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Open source software development: Some historical perspectives**by Alessandro Nuvolari**

Abstract

In this paper we suggest that historical studies of technology can help us to account for some, perplexing (at least for traditional economic reasoning) features of open source software development. From a historical perspective, open source software seems to be a particular case of what Robert C. Allen has termed "collective invention." We explore the interpretive value of this historical parallel in detail, comparing open source software with two remarkable episodes of nineteenth century technical advances.

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Introduction

Open source software development has begun to attract the systematic attention of economists and social scientists alike. Two main reasons are at the heart of this upsurge of interest. The first is the growing importance of open source products in the software industry. A number of open source projects have been crowned with remarkable technical and economic success. Apache (a Web server), Linux (an operating system), Sendmail (an Internet mail

agent) are the most notable examples. The second reason is that some features of open source software development appear, at least at first sight, quite paradoxical to traditional economic reasoning. Lerner and Tirole (2001) identify four "key research questions" that need answers:

1. As a spontaneously provided "pure" public good, open source software should be prone to the free-rider problem; how can open source software projects encourage the active participation of talented developers who are not directly rewarded for their efforts?
2. Why do profit-motivated firms collaborate in open source projects? What type of economic return do they expect?
3. The most notable cases of open source are highly complex software products, involving an articulated division of labour and the solution of a series of stringent coordination problems. How have loosely coordinated networks of "hackers" [1] been able to manage effectively this complexity?
4. Finally, open source projects are based on an institutional arrangement (public license) in which the prerogatives descending from the creation of new useful knowledge are very different from those which are granted under traditional intellectual property rights regimes (patents, copyrights and trade secrets). What is the impact of this specific institutional arrangement on the rate of technological innovation? How does it perform compared with traditional schemes of intellectual property rights protection?

In this paper we suggest that nineteenth centuries experiences of technical change can provide some useful insights for the investigation of these issues. Historically, open source software seems to be another case of a particular type of innovation process that Robert Allen has termed as "collective invention" [2]. Within "collective invention" settings, rival firms (or independent individual developers) freely release one another *pertinent* information concerning the solution of non-trivial technical problems. Each firm, in turn, makes use of the this information to incrementally improve on a basic common technological layout. It seems worthwhile to dig deeper into this apparent historical parallel. We compare open source software development with two episodes of nineteenth century technical change. The first one is the case of the iron industry of Cleveland (U.K.) described in Allen's paper, while the second one is the case of the Cornish pumping engine. In this way, we hope to get a deeper understanding of the salient features of open source software and to provide a preliminary interpretative framework that can fruitfully guide further research.

The rest of the paper is organised as follows. The next section provides a short account of the historical evolution of open source software development. The third section, on the Cleveland blast furnaces, is devoted to a thorough re-examination of Allen's paper. This is necessary because some of the conceptual issues raised by Allen have been not fully appreciated in the subsequent literature. The next section describes the case of the Cornish pumping engine. This case is particularly interesting for our purposes because it originated from a harsh dispute over intellectual property rights that has striking resemblances with the conflict between the open source community and Microsoft. The final section summarizes and draws conclusions.

Open source software: A short interpretive history

Open source programs are simple completely accessible and "open" programs, distributed with their source code [3]. This feature makes it possible for sophisticated users to modify code and

introduce improvements or modifications to programs. In turn, these alterations are redistributed to a community of interested parties for use and further modification. As a consequence, open software projects tend to involve at times a fairly large number of developers, whose main "connecting agent" is constituted by the mere sharing of source code. The actual details of the distribution can vary with the specific license under which the programs are distributed.

The practice of sharing source code is not an entirely novel feature in the software industry. The first "intensive" users of mainframe computers were universities and corporate research laboratories. In that environment, computer programs were eminently seen as research tools, and it was seen as a normal practice to share code with other developers. Richard Stallman describes what was this practice at the MIT Artificial Intelligence laboratory in the early 1970s this way:

"Whenever people from another university or a company wanted to port and use a program, we gladly let them. If you saw someone using an unfamiliar and interesting program, you could always ask to see the source code, so that you could read it, change it, or cannibalize parts of it to make a new program." [4]

This practice of sharing programs among users generated a powerful drive towards the creation of so-called "portable" software — programs that could easily be ported to different computer platforms. A major step in this direction was the development of the Unix operating system (by Ken Thompson) and of the C programming language (by Dennis Ritchie) at Bell Labs in 1969. Unix could be run on a wide range of machines [5]. Additionally, Unix computers worked often together on networks. The creation of a community of interconnected Unix users stimulated further the habit of sharing programs [6].

This situation changed dramatically in the early 1980s. AT&T (not legally constrained by its role as a telephone company) began to sell licenses for Unix. Furthermore, concomitant advances in computer technology (the widespread diffusion of the personal computer and workstation) reinforced the drive towards the increased commercialization of software products [7]. Many talented programmers moved away from universities and research labs to private software firms, where they were bound by non-disclosure agreements. In the case of Unix, the proliferation of different commercial versions proved to be disastrous, leading to a "balkanisation" of users and progressive frustration in creating generalized cross-platform applications [8].

In reaction to these developments, in 1984 Richard Stallman founded the Free Software Foundation (FSF). The aim of the foundation was to recreate the "open" environment characteristic of computing in its early history. The first task chosen by the FSF was the production of a non-proprietary operating system in order to create an "open" environment, named GNU (which stands for "GNU is Not Unix").

In the late 1980s, Stallman and the FSF recreated a non-proprietary "GNU version" of many components of Unix. The programs were developed in such a way that they could run on almost every version of Unix. The development of GNU software was organized by means of a sort of "future tasks" list, which was used to stimulate FSF collaborators to work at the development of the missing parts of the GNU system [9].

The FSF project also included the creation of a Unix compatible kernel [10], called Hurd. The development of the kernel proved to be the most difficult stage of the GNU project. Stallman and his group seemed to be overwhelmed by the technical difficulties of the undertaking, so that the release of Hurd was repeatedly delayed.

In order to protect the GNU software from being turned into proprietary software, Stallman introduced a particular licensing procedure called General Public License (GPL, also known as "copyleft"). The GPL permits the free distribution, modification and redistribution of a modified

version of the programs it covers. The main characteristic feature is that modified versions of programs licensed under the GPL, must be also licensed under the same terms. This is also called the "viral" clause, because it "infects" all the code that is bundled together with GPL pieces of code.

In 1991 Linus Torvalds, then a computer science student at the University of Helsinki, announced, on an Internet newsgroup, that he was working on a free version of Unix and he asked for help in bug fixing. Torvalds also declared that he was willing to include in future versions, new features developed by others as long as they would have also been freely redistributable (Torvalds adopted the GPL–copyleft license scheme).

The initiative met an extraordinary success. In 1994, when Torvalds released Linux 1.0, the operating system could compete successfully in stability and reliability with commercial versions of Unix. An interesting feature of the distribution scheme adopted by Torvalds is that users could download either even-numbered releases which are relatively more stable and bug-fixed, or odd-numbered releases which incorporate the latest developments and for this reason have a more experimental nature. When the current odd-numbered version is sufficiently tested and bug-fixed, it is then distributed as the next even-numbered.

In the second half of the 1990s, Linux was further refined, incorporating a number of new features. The community of developers grew exponentially. The decisive "official recognition" of its potential came, perhaps, in 1999, when a Microsoft internal memorandum indicated that Linux (and, in more in general terms, the diffusion of the open source as a process of software production) was a major competitive threat for the company [11].

Eric S. Raymond (a programmer involved in several "open source" projects), made one of the first comprehensive appraisals of the "open source" phenomenon (Raymond, 1999). In his now famous paper entitled "The Cathedral and the Bazaar," Raymond examined problems arising from the management of large and complex software projects. He contrasted two archetypical modes of software development, identified as the "cathedral" and the "bazaar." In the "cathedral" mode, software is developed from a unified *a priori* project that prescribes all the functions and the features to be incorporated in the final product. Programmers' work is centrally coordinated and supervised in order to assure the integration of various components. Needless to say, this mode of development is characteristic of commercial software. In opposition to the "cathedral," there is the "bazaar" mode, where software emerges from an unstructured evolutionary process. Starting from a minimal code, groups of programmers add features and introduce modifications and patches to the code. There is no central allocation of different tasks; developers are free to develop a given program in directions they favour. This is, what seems to be, the Linux style of software development. Amazingly, the "bazaar" mode of software development seems, to work and to be able to produce effectively highly complex software products.

Open source projects are typically characterized by minimal coordination. Decentralized developers are completely free to introduce modifications or corrections to a given program. The "owner" of the project — the individual in "charge" of the project who releases successive "official" versions of the program — will check alterations and integrate the most valuable ones in future releases. Raymond, in his analysis, clarifies that this type of "bazaar" development is based on a necessary *precondition*:

"It is fairly clear that one cannot code from ground up in bazaar style. One can test, debug and improve in bazaar style, but it would be very hard to *originate* a project in bazaar mode ... Your nascent developer community needs to have something runnable and testable to play with. When you start community building, what you need to be able to present is a *plausible promise*. Your program doesn't have to work particularly well. It can be crude, buggy, incomplete and poorly documented. What it must not fail to do is (a) run, and (b) convince potential co-developers that it can be evolved in something really

neat in the foreseeable future." [12]

Raymond's "plausible promise" defines an essential feature of successful open source projects. Raymond points out that, although an open source project is always in a somewhat *fluid design state*, nevertheless it should define, possibly from the very outset, a solid architectural structure capable of sustaining streams of future decentralized developments [13].

In subsequent papers, Raymond addressed the incentive structure underpinning open source projects. It is useful to approach this problem by considering the nature of programming activity. Programming is creative problem-solving. This creative element introduces a sort of aesthetic dimension, so that one can speak of "elegant," "beautiful" or "innovative" solutions. For example, speaking about Linux, Linus Torvalds observed:

"Originally Linux was just something I had done and making it available was mostly a "look at what I've done — isn't this neat?" kind of thing. Hoping it would be useful to somebody, but certainly there is some element of "showing off" in there too." [14]

Hence, the value of a programming contribution can be "properly" appreciated only by other experts. In open source projects, individual contributions are acknowledged in a credit file. Thus, participants in open source projects are provided with appreciation from a large and competent audience. The desire for independent peer recognition, according to Raymond, represents one of the most important incentives for becoming involved in open source projects [15].

It is important to recognize that participants' belief that their contribution will be fairly appraised and, if deserving, taken into account in future releases is of the outmost importance for the success of a given project. This points to another necessary precondition for success: the legitimisation of the "owners" of the project. Participants must trust the capacity of the owners, not only in judging the merits and the limits of every contribution, but also in their ability to merge them (avoiding conflicts that might ultimately lead to "forking") in such a way to assure that the overall project will evolve in a coherent way.

The reward system, based on peer review, used in open source software projects seems to mimic quite closely procedures that are typical of scientific research (Willinsky, 2005). Dasgupta and David (1994) have argued that the fundamental difference between science and technology consists in the different institutional set-ups that "regulate" the production of knowledge in the two domains. Scientific research is governed by a reward system based on public disclosure of the findings and peer review, whereas the production of "technological" knowledge tends to have a distinctively proprietary character, being protected by patents or trade secrets (the rewards for the production of this type of knowledge typically derive from the "commercialisation" of research).

Interestingly, *in specific historical instances*, the production of technological knowledge appears to have been governed by sets of "open knowledge institutions," clearly akin to those of "open science." In this sense, open source software development can be seen as another case of collective invention. In the rest of this paper, we will explore this historical parallel in detail, trying to derive further insights into the interpretation of procedures for "open source" software development. However, it is important to note that although software creation is the result of a purely intellectual production process, it shares important similarities with other more "mundane" industrial engineering activities, in particular with those dealing with the production of "complex products." Complex capital goods, like complex software systems, are composed of a large number of interacting components. In these cases, the outcome of all the potential interactions cannot be fully predicted *ex ante*. Thus, a number of defects and limitations can be identified and "debugged" only after a more or less long phase of actual use of the product in question [16].

Collective invention: The Cleveland blast furnaces

According to Allen, in capitalist economies four main sources of invention can be discerned: (1) non-profit institutions such as universities and government-financed research centres, (2) R&D laboratories of private firms, (3) individual inventors, and, (4) collective invention settings. In collective invention settings, competing firms freely release each other information on the design and performance of technologies they have just introduced. Allen has noticed this pattern of behaviour in the iron industry of Cleveland (U.K.) during the mid-nineteenth century:

"...[I]f a firm constructed a new plant of novel design and that plant proved to have lower costs than other plants, these facts were made available to other firms in the industry and to potential entrants. The next firm constructing a new plant build on the experience of the first by introducing and extending the design change that had proved profitable. The operating characteristics of the second plant would then also be made available to potential investors. In this way fruitful lines of technical advance were identified and pursued." [17]

Information was normally released through both formal (presentations at meetings of engineering societies and publication of design details in technical journals) and informal channels. Additionally, this information was not protected by patents. As a consequence of this information sharing, Allen demonstrated that the height of furnaces and their blast temperature increased steadily by means of a series of small, but continuous, steps. Increases in furnace height and blast temperature resulted in lower fuel consumption and in reduced production costs [18].

We noted earlier in this paper that open source software development can be seen a case of "collective invention." Allen described the very restrictive set of conditions that allowed such a pattern of technical change to emerge [19]. Allen pointed to a combined effect of three essential factors.

The *first* factor relates to the nature of technological advance. In the period in question, there was no consolidated theoretical understanding of the working of the blast furnace. Thus, the performance of a new blast furnace was, to an important degree, uncertain. The best engineers could do was to derive design principles on the basis of previous experiences. In an analogous vein with odd and even Linux versions, iron industrialists could commission either a new "leading edge" blast furnace (*i.e.*, a taller furnace operating at higher temperatures) bearing the related risks of a more uncertain future performance, or an imitation of what was deemed to be best existing "safe" design, which was a less risky choice. Examples of both types of behaviour have been documented [20].

Secondly, Allen shows that a mechanism based on reputation, assuring the existence of a mutual individual incentive to disclose technical information to outsiders, was also at work in Cleveland. Blast furnaces were designed by independent consulting engineers who moved from firm to firm. The diffusion of technical information related to the design and performance of different blast furnaces allowed engineers to consolidate their reputation and improve future career prospects.

Thirdly, this disclosure of information did not prevent owners of blast furnaces from reaping economic benefits from their innovations (so that one does not need to invoke any relinquishment of profit-oriented behaviours in order to account for knowledge disclosure).

Iron industry entrepreneurs, in most cases, were also owners (or they had mining rights) of iron ore mines in the Cleveland district. Improvements in the efficiency of blast furnaces in the area enhanced the value of iron ore deposits located in the region [21]. As a result, there was more interest in improvements to the *average aggregate performance* of blast furnaces rather than in that of individual ones — only improvements in the average aggregate could actually influence the value of iron deposits. In economic terms, the receiver of the externality (information disclosure), by erecting a new well-performing blast furnace, in turn generated a new externality beneficial to the sender. This self-reinforcing process further stimulated propagation of information among iron producers.

This pattern of behaviour has also a clear counterpart in the case of open source, with the entrance of commercial companies in market segments that are *complementary* with open source software projects [22]. In this way, we see the emergence of an industry structure similar to Cleveland, where the returns from collective innovative activities are reaped via the development of complementary market segments. These segments in turn are positively affected by the rapid rate of innovation in the "knowledge sharing" sector. A variety of corporations have a concrete interest in fostering the continuous improvement of Linux [23]. Hence, these companies are effectively sponsoring new developments of Linux and other open source initiatives. The historical parallel, in this case, can explain why private companies operating in "complementary segments" are willing to release the results of their open source efforts.

The Cornish pumping engine

A particularly striking episode of nineteenth century technical change is the case of the Cornish pumping engine [24]. The Cornish pumping engine fits nicely in Allen's notion of collective invention. Since intellectual property rights issues are often raised in the ongoing discussion of the merits and limitations of open source software development and, as in the case of the Cornish pumping engine a debate on the merits of alternative intellectual property rights regimes featured prominently, it is probably useful to examine this historical episode in detail.

In the seventeenth and eighteenth centuries mining activities were severely hampered by flooding problems. Not surprisingly, some of the first attempts at employing steam power were aimed at finding a workable solution to mine drainage. In 1712, after a prolonged period of experimentation, Thomas Newcomen developed a steam pumping engine that could be used effectively for mines. Using steam at only atmospheric pressure, the Newcomen engine was well within the limits of the engineering capabilities of the time. Moreover, the Newcomen engine was robust, reliable and based on a quite simple working principle. As a consequence, once it was installed, it could work for a long period with almost negligible maintenance costs. Given these merits, it is not surprising that Newcomen types of engines soon were widely adopted in mining activities.

The Newcomen engine had a significant shortcoming of high fuel consumption, caused by alternatively heating and cooling the cylinder at every stroke. In coal mining, where large supplies of coal were available, high fuel consumption did not represent a major limitation, but in other mining operations fuel inefficiency limited the diffusion of the engine [25].

Since the early diffusion of the Newcomen engine, fuel consumption was considered as the main "metric" to be used in the evaluation of the overall performance of a steam engine. The most common measure of fuel efficiency was termed the "duty" and was calculated as the quantity of water (measured in lbs.) raised one foot high per bushel (84 lbs.) of coal

consumed. From an engineering viewpoint, the "duty" is a measure of the thermodynamic efficiency of the steam engine. However, "duty" also has an important economic meaning because it is a measure of the productivity of a steam engine with respect to the largest variable input used in the production process [26].

In 1769 James Watt conceived an alternative design of the steam engine — the introduction of a separate condenser — that allowed for a drastic reduction in coal consumption. The Newcomen engine, as improved by John Smeaton in the early 1770s, was capable of a duty between seven and 10 million lbs. Watt initially raised the duty to 18 million and later, when his new engine design was fully refined, to 26 million. Such an economy of fuel made profitable the use of the steam engine in mines situated where coal was expensive. In fact, the first important market for the engine developed by Watt was the Cornish copper and tin mining district. In Cornwall, coal had to be imported from Wales by sea and was extremely expensive. Between 1777 and 1801, Boulton and Watt erected 49 pumping engines in the mines of Cornwall. Jennifer Tann described the crucial role of "Cornish business" for the fortunes of the two partners in these terms:

"Whether the criterion is the number of engines, their size or the contribution to new capital, Cornish engines comprised a large proportion of Boulton & Watt's business during the late 1770s to mid 1780s. From 1777 to 1782, Cornish engines accounted for more than 40 percent of Boulton & Watt's total business and in some years the figure was significantly higher. In the early 1780s Cornish business was more fluctuating but with the exception of 1784, Cornish engines accounted for between 28 and 80 percent of Boulton & Watt's business." [27]

The typical agreement that Boulton & Watt stipulated with Cornish mine entrepreneurs (commonly termed "adventurers") was that the two partners would provide the drawings and supervise the construction of the engine. They would also supply some particularly important components of the engine, such as some of the valves. These expenditures would have been charged to the mine adventurer at cost (*i.e.*, no profit for Boulton & Watt). In addition, the mine adventurer had to buy other components of the engine not directly supplied by partners and build the engine house. These were all elements of the total fixed cost associated with the erection of a Boulton & Watt engine.

The profits for Boulton & Watt resulted from royalties they charged for the use of their engine. Watt's invention was protected by a 1769 patent for the separate condenser, which an Act of Parliament prolonged until 1800. The pricing policy of the partners was to charge an annual premium equal to one-third of the savings of fuel costs attained by the Watt engine in comparison to a Newcomen engine. This required a number of quite complicated calculations, aimed at identifying the *hypothetical* coal consumption of a Newcomen engine supplying the same power as the Watt engine installed in the mine.

In the beginning, this type of agreement was accepted on very favourable terms by mine adventurers. Eventually, the pricing policy of Boulton & Watt was perceived as extremely oppressive. Firstly, the winter months during which most water had to be pumped out (and, consequently, the highest premiums had to be paid) were also the least productive for the mines. Secondly, mine adventurers were informed about the size of their royalty payments to Boulton & Watt only after they had matured. Finally, in the late eighteenth century, several engineers in Cornwall had begun to work on further improvements to the steam engine, but their attempts were frustrated by Boulton & Watt's absolute refusal to license their invention. The most famous case in this respect was that of Jonathan Hornblower who had erected the first compound engine in 1781 and who found the further development of his invention obstructed by the actions of Boulton and Watt [28].

Watt's patent was very broad in scope (covering all engines making use of the separate condenser *and* all engines using steam as a "working substance"). In other words, the patent had a very large blocking power. The enforcement of almost absolute control on the evolution

of steam technology, using the wide scope of the patent, became a crucial component of Boulton and Watt's business strategy. This strategy was motivated by the peculiar position of the company, as consulting engineers decentralizing the major part of engine production. All in all, it seems quite clear that Watt's patent had a highly detrimental impact on the rate of innovation in steam technology (Kanefsky, 1978).

After considering to submit a petition to Parliament asking for a repeal of the extension of Watt's patent, in the 1790s Cornish adventurers decided to explicitly challenge its validity by installing a number of "pirate" engines erected by local engineers. A lengthy legal dispute followed. The dispute ended in 1799 with the courts confirming the legal validity of Watt's patent, a complete victory for Boulton & Watt. The dispute had far-reaching consequences. Boulton & Watt, with their legal victory (pursued with relentless determination), completely alienated any residual sympathy towards them in Cornwall. After the expiration of Watt's patent in 1800, steam engine orders to Boulton & Watt from Cornish mines ceased completely and the two partners had to call their agent in the county back to Birmingham.

Following the departure of Boulton & Watt, the maintenance and the improvement of Cornish pumping engines underwent a period of "slackness," as mine adventurers were content with financial relief coming from the cessation of royalties. This situation lasted until 1811, when a group of mine "captains" (mine managers) decided to start publishing a monthly journal reporting the salient technical characteristics, operating procedures and performance of each engine. The explicit intention was twofold. First the publication would permit the rapid diffusion of best-practice techniques. Secondly, it would create a climate of competition among the engineers entrusted with different pumping engines, with favourable effects on the rate of technical progress.

Joel Lean, a highly respected mine captain, was appointed as the first "engine reporter." The publication was called *Lean's Engine Reporter*. After Lean's death, the publication of the reports was continued by his son and lasted until 1904.

As Cardwell has aptly noticed:

"The publication of the monthly *Engine Reporter* seems to have been quite unprecedented, and in striking contrast to the furtive secrecy that had surrounded so many of the notable improvements to the steam engine. It was a co-operative endeavour to raise the standards of all engines everywhere by publishing the details of the performance of each one, so that that everybody could see which models were performing best and how much." [29]

Thus, the very publication of *Lean's Reporter* seems indeed to mark the transition from a proprietary technical knowledge regime to a new collective invention one.

Concomitant with the beginning of the publication of *Lean's Engine Reporter*, Richard Trevithick and Arthur Woolf began erecting high-pressure engines in Cornish mines. The layout of the engine designed in 1812 by Richard Trevithick at the Wheal Prosper mine soon became the basic one for Cornish pumping engines. Interestingly enough, Trevithick did not patent his high pressure engine:

"Trevithick only regarded this engine as a small model designed to demonstrate what high-pressure could do. He claimed no patent rights for it; others were free to copy it if they would." [30]

Following the publication of the engine reports, the thermodynamic efficiency of Cornish engines improved steadily. On strictly engineering grounds, this amounted to a very effective explorations of the merits of the use of high-pressure steam centred on the designs originally introduced by Trevithick and Woolf. Figure 1 displays the evolution over time of the efficiency

of Cornish steam engines.

Figure 1: Duty of Cornish engines.
Source: Nuvolari (2004).

Figure 1 clearly indicates that the practice of information sharing resulted in a marked acceleration in the rate of technical advance. As in the case of the Cleveland iron industry described by Allen, the rate of innovation in Cornish engines appears to be tightly linked with the rate of capital formation. Installation of new productive capacity permitted experimentation with design alterations facilitating the discovery of new improvements. Hence, the period of high duty growth coincided with the rapid expansion of the Cornish mining industry, conversely the phase of recession after the 1850s translated itself into a slow decline of average duty (Barton, 1968; 1969).

It is worth noticing that, although centred around the basic layout created by Trevithick, the design of Cornish pumping engines remained always in a fluid state. By "fluid" we mean that Cornish engineers, after Trevithick, did not stop exploring design modifications. This resulted in a more thorough exploration of technological opportunities [31].

Interestingly, in contemporary engineering literature, engines built on the basis of this design layout were not ascribed to this or that particular engineer, but simply known as "Cornish"

engines, correctly acknowledging the cooperative and cumulative character of this particular form of technological development.

The available evidence also suggests that the three conditions that Allen considers as crucial prerequisites for the emergence of a sustainable collective invention were amply satisfied in the Cornish mining district.

Firstly, analogous to the blast furnace case, the design of steam engine was a rather risky undertaking from an engineering point of view. Technology was far ahead of a scientific understanding of the factors effecting the overall performance of a pumping engine. Engineers could not rely on solid theoretical principles in designing a new steam engine. The best they could was to extrapolate from existing designs. As a result, the release of information greatly improved the exploration of technological opportunities.

Secondly, as in the case of Cleveland blast furnaces, Cornish pumping engines were commissioned on a one-off basis to independent consulting engineers. In this way, the very publication of the *Engine Reporter* acted as a "credit file" that steam engineers could use to signal their talents.

Finally, mine owners, had often shares in different mines and, for this reason, were more interested in improvements of the aggregate profitability of the district. The development of "local" technology, such as the Cornish engine, was one way of achieving this. Furthermore, as in Cleveland, improvement in the *average aggregate performance* of Cornish engines had the positive side effect of increasing the value of the Cornish ore deposits.

To sum up, the peculiar organisation of the Cornish mining industry made mine entrepreneurs interested in improvements in the *aggregate average performance* of pumping engines used and, at the same time, engineers in publicly signalling the *above average performance* of the engines they had erected. Thus, *Lean's Engine Reporter* successfully reconciled tensions between collaboration (among mine adventurers) and competition (among engineers) operating in the Cornish mining district.

Besides these factors, it is quite clear that the transition to a collective invention regime in Cornwall was also motivated by the disappointing experience during the Boulton & Watt monopoly period. After the beginning of the publication of *Lean's Engine Reporter*, Cornish engineers followed the example of Trevithick with his Wheal Prosper engine and preferred not to take out patents for their inventions. Table 1 reports the geographical distribution (measured using the stated addresses of the patentees) of patents in steam power technology over the period 1698–1852 [32].

Table 1: Geographical distribution of British steam engine patents, 1698–1852. Source: Nuvolari (2004).

* Cornwall including the patents taken by Arthur Woolf.

Location	Number of patents 1698–1852	Percent 1698– 1852	Number of Patents 1698–1812	Percent 1698– 1812	Number of Patents 1813–1852	Percent 1813– 1852
Cheshire	14	1.23	0	0	14	1.39
Cornwall	17	1.50	8	6.25	9	0.89
Cornwall*	21	1.85	12	9.38	9	0.89
Derbyshire	11	0.97	1	0.78	10	0.99
Durham	13	1.15	0	0	13	1.29

Essex	6	0.53	0	0	6	0.60
Gloucestershire	20	1.76	8	6.25	12	1.19
Hampshire	9	0.79	0	0	9	0.89
Kent	31	2.73	1	0.78	30	2.98
Lancashire	145	12.78	5	3.91	140	13.90
Middlesex and London	395	34.80	40	31.25	355	35.25
Northumberland	22	1.94	2	1.56	20	1.99
Nottinghamshire	13	1.15	1	0.78	12	1.19
Shropshire	6	0.53	3	2.34	3	0.30
Somerset	4	0.35	2	1.56	2	0.20
Staffordshire	27	2.38	5	3.91	22	2.18
Suffolk	5	0.44	0	0	5	0.50
Surrey	88	7.75	10	7.81	78	7.75
Warwickshire	58	5.11	8	6.25	50	4.97
Worcestershire	11	0.97	1	0.78	10	0.99
Yorkshire	63	5.55	11	8.59	52	5.16
Ireland	13	1.15	1	0.78	12	1.19
Scotland	47	4.14	6	4.69	41	4.07
Wales	12	1.06	1	0.78	11	1.09
France	21	1.85	0	0	21	2.09
United States	13	1.15	2	1.56	11	1.09
Other	71	6.26	12	9.38	59	5.86
Total	1,135	100	128	100	1,007	100

The London and Middlesex area hold a predominant position. In this respect the pattern of patenting in steam technology mirrors that for overall patenting outlined by Christine MacLeod [33]. It is likely that this high number can be explained both by the growth of the metropolis as a commercial and manufacturing centre and proximity to the patent office, which gave would-be patentees the possibility of following closely administrative procedures related to the granting of patents. Surrey also has a quite high concentration of steam patents. A number of engineering firms specializing in the production of capital goods may account for Surrey's patent concentration [34]. Other notable locations with high numbers of steam patents are Warwickshire, Lancashire and Yorkshire, where patents were probably related to the increasing use of steam power by local industries. One should take into account that patents were essentially an urban phenomenon [35] and so they were concentrated in urban areas such as Birmingham, Liverpool, Manchester and Leeds.

Over the entire period 1698–1852, the share of Cornwall in total patenting is 1.85 percent, which does not reflect the major contribution of the county to the development of steam power technology. Breaking down the period 1698–1852 into two sub-periods (1698–1812 and 1813–1852), in order to take into account the publication of *Lean's Engine Reporter* is even more revealing. In the first period, Cornwall [36] has the highest number of patents after the

London and Middlesex area, with a share of 9.38 percent. In the second period, the share of Cornwall drops to a negligible 0.89 percent; this is exactly the period during which the Cornish pumping engine was actually developed. In our view, this finding is indicative of the widely perceived awareness in the county of the benefits stemming from the adoption of a collective invention regime for the rate of innovation. After the unfortunate experience with the Boulton & Watt monopoly, it seems quite clear that in the Cornish engineering community, an *ethos* prescribing the full release of technical innovations into the public domain emerged and became progressively established.

The case of Arthur Woolf is particularly illustrative. Woolf was one of the leading figures in the Cornish engineering community (Harris, 1966). Born in Cornwall, he had an initial apprenticeship with steam engineering by working with Jonathan Hornblower. In the first decade of nineteenth century he moved to London, where he was entrusted with the steam engines of the Meux & Reid brewery. In this period Woolf took out four patents for innovations in steam engines, in particular for his famous compound engine patented in 1804. In 1812 he moved back to Cornwall, where he tried to commercialise his compound engine by means of an agreement similar to the one proposed by Boulton & Watt (royalties paid as a proportion of fuel savings). His initiative was unsuccessful. Most mine adventurers awaited the expiration of the patent in 1818 before installing this type of engine [37]. In 1823, Woolf invented a new valve for steam engines, the double-beat valve. The adoption of this type of valve greatly facilitated the operation of the engine [38]. He did not file for a patent for this invention.

Another example that confirms the negative attitude towards patents existing in the Cornish mining district is the limited diffusion of the two-cylinder compound engine patented by Cornish engineer, James Sims, in 1841. The first engine of this type erected at the Carn Brea mine performed particularly well in terms of duty (it was the second best engine in the *Reporter* in the early 1840s). However, being a patented design made the engine quite unpopular with other engineers and mine owners, who, in the end, preferred not to adopt it [39].

One can point to other Cornish inventions in steam technology which were not patented. The "Cornish water gauge," an instrument which allow a prompt check of the height of water in the boiler, invented by Richard Hosking in 1833, is a noteworthy case. In his *Treatise*, Pole describes it as "a very ingenious apparatus ... almost unknown out of the county" [40]. The invention was awarded a prize by the Royal Cornwall Polytechnic Society and a detailed description was published in the Society's *Reports*. In fact, since its foundation in 1833, the Royal Cornwall Polytechnic Society, a local learned society, awarded a yearly prize for "Inventions and Workmanship." A perusal of the yearly *Reports* of the Society reveals many inventions related to steam engineering. For the period 1833–1841, none were patented [41]. It is also interesting to note that leading mine entrepreneurs, such as John Taylor [42], tried to steer the direction of inventive efforts by instituting prizes for inventions aimed at specific purposes (such as water meters for boilers and stroke counters). Overall, it is hard to describe the technological significance of these inventions. Remarkably, William Pole found some of them worthy to deserve a description in his *Treatise*, which indicates that they probably were not of trifling importance [43].

Passages in contemporary engineering literature also indicate this consciousness. For example, John Taylor — a leading mine entrepreneur — wrote in 1830:

"Under such a system [the *Lean's Engine Reporter*] there is every kind of proof that the application of steam has been improved, so as to greatly economise fuel in Cornwall, and also the rate of improvement has been fairly expressed in the printed reports ... [A]s since the time of Boulton and Watt, no one who has improved our engines has reaped pecuniary reward, it is at least fair, that they should have credit of their skill and exertion. We [adventurers] are not the partisans of any individual engineer or engine maker; we avail ourselves of the assistance of many; and the great scale upon which we have to experiment

makes the result most interesting to us." [44]

Concluding remarks

In general terms, current conventional economic wisdom considers strong and broad intellectual property rights as a key stimulus to technical progress. Strong intellectual property rights are deemed to constitute an indispensable incentive for motivating an adequate level of private investment in the search for new technologies. At the same time, broad and well specified intellectual property rights should promote a relatively ordered exploration of the space of technological opportunities [45].

Evidence presented in this paper casts serious doubts on the general validity of these assumptions. In fact, in certain industries such as those examined in this paper where the dynamics of technological change display a cumulative and incremental character, the protection of "commons" of freely accessible knowledge is likely to yield much higher rates of innovation than the enforcement of strong intellectual property rights [46].

It is worth mentioning Hunter's account of the development of the high pressure engine for the western steamboats in the United States during the early nineteenth century. In this study, Hunter emphasized the significance of various flows of incremental innovations [47]. In the light of the present discussion this passage from Hunter's contribution 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 the steamboat's development to maturity was claimed and patented as a distinctive and original development." [48]

Another case that can be interpreted as a rather clear-cut episode of collective invention is Judith McGaw's (1987) study of the community of Berkshire paper manufacturers [49].

All these episodes seems to have been characterized by the emergence of particular institutional set-ups (which following Allen might be termed "collective invention regimes") ensuring that new technological knowledge remains in the public domain. In some instances, an additional feature of these institutional arrangements was the creation of a system for the

public acknowledgement of the merits of various individual contributions.

In this paper, we have merely assembled some suggestive evidence and put forward some interpretative hypotheses. In other words, the cases presented here point towards a very promising research agenda. The recent upsurge of interest in open source software can provide the stimulus for further research in this direction, leading us towards a deeper understanding of the emergence and consolidation of collective invention regimes and opening up the possibility of extending the open source mode of invention beyond software [50].

About the author

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Notes

1. In the programmers' community the term "hackers" is used to indicate those "who love to program and enjoy being clever about it" (Stallman, 1999, p. 53). The term "hackers" is very often used in the media to denote those who try to tamper with computer systems and programs. This use of the word, however, is completely unwarranted; see, for example, Vegh (2005).
2. See Allen (1983). The relevance of "collective invention" in the sense of Allen for understanding open source software has also been suggested by Cowan and Jonard (2003) and Foray (2004).
3. Source code is written in computer languages such as C++ and Pascal. Proprietary software producers typically distribute only the object code.
4. Stallman, 1999, p. 53. Cooperation in software development was also enhanced by the ARPAnet — a network connecting computers at universities, research labs and other defence contractors in 1969; see Raymond, 1999, p. 8.
5. On the early history of Unix see Salus (1994).
6. This was permitted by the development of a new feature of Unix — UUCP (Unix-to-Unix-

Copy) — which made it possible to exchange files and data.

7. On the evolution of the U.S. software industry in the 1980s, see Steinmueller, 1996, pp. 30–41. The growth of the software industry in the United States was also accompanied by a progressive strengthening of legal protection for software, until the upholding of patents for "pure" software products. See Merges (1996).
8. Raymond, 1999, p. 22.
9. Stallman, 1999, p. 62.
10. The kernel is the core part of the operating system that controls access to hardware.
11. The report is known as the "Halloween document;" see Valloppillil (1998). On the evolution of Linux in second half of the 1990s see Moody (2001).
12. Raymond, 1999, pp. 57–58 (*italics in original*).
13. Unix-type architecture is particularly suitable to "modularized" developments. Modularized developments are probably enhanced by the fact that the "common ethos" of open source communities tend explicitly to favor the submission of "neat" modifications or additions. See Moody, 2001, p. 14.
14. Torvalds, 1998.
15. Lerner and Tirole (2002) argue that open source projects act as a stage where programmers can signal their skills and enhance their future career perspectives. Raymond also notices that "occasionally the reputation one gains in the hacker culture can spill over into the real world in economically significant ways." However, this is rather sporadic so it would be wrong to regard it as the main motivational drive; Raymond, 1999, p. 97.
16. The similarity between software development and the construction and implementation of complex engineering products was also suggested by Rosenberg (1982, pp. 120–149). Also, Torrisi (1998, p. 42) emphasizes that some procedures of software production are close to those of mechanical engineering.
17. Allen, 1983, p. 2.
18. It is important to notice that Allen's notion of "collective invention" does not refer to the exchange of information between users and producers studied by Lundvall (1988). "Collective invention" also differs from the "know-how trading" described by von Hippel (1987). In "know-how trading," engineers "trade" proprietary know-how in the sense that information is exchanged on a bilateral basis (non-participants to the transaction in question are excluded). Within collective invention, all the competing firms of the industry have free access to the potentially proprietary know-how. See von Hippel, 1987, pp. 296–297.
19. Harhoff, *et al.* (2002) describe, using a game-theoretic approach, a number of contexts in which "free revealing of innovations" is economically rational.
20. Allen, 1983, p. 5.
21. Because of the chemical composition of iron ore and other factors, technical progress in Cleveland blast furnaces was location specific and other iron producing areas could not benefit from innovations introduced there; Allen, 1983, pp. 17–19.

22. On the possible commercial software reactions to open source projects see Lerner and Tirole (2002) and Raymond (1999), pp. 137–195.
23. Red Hat and other corporations have sold "tested" versions of Linux together with a variety of support services. The main source of revenues comes from the sale of services. On the business strategy of Red Hat, see Young (1999) and Raymond, 1999, pp. 165–166 and 183–188.
24. This section draws partially on Nuvolari (2004).
25. Von Tunzelmann, 1978, chapter 4.
26. Von Tunzelmann, 1970, pp. 78–79.
27. Tann, 1996, pp. 29–30.
28. Jenkins, 1931; Torrens, 1994. Boulton and Watt tried, through their agent in Cornwall Thomas Wilson, to discredit the performance of the Hornblower engine in advertisements published in local newspapers and in several pamphlets addressed to mine owners. This might be considered as a typical example of the FUD (fear, uncertainty and doubt) strategy so much chastised by Microsoft opponents. Boulton and Watt also applied successfully to Parliament for a rejection of Hornblower's request of extension of his patent; see Jenkins, 1931.
29. Cardwell, 1971, p. 156.
30. Rowe, 1953, p. 124.
31. On the technological history of the Cornish pumping engine, see Barton (1969). One might also note that this process of continuous design modification makes it difficult for technology historians to devise a clear technological definition of the Cornish steam engine.
32. See Andrew, *et al.* (2001) for a detailed quantitative analysis of the pattern of steam power patenting over the entire nineteenth century.
33. MacLeod, 1988, pp. 119–124.
34. MacLeod, 1988, p. 124.
35. MacLeod, 1988, p. 125.
36. Included in the count are patents taken out by Arthur Woolf; at the time, Woolf was working for the Meux & Reid brewery in London.
37. Farey, 1971, pp. 188–189.
38. Hills, 1989, pp. 109–110.
39. Barton, 1969, pp. 110–112.
40. Pole, 1844, p. 109.
41. We used Woodcroft (1854) to check that inventions which were awarded a Royal Cornwall Polytechnic Society prize over the period 1833–1841 were not patented.

42. For an account of Taylor's life and business and engineering activities, see Burt (1977).
43. See, Pole, 1844, p. 122.
44. Taylor quoted in Farey, 1971, pp. 251–252.
45. See Mazzoleni and Nelson (1998) for a rather sceptical overview of the theoretical arguments and the empirical evidence supporting such a proposition.
46. Merges and Nelson (1994) have provided a number of examples, in what they call "cumulative systems" technologies (*i.e.*, technologies composed of many interacting elements where innovations are, most of the time, refinements and improvements of previous inventive steps). For these technologies, the enforcement of a strong regime of intellectual property rights stifled technical progress. In some cases, deadlocks were overcome only when the government stepped in, inducing the main players in the industry to stipulate agreements prescribing automatic or semi-automatic cross licences of patents. Heller and Eisenberg (1998) considers the case of biomedical research in a similar perspective.
47. Hunter, 1949, pp. 121–180.
48. Hunter, 1949, pp. 175–176.
49. The relevance of McGaw's study was suggested by Cowan and Jonard (2003).
50. See von Hippel (2001) for similar considerations. For an insightful discussion of a number of contemporary examples of community-based innovation, see Shah (2005).

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