Laboratory of Economics and Management
Sant'Anna School of Advanced Studies
Piazza Martiri della Libertà, 33 - 56127 PISA (Italy)
Tel. +39-050-883-343 Fax +39-050-883-344
Email: lem@sssup.it Web Page: http://www.lem.sssup.it/

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Working Paper Series

Knowledge Sharing among Inventors: Some Historical Perspectives

James Bessen °
Alessandro Nuvolari *

° Boston University School of Law
* LEM-Scuola Superiore Sant'Anna, Pisa, Italy

2011/21 December 2011

KNOWLEDGE SHARING AMONG INVENTORS: SOME HISTORICAL PERSPECTIVES*

By

James Bessen
(Boston University School of Law)

Alessandro Nuvolari
(Sant'Anna School of Advanced Studies)

ABSTRACT:

This chapter documents instances from past centuries where inventors freely shared knowledge of their innovations with other inventors. It is widely believed that such knowledge sharing is largely a recent development, as in open source software. Our survey shows, instead, that innovators have long practiced "collective invention," including in such key technologies as steam engines, iron and steel production and textile machinery. Generally, innovators' behavior was substantially richer than the heroic portrayal often found in textbooks and museums. Knowledge sharing sometimes coexisted with patenting, at other times, not, suggesting the importance of public policy that accommodates knowledge sharing to foster cumulative innovation.

Key words: technological change, knowledge sharing, collective invention, patents

JEL codes: N70, O33, O34

* We would like to thank Bob Allen, Christine MacLeod, Peter Meyer, Petra Moser, Kevin O'Rourke, Maarten Prak, Stefan Thomke and Eric von Hippel for helpful comments and discussions. Alessandro Nuvolari gratefully acknowledges the Jemolo Fellowship Scheme and the hospitality of Nuffield College, Oxford whilst writing this chapter.

1. INTRODUCTION

During the 1980s innovation scholars became increasingly aware of the importance of knowledge sharing as a fundamental "source" of innovations. In one of the early studies of the phenomenon based on a large number of case studies of Irish, Spanish and Mexican firms, Allen et al. (1983) noted that, rather surprisingly, knowledge sharing of innovations was taking regularly place even among "apparent competitors." Subsequently, Eric von Hippel documented the existence of widespread and systematic knowledge sharing activities among competitors in a detailed case study of the US steel mini-mill industry, noting that plant managers routinely shared proprietary know-how with competing firms (von Hippel, 1987, see also Schrader 1991). This was important because it not only diffused new techniques, but it also facilitated further, cumulative improvements.

Yet von Hippel also recognized that this phenomenon might have deep historical roots, citing the historical study of Robert Allen (Allen, 1983). Allen, writing about the pig iron industry of Cleveland (UK) during 1850-1870, observed an instance of "free exchange of information about new techniques and plant designs among firms in an industry" (Allen, 1983, p. 2). This exchange of knowledge facilitated innovations that built cumulatively on previous advances. Allen called this behavior "collective invention."

Nevertheless, it is still widely believed that knowledge sharing is mainly a modern development, perhaps related to the drastic reduction of costs for exchanging information brought about by advances in information and communication technologies. For example, Henry Chesbrough (2003, p. 24) describes today's "Open Innovation" as a sharp break from the paradigm of the early twentieth century when R&D labs were largely self-sufficient, only occasionally receiving outside visitors, and when researchers would only occasionally venture out to visit universities or scientific expositions. Similarly, popular history books and museums often highlight the "heroic inventor" with little attention to cooperation between innovators in the past.

Interestingly enough, economic historian Joel Mokyr (2009), has recently pointed to the "industrial enlightenment" as a critical pre-condition for the emergence and consolidation of the industrial revolution in the late eighteenth century. Mokyr's concept of industrial enlightenment refers to a knowledge revolution that progressively gained momentum during the eighteenth century. Two key-features of this knowledge revolution were: i) a drastic reduction in the costs of accessing extant bodies of knowledge (thanks to the expanding publication of scientific and technical books and journals); ii), a concerted attempt to create "a public sphere" for the fruitful interaction between scientific researchers and practitioners confronted with technical problems. Clearly, Mokyr's "industrial enlightenment" emphasizes the historical significance of knowledge sharing activities and, in particular, the establishment of formal and informal exchanges of information between "natural philosophers" and "manufacturers". At the same time, however, Mokyr remains skeptical about the significance of knowledge sharing among inventors competing in the same industry, delivering this stark assessment:

> There are three reasonably well-documented cases of successful collective invention: the case documented by Allen (1983) of the Cleveland (UK) iron industry between 1850 and 1875, the case documented by MacLeod (1988, 112-113, 188) of the English clock and instrument makers; and the case documented by Nuvolari (2004) of the Cornish steam-engine after 1800. Examples of such cases are not many, and they required rather special circumstances that were not common, and collective invention in its more extreme form, to judge from its short lifespan, was vulnerable and ephemeral (Mokyr, 2008, p. 81)

In contrast, there is growing evidence of recent knowledge sharing that goes well beyond the steel mini-mills and open source software. Since the seminal papers by Allen (1983) and von Hippel (1987), knowledge sharing activities by competing firms have rapidly developed into one of the major themes of the innovation studies literature (see Penin, 2007 and Powell and Giannella, 2010 for useful surveys). Within this broad literature, an important stream of research has focused, in particular, on knowledge sharing by users (Harhoff, Henkel and von Hippel, 2003; von Hippel, 2005, Shah 2005).

If the nineteenth century saw little knowledge sharing, then it would be important to understand why innovation today seems so fundamentally different. On the other hand, perhaps the conventional assessment of nineteenth century knowledge sharing is not accurate. Perhaps knowledge sharing occurred more frequently and was more important than is generally recognized. Indeed, we are aware of numerous examples where the conventional assessment seems misleading. For example, textbooks, popular history books and museums typically attribute the rapid growth in the productivity of US wheat production to the invention of mechanical threshers, reapers, etc., by individual inventors such as Cyrus McCormick. However, recent scholars have found that this revolution in productivity would not have been possible without extensive biological innovation based on the sharing of knowledge and of seed varieties by farmers (Olmstead and Rhode 2008, Chapter 2).

In this chapter we take a second look at the historical evidence concerning knowledge sharing activities by competing agents during the eighteenth and nineteenth centuries. As we shall show, the historical record shows clearly that knowledge sharing and free revealing among inventors have been historically important sources of innovation. Although the evidence is not sufficient to judge whether knowledge sharing occurs more frequently today or not, the evidence shows that it was common in the past, notably in some critical technologies. Furthermore, there has long been a tension between the depth and scope of open knowledge sharing activities and the operation of patent systems.

In this regard, Henkel and von Hippel (2005) argue that one of the most important welfare gains stemming from user innovation is linked with greater propensity of users to openly share their innovations without claiming intellectual property rights. On this ground, von Hippel (2005) argues for a more comprehensive assessment of the welfare effects of intellectual property rights policies. The historical evidence on knowledge sharing raises the possibility that patent systems may not be the only factor driving innovation. Perhaps a careful reassessment of the historical role of knowledge sharing might be a first step toward understanding the relative importance of patents and of knowledge sharing institutions in different markets, for different types of technologies, and at different phases of the technology life cycle.

2. Knowledge sharing among inventors: some historical evidence

In his paper, Allen speculated that “under the conditions prevailing during the nineteenth century, [collective invention] was probably the most important source of inventions” (Allen, 1983, p. 21). Allen’s conjecture rests on the idea that, before the establishment of corporate R&D laboratories, in many industries inventive activities were carried out as a by-product of investment processes without resorting to patent protection. If so, we should expect that, during the nineteenth century, a significant number of inventions were not covered by patents.

Detailed quantitative assessments of the amount of inventive activity undertaken outside the coverage of patent protection remain inherently speculative. The appeal of patents for economists and economic historians largely stems from the opportunity to study systematically the full universe of patented inventions. By contrast, any sensible catalogue of the inventions that remained unpatented is likely to be fraught with omissions and related biases, or restricted in long-term comparisons. Moser's (2005, 2010) research probably provides the best quantitative snapshot of the volume of inventive activity undertaken outside the patent system in the mid-nineteenth century. Moser examined how many of the inventions put on display at the Crystal Palace exhibition of 1851 were patented. Only 11.1 percent of the 6,377 British inventions were patented.

One might be tempted to ascribe this remarkably low patent propensity to the high costs and cumbersome administrative procedures of the English patent system during the first half of the nineteenth century. However, Moser's findings are similar for the United States, where the patent system was characterized by a smooth application process and low patent fees: only 15.3 percent of 550 US exhibits were patented. Clearly, Moser's findings show that appropriating inventions by means of patents was not a major concern for many nineteenth century inventors. But can we also assume that the low level of patent propensity estimated by Moser was coupled by knowledge sharing among inventors as it assumed in the collective invention model? The answer is that we do not know yet. Much research still needs to be done. However, since the publication of Allen's paper, economic historians and historians of technology have been able to identify several other examples of knowledge sharing activities among inventors coupled with limited or no use of patent protection.

2.1 Knowledge sharing among inventors in the early modern period

Technical change in the early modern period was mostly the result of the accumulation of incremental innovations and improvements. In this historical phase, episodes of major innovations credited to specific individual inventors are rare (probably the case of Gutenberg and the printing press represents the most significant exception). Epstein has compared technological innovation in the early modern period to the invention and transmission of jokes. Jokes typically have no recognizable author and they are simply passed on by word of mouth (Epstein, 1998, p. 699). Interestingly enough, a certain degree of awareness of the "collective" nature of innovation is reflected in the common habit of using the names of localities as eponyms for specific innovations. For example, the use of eponyms such as the "Bolognese" silk-throwing machine or the "Dutch" loom, etc., suggest an appreciation that these inventions were the product of a community of inventors, rather than a single individual.[1] Another revealing example of this awareness is Denis Diderot's conceptualization of invention. Diderot, noting that inventions emerged from adaptations and recombinations of already existing techniques by communities of artisans and technicians, had no particular qualms in asserting that individual inventors should be denied exclusive rights on innovations (Hilaire-Perez, 2002).

This awareness of the collective nature of innovation processes and of the possible benefits arising from knowledge sharing is also revealed by guild regulations concerning the transmission of technological knowledge. Today, the resilience of guild systems after 1500 is frequently seen as an

[1] The convention of using the names of individual inventors names as eponyms for specific technologies is probably to be traced back to the second half of the eighteenth century and is a manifestation of the cultural shift leading to the "glorification" of the heroic inventor as a national benefactor described by MacLeod (2007). MacLeod (2007) describes the British case, but analogous shifts in the public perception of inventors took place in all western countries during the nineteenth century.

institutional obstacle to the development of new technologies (Mokyr, 1990, pp. 191, 258-60). Several scholars have recently challenged this view, especially Epstein who argues that, in a world of largely tacit technological knowledge, some features of the guild system, such as apprenticeship regulations, were an effective mean of transmitting and consolidating technical skills. Epstein contends that the overall contribution of the guild system to technological progress in early modern Europe was positive. In fact, the traditionally negative judgment of craft guilds appears to be based on a number of documented instances when guilds opposed introducing specific inventions. Epstein invites us to be extremely careful in drawing generalizations from these cases (Epstein, 1998; see also the essays collected in Epstein and Prak, 2008). In fact, guild regulations and practices, by emphasizing the "collective ownership" of skills and technical know-how, actively promoted the sharing of technical knowledge in a period when its transmission by other means such as printed texts was inherently limited (Epstein, 2004). Since guild inventions took the form of incremental improvements and refinements to current processes and products, they tended to be much less visible in the historical records (Epstein, 1998, p. 696).

One of the most important inventions emerging from the knowledge sharing activities taking place within the guild system is the fluyt. The fluyt was a successful design of sailing ship developed in the Netherlands during the sixteenth century. This ship would become the favorite cargo employed by the Dutch East India Company during the seventeenth century. In his detailed historical study of the Dutch shipcarpenters' guilds, Unger (1978, p. 80) found evidence of systematic knowledge sharing activities involving technological matters, progressively leading to the design of the fluyt, occurring during the several business and social meetings that guild members were required to attend.

The emphasis on the collective ownership of the "trade" knowledge could result in opposition to patents. Between 1688 and 1718, the London Clockmakers Company lobbied intensively for the repeal of specific patents related to their trades. Yet at the same time, a number of important innovations in clock and instrument making, such as improved versions of the thermometer and of the barometer, were successfully introduced (MacLeod, 1988, pp. 112-113; Turner, 2008). Perez has documented in detail the knowledge sharing practices among inventors in the highly successful Lyon silk industry. In Lyon, the manufacture of silk was organized by the powerful silk guild of the "Grande Fabrique". Intriguingly, Perez has termed these knowledge-sharing practices of the Lyonnaise guild system as "open technique" institutions, drawing an explicit parallel with Allen's "collective invention" (Perez, 2008, Foray and Hilaire-Perez, 2006). Notably, the "open technique" innovation system of Lyon was able to outcompete London in the production of silk. In London, the organization of inventive activities was based on the widespread use of secrecy and patents (Cotterau, 1997, pp. 139-143).

Karel Davids (2008, pp. 394-400) argues that free exchange of knowledge among inventors was also a common practice among millwrights in the Zaankstreet in the Netherlands, during the seventeenth and eighteenth centuries. Zankstreet millwrights normally refrained from applying for patents (Davids, 2008, p. 408). Hence, according to Davids, the Zankstreet district represented another clear-cut case of "collective invention". Again, this type of organization of inventive activities yielded high rates of technical progress. The Zaankstreet became one of the cutting-edge industrial districts in Europe and was the first place where wind power was adopted on a massive scale during this period.

2.2 Knowledge sharing among inventors during the Industrial Revolution

Knowledge sharing among inventors also played a role during the Industrial Revolution. The best documented case of collective invention during this period is the early development of the high pressure steam engine in the Cornish mining district (Nuvolari, 2004; Nuvolari and Verspagen, 2007). In Cornwall, steam engines were used to pump water out of copper and tin mines. Since coal in Cornwall was relatively expensive, the Cornish mining district had been one of the early adopters of Boulton and Watt engines that represented the best practice of the time in terms of fuel efficiency. Significantly, Watt patented his design for an engine with a separate steam condenser with a very broad specification. After Boulton and Watt's penetration in the Cornish market, several engineers began to develop further improvements, but were frustrated by Boulton and Watt's tight enforcement of Watt's patent (Nuvolari and Verspagen, 2007). The ultimate outcome was a period of stagnation in fuel efficiency.

In the wake of this disappointing experience, Cornish steam engineers typically preferred not to patent their inventions after Watt's patent expired in 1800. Accordingly, the share of Cornish patents in steam engineering for the period 1813-1852 fell to under one per cent of the national total (Nuvolari, 2004, p. 358). Furthermore, in 1811, Cornish mining engineers and entrepreneurs launched a monthly publication containing detailed reports on the performance, technical details and operating procedures of the steam engines at work in the county. The explicit intention was twofold. First, the publication would permit the rapid identification and diffusion of best-practice techniques. Second, it would create a climate of competition and emulation in the Cornish engineering community with favorable effects on the rate of technical progress. Joel Lean, a highly respected mine "captain" was entrusted with the compilation of the reports and the publication was known as Lean's Engine Reporter. It is exactly after the publication of Lean's Engine Reporter that Cornwall attained the world technological leadership in steam engineering with the introduction of a particularly successful high-pressure condensing engine that would become known as the "Cornish" engine (Barton, 1969).[2] It can be shown that the systematic comparison of technical features, operational procedures and performance of the engines allowed engineers to identify the best design configuration, for example in terms of cylinder size, for attaining economies of fuel (Nuvolari and Verspagen, 2009).

Although not as systematic as in Cornwall, a similar ethos seems to have pervaded the nascent civil engineering profession, which was responsible for many of the innovations in transport. Very little of the problem-solving activity that underpinned the engineering of bridges, tunnels, cuttings, embankments, etc.—whether for roads, canals or railways—is reflected in the patent records. Rather, civil engineers tended to share and publish their solutions, with a view to enhancing their professional reputations (MacLeod, 1988, pp. 104-5).

In another recent contribution, Allen suggests that the organization of inventive activities by means of collective invention was also characteristic of other technologies developed during the Industrial Revolution (Allen, 2009). The first case he mentions is the development of coal-burning houses in London during the seventeenth century. Since most of the innovations in this field were unpatentable, builders copied and adapted innovations from each other (Allen, 2009, pp. 92-93). The second case he describes is the adoption of clover, sainfoin and turnips in crop rotations by

[2] Notably, even though specific inventions introduced in Cornwall can be ascribed to individual inventors (eg, the tubular boiler to Richard Trevithick, the compound engine design and the double beat valve to Arthur Woolf), the high pressure condensing engine would become known as the "Cornish" engine, giving credit to the whole community of engineers.

open field farmers (Allen, 2009, pp. 68-74). Furthermore, even inventions that originally were developed by individual inventors such as James Hargreaves' spinning jenny were improved and refined by means of collective invention processes. For example, the original spinning jenny had 12 spindles, but very soon a 24 spindles models were developed for use in cottages and models of 80 up to 120 spindles for use in workshops. According to Allen (2009b, p. 906): "[t]hese improvements in the jenny were accomplished without patents and were affected by collective invention."

Were these examples of knowledge sharing activities a response to the very imperfect English patent system of the time? To obtain an English patent, an inventor had to pay expensive fees and endure unwieldy administrative procedures. Perhaps if the English patent system were more like its American counterpart—with low fees and simple procedures—more English inventors would have chosen to appropriate returns using patents. This might have led to less knowledge sharing, but perhaps higher levels of private investment in the search for innovations. This interpretation would be consistent with the assessment of the US patent system put forward by Khan and Sokoloff (1998). According to Khan and Sokoloff (1998), the highly accessible US patent system was a key driver of technical change in the nineteenth American economy.

Yet, it would be wrong to assume that collective invention was just a British phenomenon. For example, in his account of the development of the high-pressure engine for the western steamboats in the United States during the early nineteenth century, Hunter emphasized the significance of various flows of incremental innovations (Hunter 1949: 121-80). In the light of the present discussion this passage is particularly intriguing:

> Though the men who developed the machinery of the western steamboat possessed much ingenuity and inventive skill, the record shows that they had little awareness of or use for the patent system. Of more than six hundreds patents relating to steam engines issued in this country down to 1847 only some forty were taken out in the names of men living in towns and cities of the western rivers. Few even of this small number had any practical significance. In view of the marked western preference for steam over water power and the extensive development of steam-engine manufacturing in the West, these are surprising figures. How is this meager showing to be explained and interpreted ? Does it reflect a distaste for patents as a species of monopoly uncongenial to the democratic ways of the West, an attitude sharpened by the attempts of Fulton and Evans to collect royalties from steamboatmen? Or, were western mechanics so accustomed to think in terms of mere utility that they failed to grasp the exploitative possibilities of the products of their ingenuity ? Or, did mechanical innovation in this field proceed by such small increments as to present few points which could readily be seized upon by a potential patentee ? Perhaps each of these suggestions – and especially the last - holds a measure of the truth. At all events the fact remains that, so far as can be determined, no significant part of the engine, propelling mechanism, or boilers during the period of the steamboat's development to maturity was claimed and patented as a distinctive and original development (Hunter, 1949, pp. 175-176).

Interestingly, Hunter suggests that the litigation of the patents taken by Robert Fulton and Oliver Evans may account for the negative attitude of western mechanics towards patents (Hunter, 1949: 10, 124-6). At the same time, Hunter is able to document the emergence among western steamboatmen and mechanics of a number of rules of thumb in steam boat design and operating practices that were continuously refined and improved by means of information exchanges (Hunter, 1949, pp. 176-180). This steady accumulation of many minor changes and alterations to the design of the steamers produced improvements in carrying capacity, increases of speed, reduction of cargo collection times, etc., leading to a rate of productivity growth without parallel in the transport technology of the period (Mak and Walton, 1972).

In the United States, knowledge sharing was also important in the development of the critical cotton textile industry, one of the harbingers of industrialization. In 1814, Francis Cabot Lowell built the first commercially successful power loom in North America with the help of mechanic Paul Moody. Lowell patented this loom and his company sold patent rights and also manufactured patent looms. But Lowell's company made most of its money from producing its own cloth with this technology and they discontinued patent licensing and sales after a few years (Gibb 1950).[3] In 1817, William Gilmour built the second commercially successful power loom in the US with the assistance of David Wilkinson.[4] The design of this loom was more or less freely shared: Wilkinson paid ten dollars for Gilmour's drawings. Gilmour, Wilkinson, and mechanics trained by Wilkinson engaged in the business of building looms under contract to prospective cotton manufacturers (Bagnall 1893). The rapid diffusion of the power loom owes much to the "liberal" policy of Gilmour and his sponsor, Daniel Lyman. Gilmour's design proved to be superior to Lowell's, replacing it even at the mills of Lowell's company (Gibb 1950). While patent protection was important for some weaving inventions during the Industrial Revolution, such as the loom temple, other key inventions, such as the weft fork, were not patented in the US.

Knowledge sharing practices have also been described in other classic historical studies of nineteenth century American industries. Judith McGaw's (1987) study of paper-making in Berkshire, Massachusetts during the nineteenth century documents that paper manufacturers engaged in extensive information exchanges concerning machinery to purchase and their possible adaptation to specific production tasks. In her interpretation, this knowledge sharing was key to the industrial success of the region. Similarly, Anthony F. B. Wallace found evidence of continuous free exchanges of information on the solution of technical problems among fellow mechanics and machine makers (Wallace, 1978, pp. 211-239).[5]

2.3 Knowledge sharing among inventors during the late nineteenth century

Evidence of knowledge sharing does not end with the Industrial Revolution. As noted above, Allen (1983) documented the importance of knowledge sharing for the British iron industry in the Cleveland district. Thanks to free exchange of information about new techniques and plant designs, "fruitful lines of technical advance were identified and pursued" (Allen, 1983, p. 2) leading to a high and sustained "rate of invention" in the industry. In 1854 Cleveland was producing 275 thousand tons of iron (about 9 per cent of British production). Less than twenty years later, in 1873, Cleveland's production had increased to 2 million tons, ie, 30 per cent of British production (Allen, 1981, p. 37). This increase in output was driven by a sustained stream of inventions that revolutionized blast furnace practice in the Cleveland iron district. Remarkably, throughout the period 1850-1870, Cleveland engineers claimed very few patents (Allen, 1983, p.2). By and large, this stream of inventions was the outcome of systematic knowledge sharing among engineers and designers of blast furnaces described by Allen. In the engineering literature of the 1860s and 1870s, the blast furnaces of Cleveland were recognized as the world leading technology (Allen, 1981). One

[3] By some rough estimates, profits from patent licenses and profits on equipment manufactured and sold by the Boston Manufacturing Company comprised only 6% of profits from 1817 to 1823 when these activities were discontinued (calculations available from the authors).
[4] Both of these loom designs were based significantly on English designs. Lowell visited English mills and Gilmour had been a mechanic at one. However, both inventors took over a year to get their models working and they had to develop complementary inventions as well.
[5] In the US case, knowledge sharing activities taking place in networks of mechanics and machine makers are also described by Thomson (2009). A particular interesting case described by Thomson is the knowledge sharing activities instigated by the US government in the production of firearms during the 1820s and 1830s (Thomson, 2009, pp. 54-59).

particularly intriguing contemporary assessment of the Cleveland iron district that was not noted by Allen in his original paper is the one provided by Eugène Schneider, one of the managing directors of the famous Le Creusot ironworks in France. Schneider, thought that the case of Cleveland clearly showed the advantages of organizational set-ups favoring knowledge sharing, rather than individual appropriation and protection:

> Certain localities have had very restrictive habits in their industries; that is habits of secrecy. In those localities, every one hides what is doing, or takes out a patent. The localities in which this spirit prevails very seldom advance with great speed. They remain almost always at a very low industrial level. The localities, on the other hand, which have a very liberal spirit in matters of invention and in matters of patents, advance very rapidly. The entire locality profits greatly by it, and everyone gets his share of the advantage…[O]ne of the most remarkable facts in the world is the immense progress which has been made by the locality of Middelsboro'…; 15 years ago, there was scarcely anything done there in the iron manufacture. At the present day it is the first district of the world for that manufacture, and I have found there is a most liberal spirit, everybody telling his neighbour, everybody telling any stranger who has had the honour of being admitted to those great manufacturers "This is what we do", "This is what succeeds with us", "This our invention". I have told you the result. (Schneider, 1871, p. 133).

Economic historians have pointed to other episodes of knowledge sharing among inventors occurring in the later nineteenth century besides Allen's case of the Cleveland blast furnaces. Kyriazidou and Pesendorfer (1999) suggest that collective invention also characterized the Viennese bentwood furniture industry since the 1850s. The industry was highly successful, establishing Viennese chairs as a fashion item throughout the world. At the same time, in the field of manufacturing processes, Viennese firms pioneered large scale production methods and interchangeable parts. According to Kyriaziodou and Pesendorfer, Viennese furniture firms engaged in continuous exchanges on information both on new production techniques and new product designs: "…firms were quick to copy the new products of their rivals, and even offered them under the same name in their catalogues. As a result, their chairs, which constituted the bulk of industry production, came to be known simply as 'Viennese chairs'" (Kyriazidou and Pesendorfer, 1999, p. 144). These knowledge exchanges reduced the cost of experimentation at the level of individual firms. Firms did take patents, but they did not enforce them against one another, but rather against foreign firms (Kyrazidou and Pesendorfer, 1999, p. 158). According to Kyriazidou and Pesendrofer the main factor accounting for this pattern of information exchanges was that the continuous innovation in manufacturing and product design fuelled rapid growth of industry output, limiting the emergence of possible competitive tensions.

Meyer (2003) documents extensive knowledge sharing in US Bessemer steel production. Henry Bessemer first patented his process in 1856, but extensive litigation with other inventors delayed the implementation of the method until the creation of a patent pool in the US in 1866. However, Bessemer's process did not work well at first and required substantial improvements. These were developed largely by engineering consultants such as Alexander Holley. Meyer documents how knowledge was shared through technical publications, by job mobility among engineers and by sharing patents and technical know-how among pool members. As a result, the cost of Bessemer steel rail fell from $100 per ton in 1870 to $60 per ton in 1880.

These knowledge-sharing activities were not limited to manufacturing. In a recent paper, Moser and Rhode (2011) describe the existence of widespread knowledge sharing in the community of American hobbyists rose breeders in the early 1900s. These knowledge exchanges were organized in the context of the American Rose Society and led to the creation of large number of new rose varieties. Plant varieties were not protected by patents in the US until 1930, for asexual propagation, and not until 1970 for sexually propagated varieties. More generally, Olmstead and Rhode (2008) have demonstrated highly dynamic biological innovation in nineteenth and early twentieth century US agriculture in wheat, cotton, tobacco, alfalfa, corn and livestock. Individual farmers developed many of the improvements and they freely shared their varieties and knowledge with others. With some crops, such as cotton, farmers organized into cooperatives to coordinate on the best local varieties. In later years, government assisted by gathering and diffusing knowledge of best practices. Although all this biological innovation is excluded from many accounts of nineteenth century innovation, it had very large benefits for social welfare.

Another interesting example of systematic knowledge sharing in the agricultural sector is the case of the Danish "control societies" formed by Danish farmers during the 1890s described by Faber (1931). This organizational arrangement for knowledge sharing bears a close resemblance with the Cornish case of *Lean's Engine Reporter.* Membership of the "control society" required the farmers to pay a fee. In exchange for this fee, members of the society would receive regular visits from a "control assistant" monitoring both the quantity and quality of the milk produced by each cow and the food she was fed. The data gathered in this way were then published in regular reports.[6] As a result, the breeding of cows witnessed major improvements, leading to a rapid increase of yields of cows, both in terms of milk production (lbs. of milk per cow) and of the quality of milk (increase in the fat content of milk).

Knowledge sharing among inventors was also practiced in developing countries that were trying to close their technology gaps and catch up with the world technological frontier. According to Saxonhouse (1974) and Otsuka, Ranis and Saxonhouse (1988), this was exactly the case of the Japanese cotton spinning industry. In Saxonhouse's view, this industry represented "the first completely successful instance of Asian assimilation of western manufacturing techniques" (Saxonhouse, 1974, p. 150). Over the period 1880-1900, the Japanese cotton industry was capable of successfully adopting ring spinning frames coupled with a number of other technical and organizational improvements. The exchange of information took place within the institutional framework of the All Japanese Cotton Spinners Association (Boren), and in particular of its monthly bulletin called Boren Geppo. The journal published detailed production and costs data at the plant level. These data permitted systematic comparison across plants and in this way they enhance the rapid diffusion of best practices. The journal also published systematic reports on innovations developed both in Japan and abroad (Saxonhouse, 1974, p. 160).

Finally, Peter Meyer's research has shown that knowledge sharing represented a critical ingredient for the invention of the airplane (Meyer, 2011). Throughout the period 1880-1910, a vibrant international community of inventors and scientists openly reported and discussed merits and limitations of different designs of flying machines in various books, publications and journals. Overall, few inventions for heavier-than-air flight were patented during this phase and the main line of progress consisted of inventions that were freely shared. This situation changed drastically when Wilbur and Orville Wright took their master patent for lateral control in 1906. The success of the Wrights' experiments marked a sharp turn in the history of the airplane. Lured by the prospect of commercial success, many inventors and entrepreneurs entered in this field. In contrast, with the behavior of their predecessors, these inventors aggressively patented and asserted their patent rights.

[6] The first control society in Denmark was the "Control Society of Vejen and District" created in 1895 (Faber, 1931, p. 113). Following this highly successful example, from the late 1890s, "control societies" were constituted across the entire country.

The case of the invention of the airplane shows a stark shift from knowledge sharing to a proprietary regime.

3. WHY SHARE KNOWLEDGE?

Both von Hippel (1987) and Allen (1983) argue that the knowledge sharing activities they document are fully consistent with rational individual economic behavior. Allen suggests two possible reasons for the disclosure of information in the Cleveland iron district. First, disclosure of information about a successful blast furnace design would have enhanced the reputations of the designing engineers and of the managers of the firm. This increase in reputation might have well offset any possible reduction in profits brought about by the information disclosure. In particular, reputational concerns might have been important for the engineers. Blast furnaces were typically designed by consulting engineers who moved from firm to firm (Allen, 1983, p. 17). Hence, the diffusion of information on the design and performance of different blast furnaces allowed the best engineers to signal their talents and to improve their career prospects. The second reason proposed by Allen is that the disclosure of information could increase the value of some of the assets owned by the revealing party. In the case of Cleveland, blast furnace firms typically also owned ore mines. Any improvement in the average performance of the blast furnaces was reflected in an increase of the value of the iron ore deposit, possibly making the free revealing of technical information also profitable from the point of view of the individual firm (Allen, 1983, p. 17). [7]

Von Hippel's interpretation of knowledge sharing activities is more general in scope (von Hippel, 1987). He focuses on the "competitive value" of the unit of knowledge that is revealed. When the competitive advantage offered by the unit of knowledge in question is limited, information disclosure will not result in a dangerous competitive backlash for the revealing unit. Furthermore, if the behavior is reciprocated this is likely to result in a generalized welfare gain for all firms participating in the knowledge exchange (von Hippel, 1987, p. 299). Vice versa, when the unit of knowledge in question offers an important competitive advantage vis-à-vis industry rivals, we should clearly expect firms refraining from disclosing behavior.

Von Hippel's rationale turns the focus of investigation toward understanding what market and technology conditions generate the "soft" rivalry that gives rise to knowledge sharing as well as what conditions give rise to aggressive rivalry and patenting. Bessen (2011) provides a partial answer, suggesting that under some common conditions, as technology matures the nature of firm rivalry, firms' willingness to share knowledge and their use of patents correspondingly change. In particular, knowledge sharing is more likely to occur during the early phases of technology or where local innovation has little effect on worldwide prices—factors that appear consistent with many of the examples discussed here.

Thus individually rational economic agents might well have good reason to share knowledge just as they might have good reason to patent. These choices, however, depend very much on the specific circumstances and they make clear that very simple theoretical models of patenting might not reflect the richness of actual innovative behav

[7] Allen (1983, p. 4) also argues that increases in furnace height or blast temperature, being relatively minor variations of existing practices, may not have been patentable. Hence, the actual choice for an inventor in Cleveland might have between secrecy and making the information publicly available (Allen, 1983, p. 6). In this respect, perhaps, there is an interesting difference between collective invention in Cleveland and in Cornish steam engines. In Cornwall, while variations is steam pressure and in cylinder sizes might have not been patentable, other, clearly patentable inventions such as the double-beat valve or the Cornish water-gauge (an instrument allowing a prompt monitoring of the level of water in the boiler), were not patented, but freely shared (Nuvolari, 2004, p. 359; Pole, 1844, p. 109).

4. CONCLUSION

These cases of knowledge sharing among inventors suggest a reappraisal of its role in history. Knowledge sharing among innovators in the past was not extremely rare nor was it a marginal activity. Although we have not established the full extent of collective invention, it is clear that key technologies at the heart of industrialization, such as high-pressure steam engines, iron and steel production techniques, steamboats, textile machinery, airplanes, etc., were, at times and places, developed through processes of collective invention.

While outstanding individuals also made important contributions in many of these technologies, those histories that focus exclusively on "heroic inventors" are misleading and incomplete. The story of Cyrus McCormick and his mechanical reaper might be a more compelling narrative than the stories of farmers, often nameless, who painstakingly developed and shared new varieties of wheat that could be cultivated on the Great Plains. Yet their innovations and knowledge sharing were no less important.

Furthermore, these examples make clear that patents are not universally important to innovation. Indeed, many of these technologies developed outside the purview of the patent system. In some cases, such as with aviation, aggressive patenting put an end to a period of extensive knowledge sharing. Yet in other cases, knowledge sharing and patents coexisted, such as the Bessemer patent pool or the early mechanics who would freely share patented inventions with other mechanics but not with manufacturers (Wallace 1978). In other cases, patents may nevertheless be crucial to encouraging innovation. The relationship between innovation, patents and knowledge sharing is a subtle and complex one. The optimal policy needs to apply to the full range of market conditions, technological maturity, etc., in order to encourage both knowledge sharing and proprietary incentives. An unbalanced policy might, for instance, provide strong patent incentives to incrementally improve mature technologies but it might also inhibit the development of early stage technologies, undermining important new technologies.

More generally, our examples of knowledge sharing suggest a greater continuity between innovation in the nineteenth century and today. Today's highly innovative open source software community and the user innovation communities identified by von Hippel and his associates (von Hippel 2005, Shah 2005) may have much in common with previous generations of innovators in the way they share knowledge. Moreover, the history of knowledge sharing may be a particularly good source for understanding a richer picture of the institutions and incentives that shape innovation then and now.

5. References

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