh-Dole Act of 1980 and University–Industry Technology Transfer: A Model for Other OECD Governments?," *Journal of Technology Transfer* 30, no. 1-2 (January 2005): 115-127; and Jerry Thursby

and Marie Thursby, "Who is Selling the Ivory Tower? Sources of Growth in University Licensing," *Management Science* 48, no. 1 (January 2002): 90-104.

35. "It is striking that the present discussion [of university-industry collaboration] focuses so closely on the here and now [and that] there is very little examination of the roles traditionally played by American universities or how these roles have evolved…" Nelson and Rosenberg, (1994), 324.