Early Examples Of User-Based Industrial Research

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Economic theory has had *relatively* little to say about either innovation or, more specifically, user-based industrial research. When the subject has been explored, the goal has been to derive a satisfactory *general* theory of innovation or to achieve definitive empirical results, yet these models have yielded results viewed as not robust [27, pp. 644-60; 1, pp. 276-87]. This problem has been attributed to a failure of the profession to allocate sufficient intellectual resources to the problem [12, p. 223]. Reallocation of intellectual resources would seem to be a simple problem, one that might be easily corrected.[1] The problem is, however, a larger one.

Economists have generalized the microeconomics of innovation as a patent race--a race impeded by the costs of investment in R&D and by patent preemption and innovation adoption strategies, yet a race that attracts numbers of contestants seeking the expected rewards of enhanced profits [30, p. 390; 26, pp. 850-53]. Recently, inter-firm industrial research has become an increasingly popular topic, due to growing recognition of extensive use of such arrangements in Japan. Cooperative research is typically assumed to take the form of an industry-wide cooperative R&D consortium [3, pp. 70-71]. Benefits and costs can be identified. Benefits of research collaboration include more efficient use of complementary skills and assets and cost reduction for individual firms who choose to participate in joint R&D; costs include increased risk of collusion and reduced diversity in industry R&D portfolios [13, p. 542].

Results of this new work on cooperative research have been disappointing [8, p. 5]. The problem may be that the tools are inappropriate to the task at hand. Models that concentrate on adjustment to price signals exclude the possibility of organized interaction between producers and users

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[1]Economic studies of innovation have increased greatly in quantity, due in large part to increasing concern over the U.S.'s faltering technological leadership. See Richard R. Nelson and Gavin Wright, "The Rise and Fall of American Technological Leadership," *Journal of Economic Literature*, 30 (December 1992), pp. 1931-64 for a good historical perspective on the question and Giovanni Dosi et al., *Technical Change and Economic Theory* for more general discussions of the importance of technology in economics and critiques of treatment of the topic by the economics discipline.

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[17, p. 68]. Empirical studies also suggest the importance of users to the innovation process: for example, Daniel Hamberg observed that customers have been the "most frequent source of projects originating outside the research lab" [9, p. 183]. Eric Von Hippel found in another study that seventy-five percent of commercially successful industrial product innovations come in response to consumers' need rather than to a perceived "technological opportunity" [31, p. 213]. Bengt-Ake Lundvall also examined specific cases of innovation involving interaction between professional users and producers and found the users to be important to the success or failure of the innovative process in these cases. An alternative economic theory, or more precisely, alternative theories, of firms and innovation, using different 'tools,' are emerging, in which cooperative research is viewed to take many forms besides the industry-wide arrangements typically assumed.

Important elements of a user-producer relationship in innovation have also been highlighted. Lundvall has proposed careful examination of specific elements of user-based research--communication between buyer and seller as a *process of learning* and "technological interdependencies:" in drawing these hypotheses into a 'model' of user-producer innovation, Lundvall stresses that *qualitative information* about producer inputs, user needs, and the "environment of the firm" must be incorporated into the analysis [17, pp. 51-70; 18, pp. 349-352]. Using a framework that explicitly assumes innovation to be a *process*, Jorde and Teece also emphasize the usefulness to producers of feedback from users and suppliers [11, pp. 49-50].

Although much of the work on user-based research is recent, inter-firm and user-based research are not recent phenomena. Inter-firm research in fact existed in the pre-World War II U.S. Fleming's study of early twentieth century industrial research in the U.S. described several cooperative industrial research efforts, noting that manufacturers' and technical associations engaged in research work "for the common benefit of their members" [7, pp. 32-33]. Bartlett, Rae and Birr have noted that increased coordination of national economic activity in World War I was accompanied by cooperative industrial research through institutions such as the National Research Council [2, p. 35; 25, p. 265; 4, p. 199]. Lewis observed that after the war, trade associations and commercial labs continued to be used for cooperative research efforts [16, p. 630]. By 1940, there were various forms used for cooperative industrial research: larger-scale collaborative research under the auspices of technical societies and trade associations; smaller-scale inter-firm projects aimed at developing new products or processes; and cooperative efforts linking universities, government agencies, and private consulting laboratories [22, p. 5; 19, 85].

A striking illustration of the importance of user-based research can be found in the steel industry. The steel industry was dominated during the first two decades of this century by a dominant firm, U.S. Steel, and, as might be expected, this dominant firm was substantially able to coordinate industry practice. Under U. S. Steel's regime of price leadership, the steel industry was not very competitive and not characterized by a high level of industrial research. There was, however, considerable research into steel, conducted by prominent steel users--the Pennsylvania Railroad (or the Penn) and several automakers. These steel users launched various research efforts to improve steel--research efforts needed because these major users of steel decided that they were not receiving steel of adequate quality from steel producers. This user-based research was a significant factor in inducing some major innovations in steel in the early twentieth century.[2]

Let me briefly outline some causes and consequences of research into steel by steel users, beginning with the earliest steel innovator among these users, the Penn. The Penn was one of the leading railroad systems in the U.S. during the late nineteenth century, and was recognized both for innovating many organizational and operational techniques and for achieving high standards of quality service in many endeavors [5, pp. 151-54]. In its drive for quality, the Penn established an industrial research operation in 1875, recognizing that it could not rely on producers' reputations as sufficient guarantee of quality materials. Dr. Charles B. Dudley was hired in 1876 to head the chemical lab; as a trained chemist he established use of scientific analysis of materials rather than price as an indicator of product quality. The Penn quickly came to rely on scientific methods for securing reliable information concerning the quality of materials supplied to the railroad. This was a novel approach; at the time the industrial community--producers and users alike--had little scientific understanding of many materials. The Penn's research, therefore, was necessarily targeted at developing a body of consistent scientific knowledge about the properties of existing products and processes used by the railroad, rather than the new product and process development that we have come to associate with industrial research. The Penn labs worked to develop systematic scientific procedures for physical and chemical testing of a variety of materials used by the railroad--coal, oils, paints and steel--and to establish the requisite characteristics for these products.

Steel was a major area of research for the Penn, given the large amount of steel used in its cars and rails--"considered first not only on account of [its] commercial importance, but also from the fact that the use of inferior steel might endanger the lives of passengers and employees." Early efforts were devoted to analysis of such products as stay bolt iron, steel car axles, and steel rails. The Penn's efforts to improve steel rails were initiated in 1879 with a study that resulted in a decision that 'softer' steel rails would yield greater durability and considerable savings. Subsequently, it developed its first specification for steel rails, to be issued to steel rail producers, who were expected to alter their techniques to comply with this specification. The Penn's use of specifications thus became a systematic way of collecting and using its research knowledge.

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[2]Much of this present work draws heavily on [14], in which extensive citations from the Pennsylvania Railroad archives at the Hagley Museum and Library at Wilmington, Delaware, the *Proceedings of the American Society for Testing Materials*, and volumes of *The Iron Age* from 1900 to 1930, are used to detail the backward linkages in steel innovation between the railroad, the testing society and other engineering societies, and the steel industry in the early decades of the twentieth century. The reader is referred to that source for primary source documentation of the history recounted here.

And the Penn's established procedures for research and reputation for quality made its steel specifications the standard for some materials, notably steel rails. Its early research efforts were aimed at twin objectives--improving materials and reducing costs. The Penn gradually moved into research to examine new manufacturing techniques and to discover useful new materials and products--for example, an effort to find a cheaper alternative for india rubber springs yielded both a new steel from the supplier and a new product for the railroad. When the Penn constructed new lab facilities during the 1910s, it included a heat-treatment lab and a small manufacturing laboratory where "new products [were] manufactured . . . until such time as it is found advisable to purchase them from 'outside' manufacturers." The declared goal remained procurement of high quality materials and products at low cost; yet the Penn had clearly achieved a more historically significant goal: in the mid-1910s it was already "in the lead in dealing with the many and diversified technical problems continually arising."

A key aspect of the early research work of the Penn was its process of consulting with producers--in fact, this could be described as the crucial part of user-based innovation. Determining whether the technical details in their specifications could be met by producers was a key part of writing the specifications that the Penn began to issue in the 1870s. Once its labs had completed its studies, they codified the information in the form of a proposed specification and sent the specification to producers for comments before formal issuance. They enforced the use of formal specifications by returning materials to any producer who failed to meet specifications. By means of this process, the Penn solicited cooperation upfront from producers and enforced cooperation after the fact. Moreover, consultation with suppliers and use of specifications were important ways in which the Penn induced industrial research on the part of some producers--particularly because specifications, once issued in final form, served as the basis of contracts with producers.

Did Penn's example cause steel producers to become more innovative on their own? There are mixed successes to report. On the one hand, a few steel producers moved into industrial research by 1900, primarily to meet Penn specifications. Later, some producers began to work with the Penn to improve products. On the other hand, there was a real hindrance to steel innovation--the widespread ignorance in the steel industry about the science of metallurgy. Moreover, most steel producers by then had institutionalized Carnegie's 'hard driving' of the steel mills, a manufacturing practice geared more at producing large quantity rather than refining product quality, and a practice that came to be criticized by steel users as being responsible for defective steel. Thus the Penn's use of specifications and consultation with producers became important in establishing that the Penn would not accept defective steel, even in the early days of its own research efforts when it could not yet establish the underlying metallurgical causes for such defects.

The story of how user-based research into steel rails led to interaction between user and producer to produce better quality steel rails provides brief illustration of this. The Penn was one of the few railroads engaged in research into rail steel in the early twentieth century; and attested that its specifications produced the "best rails it can get for the money." Yet even in 1908 its specifications for steel rails left many crucial aspects of improving rail quality to the rail producer, for the Penn recognized "that it is merely a purchaser, not a manufacturer." As a result, early Penn rail specifications did not eliminate failures; and failed axles and rails threatened the railroad's reputation for safety. A pronounced increase in rail failures and wrecks after 1908, signalled the need to conduct research into different kinds of steel and to integrate research findings into specifications. In 1912 Penn president Samuel Rea established a special in-house committee on steel rails to look for ways to improve rail steel. The committee launched its first study to examine failed rails for evidence of manufacturing problems and to investigate actual manufacturing processes. The Penn concluded that faulty manufacturing processes were responsible for most rail failures; and recommended major improvements in every area of rail manufacture. However, the Penn did not completely modify its specifications to match its own recommendations; the railroad remained

> . . . hampered continually by the attitude of the steel manufacturers in opposing changes, because of greater cost and the necessity for considerable reconstruction of present mills.

During the 1910s, the Penn continued to compile evidence on steel manufacturing practices and rail failures, and concluded that failed rails resulted from careless mill practices and "great laxity in following the specifications." One solution was to make specifications more strict. Producers initially resisted; but during the 1910s, the Penn was able to work more closely with producers, using its specifications to enforce this cooperation--it began, for example, to require on-site testing of steel, access to manufacturers' rail mills, and even began to specify several manufacturing details. Although these additional conditions increased rail prices, they were viewed as cost-effective. Yet the Penn did not receive all desired concessions from producers and even softened some clauses because of threats of increased prices.

Merely increasing the number and rigor of tests and specifications would not be completely successful in obtaining better steel; thus the Penn initiated efforts to improve manufacturing methods, working directly with steel producers. Cooperative efforts with steel producers were not always easy to initiate: for example, a joint study into manufacturing causes for transverse fissures was proposed to Bethlehem Steel as the producer of a rail that had recently failed and caused a wreck; this suggestion was followed by a pecuniary threat: the Penn refused to order more rails unless they came to "some suitable arrangement on the subject."

Between 1915 and 1930 many cooperative investigations were launched into new rail steels and new rail manufacturing techniques, supported by both materials and technical assistance from steel producers. One major effort concerned heat-treatment. The Penn became interested in the heat-treatment process in the 1910s, viewed as the "next step in advance." Cambria and Pennsylvania Steel assisted the Penn during the mid-1910s in its studies of heat treatment; the Penn declared that it was "gratifying that these people are taking an active interest in this problem." Although commercial-scale heat treatment was a technical obstacle at the time, the promising results kept it in the Penn's research agenda. Experimentation slowed during the war; and for a time the Penn considered building its own heat treatment plant, working with Cambria on the design. However, due to the excessive costs of such a plant, the Penn postponed its plans and decided instead "to collaborate with one of the steel manufacturers, Bethlehem, for instance, rather than to go into the thing ourselves . . . the final cost of the experiment will be less to us."

The efforts of the Penn, as a major user of steel, were moderately successful in inducing some improvements in steel products. But the Penn eventually had to draw other railroads and other steel users into the effort to improve steel, because their individual efforts yielded only slow and uneven technological improvement in steel. Steel producers, for the most part, remained passive reactors to Penn suggestions. Early automakers had to take up the cause when they became major steel users.

As output of automobiles increased rapidly during the first three decades of the twentieth century, and as automakers shifted from wooden to steel auto bodies, a new and large group of steel users emerged; by 1927 automotive steel constituted thirty percent of total steel demand. Automakers initiated research into alloys and specialty steels for auto bodies, a fact observed by the industry trade journal, *Iron Age*:

> . . . the demands of the automotive interests for steels of high quality has [sic] given impetus to the alloy industry, ... In most of these developments, the initiative has been taken by the automobile interests, while the steelmakers acquiesced to their demands.

Initially, American steel producers ignored the market for specialty automotive steels--in 1903, only cold-rolled, low-carbon Bessemer steel was available for automobile components, a grade considered too unreliable by automakers for use in automobile bodies. Automakers began to experiment with alloy steels early on, but had to import steel to get the quality that they desired. To retain their domestic market, American steel producers would have to learn how to produce both longer, wider steel sheets required for automobile frames and stronger alloy steels for larger and faster automobiles.

Many automakers launched individual efforts to improve steel. Ford began to devise and use specifications for auto steel at an early date, demonstrating a "tendency . . . to buy material on finer lines than covered in the standard specifications," and went on to greater lengths to procure quality steel, integrating backward to steel production. It began in 1922 with a small experimental steel plant, complete with electric and open hearth furnaces and rolling mills, pledging "not [to confine] itself to any specific theories or methods, but [to] . . . follow leads which seem to have promise." By 1925 Ford was rolling steel from purchased steel ingots; it also experimented with electric and duplexing processes and it was well known in the steel industry that Ford eventually planned to produce all of its own steel.

Other automakers initiated research into steel and smaller-scale steel manufacturing. Dodge Brothers established a chemical lab in 1912 to analyze all raw materials and to test all output to guarantee the strength of materials used in its cars. Chrysler established a metallurgical lab to examine "the required quality of materials entering into the construction of car parts, by developing suitable production processes and determining materials standards." Studebaker established a similar lab. Chrysler and Studebaker also engaged in new product development. In one case at Studebaker a purchased alloy material "of the 'special secret composition' kind so often encountered in metallurgy" was found upon analysis to be no more than a "good grade of babbitt metal, although its cost was several cents a pound higher, the additional price probably being charged for the copyrighted name." Studebaker developed its own bearing material.

A few steel producers cooperated with automakers and captured specialty steel markets; Interstate Iron & Steel Company was especially active in working with automakers and proud of the results:

> . . . The automotive engineer today designs his parts with full confidence that the steel specified, when properly treated, will have the desired physical properties--i.e., will do the work intended. This is the result of years of experience and cooperation with the steel maker.

Newton Steel built a mill to roll automobile sheets exclusively. Michigan Steel constructed a automobile sheet plant in 1923 to produce automobile body, hood and fender sheets, and to treat special surfaces and auto body sheets for enameling. Wilson Foundry & Machine Company worked with automakers to "correlate all of the work, which results in more economical production, and much more harmonious operation of the plant." All four firms, however, were small steel producers, hoping to establish themselves in a specialty steel niche rather than compete with the major steel producers.

By 1929, in marked contrast to 1900, there were many new grades of auto steel. Over the intervening three decades, even *Iron Age* acknowledged that "the constantly improving art of steel making has permitted the production of finer automobiles at extremely low cost." Alloys were one of the real success stories emerging from interaction between automakers and steel producers. Early on, the greater expense of alloy steels hindered research by both steel producers and steel users. Steel producers, moreover, were skeptical about the claims of superior performance made about alloy steels, while automakers began to experiment with alloys due to their unique performance characteristics: by 1920, there were nine alloy steels in use in the automobile industry; and by the mid-1920s, alloys were widely recognized as having greater strength, ease of heat treatment, and general stability and uniformity. Thus, due to increased demand by users for a variety of quality steels, each possessing precise and reliable performance characteristics, alloys became an important and expanding part of the steel industry--playing "an indispensable role in industry."

And new markets for alloy steel were emerging. Even though the automobile industry had been the largest consumer of alloy steel through the mid-1920s, other industries also increased their consumption of alloy steels--e.g., locomotives, agricultural implements, mining equipment, and electrical equipment. By 1930 the aircraft industry became a large user of alloy steels. Several special-purpose alloys were developed by other steel users: AT&T developed an alloy of iron and nickel, Permalloy; Du Pont developed a corrosion-resistant alloy, Everdur; General Electric and Westinghouse conducted research into silicon and other alloy steel.

Yet even by the 1920s automakers remained somewhat dissatisfied with steel quality: as Reo Motor Corporation asserted in 1925, the "main problem, at least for the present, is one of obtaining greater uniformity from heat to heat, rather than attempting to produce new steels." Automakers continued to raise the same complaints about defective steel that rail users had raised: seams, dirty steel, warpage, and fractures.

Thus, for most of the six decades between 1870 and 1930, steel users were prominent in the field of industrial research into steel; while large steel producers, by contrast to large firms in other industries, were simply not prominent among the pioneers of American industrial research. Industrial research was not employed by steel producers as a competitive strategy to increase market share. Instead, various steel users worked to improve steel and to create new specialty steels. Steel producers responded by increasing their industrial research efforts; yet even with these increased efforts, the conventional wisdom, presented in the steel industry's own trade journal, *Iron Age*, was that steel users had induced most of this industrial research: the "increased activity on this subject was very largely due to the increasingly rigid specifications of buyers, particularly in the automobile trade." Two snapshots from its pages will illustrate.

A 1912 *Iron Age* survey of steel producers corroborated the fact that steel users were the major reason for improvements in steel. Two examples: United Steel Co. credited the automobile industry with prompting a general improvement in steel quality:

> The wonderful growth of the automobile industry in this country has probably had more to do with creating higher grade steel than any other factor.

And American Sheet & Tin Plate Co. acknowledged that the requirements for quality steel developed by steel users had induced their own research:

> To satisfactorily meet exacting requirements of these specialties the steel manufacturer has been obliged to spend large sums of money to provide the necessary means looking toward quality rather than quantity.

But problems with steel quality persisted for decades: in 1930 industrial research pioneer Arthur Little criticized steel-producers for continuing to permit steel users to take the initiative:

> Although the steel industry has long maintained a hundred or more metallurgical and control laboratories, it has for the most part depended for research upon such outside agencies as the Bureau of Mines, the Bureau of Standards, and the Iron Alloys Committee of the Engineering Foundation, and individual workers in the universities and technical schools.

In conclusion, too much of the current discussion of inter-firm research centers around speculations over whether research consortiums will degenerate into collusive arrangements. As yet, little has been said about user-producer relationships and the critical role of users in the innovative process. Yet it would appear that these examples of user-based research early in this nation's history indicate the importance of users to innovation; moreover these early efforts are quite similar to the research pools currently used by the much-lauded keiretsu in Japan. These early institutional structures for cooperative and user-based industrial research did not become the norm in this country [69]. Why not is an interesting question yet to be answered.

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