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# Do patents enable disclosure? Strategic innovation management of the four-stroke engine

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## Abstract

A significant argument in favor of patents is that they enable knowledge disclosure, which compensates for their social cost. Although patent institutions can influence disclosure levels by what they require before granting patents, innovators have a natural bias to conceal key information because such knowledge can make a competitor's second-generation invention and patent more powerful. Despite interest in the subject, little empirical research has been carried out to analyze how much information patents actually disclose and how patentees and corporations historically manage these kinds of monopolies. Using a key case study of a radical innovation—the four-stroke engine, patented by Nicolaus August Otto in 1876—we conducted a detailed technical analysis of its patents in six countries. Our research provides new insights on issues related to full (or lack thereof) patent disclosure, the management strategies designed to maintain patent monopolies, and the effects of such monopolies on future innovation, knowledge, and control of marketplaces.

**JEL classification:** N70, N83, O32, O33, O34

## 1. Introduction

There are distinct reasons for the use of patents, of which one has traditionally stood out. More than the natural right to (intellectual) private property or the necessity to reward creators for a socially beneficial contribution, nineteenth-century patent advocates argued that monopolies were granted in exchange for secrets that facilitated an open science world (Machlup, 1958: 20, 21; David, 2003). Without patents, there would be little incentive for knowledge disclosure and technological progress. Patents are the least damaging solution to promote innovation, provided that disclosure actually occurs (Scotchmer, 2012: 105). However, there were, and still are, patent opponents who point to the harmful blocking effects of intellectual property monopolies, question the incentive argument, and doubt that patents encourage disclosure (Boldrin and Levine, 2005, 2008, 2013). If technology is not simply a synonym for information, tacit knowledge is required for technology to be properly implemented; otherwise, patent specifications will never provide sufficient disclosure levels (Pavitt, 1987: 185; Nelson, 1989: 236).

Although patent institutions and practices can influence disclosure, for instance, by establishing previous technical exams for novelty and patentability or by guaranteeing patent enforceability, innovators are reluctant to disclose their innovations because it directly increases competition (Scotchmer and Green, 1990: 144). In fact, patentees are caught between two opposing forces: (i) a natural tendency to conceal as much key information as possible and to seek a larger monopoly duration and broader technical scope, and (ii) the necessity to make the invention specifications and drawings sufficiently clear and concrete to be enforceable in a court of law (and to pass technical exams, if necessary). On the one hand, if patentees hide significant information, they may encounter serious problems if others register or manufacture similar devices based on similar characteristics, because they might not be able to demonstrate their contribution to the invention. On the other hand, if they provide key knowledge, then competitors may either illegally imitate or legally develop improved and patentable devices based on such previous findings.

This dilemma has always been a problem for patentees, who naturally seek to maintain strong monopolies against competitors. For example, a well-known monopoly occurred during the British Industrial Revolution: in 1769, James Watt invented the critical separate condenser, which was patented as the "new invented method of lessening the consumption of steam and fuel in fire engines."[1] The technology was broadly described in the second item on a list of seven improvements of steam engines, but its relevance was not highlighted. Furthermore, there was not a single figure or drawing to show how separate condensers worked. Nonetheless, Watt got an initial indestructible monopoly in 1769 that was extended by an act of Parliament until 1800. It was not only an unusually long patent (31 years) but also it was very broad in scope. It was successfully used in court against all competitors. In fact, the company Boulton & Watt was created to manufacture essential parts of the engine, which exploited the patent by charging high royalties for construction and allowing its use (Nuvolari, 2004a: 353). Scholars generally agree that Watt's patent created a harmful and oppressive situation both for competitors and users, and that the patent had a negative impact on the rate of innovation in steam technology.[2] Watt's case is frequently used as an example of patenting with strategically vague specifications (Nuvolari, 2004b: 24, 25).

Although patent disclosure is essential from the perspective of both public policy and inventors, it has attracted little interest from scholars. The Watt case may certainly be an extreme example, but have patent systems solved these kinds of institutional failures? Do patents truly encourage technological disclosure? How do patentees and corporations manage such monopolies and intangible assets? Is it possible to control international disclosure, depending on patentees' commercial interests? In this article, we aim to answer these questions by focusing on another key case study: the emergence and evolution of the four-stroke engine technology and associated businesses. In 1876, Nicolaus August Otto built his four-stroke engine prototype in Cologne, Germany—and, as with Watt, it was a radical innovation. It began a long-term technological trajectory on which we still find ourselves.

Otto's firm, subsidiaries, and licensees worldwide commercialized his invention. By the beginning of the second industrial revolution, a patent was perceived as a key tool to secure intangible assets, even prior to international agreements on intellectual property rights (IPRs). In this article, we meticulously analyze Otto's innovation process, levels of knowledge disclosure across six countries, and patent and license activities driven by Otto and his firm, as well as successes and failures in pioneer, first follower, and lagging countries to explain domestic and international patent management, disclosure strategies, institutional constraints, and business results.

The article is structured as follows: Section 2 discusses the four-stroke engine technology and explores how Otto's international business emerged after only a few decades. Section 3 demonstrates the key role of patents in the internationalization process and how Otto and his agents fine-tuned specifications and drawings according to different patent systems. Section 4 provides evidence on how Otto used IPRs to globally monopolize his business and patent litigation to try to stop competitors and the consequences of these actions on the engine industry. Section 5 concludes.

## 2. The four-stroke engine technology and business

As with any new technological trajectory (Dosi, 1982), the development of the reciprocating internal combustion engine required new scientific knowledge, which Alphonse Eugène Beau de Rochas provided in 1862, when he

1 British Library (BL), Patent No. 913.

2 Recent research challenges such assumptions (Selgin and Turner, 2011), but it also recognizes that Watt's patent was key in stopping rivals, at least in advancing atmospheric and low-pressure steam technologies.

accurately detailed in a patent document the four-stroke engine thermodynamic cycle (intake, compression, combustion, and exhaust).[3] However, Beau de Rochas not only did not include technical drawings in the description but also he apparently neither built nor developed an actual engine, based on contemporaneous knowledge. Thus, Otto is acknowledged as the designer and builder of the four-stroke engine; its theoretical cycle is even known as the "Otto cycle." Even though Beau de Rochas never built an engine, his 1862 French patent caused Otto and his business several problems, as we will discuss further on.

Born in Germany in 1832, Otto did not have an advanced engineering education, although he was trained in mechanics and had extensive experience with business issues. He was a real "tweaker" (Meisenzahl and Mokyr, 2012). Working as a trader of colonial goods, he knew about Lenoir's gas engine[4] and was convinced of its virtues and commercial possibilities for internal combustion technology. He began to work on coal gas engines, building his first prototypes in 1861 and 1862. In 1864, Otto joined in partnership with Eugen Langen to form N. A. Otto & Company. Langen was a well-trained mechanical engineer with whom Otto had improved and patented new atmospheric gas engine arrangements, and with whom he would build and sell hundreds of such kind of machines (Cummins, 1989: 138–143). In 1872, two other experienced engineers, Gottilieb Daimler and Wilhelm Maybach, joined Otto and Langen, which gave birth to one of the strongest, most creative technical teams specialized in thermal engines at that time. Otto, who was in charge of the partnership, facilitated the improvement of atmospheric gas engines, the expansion of the firm, and the exploration of new technological paths. Each of these engineers had their own style and intuition, but it was Otto who invented the first four-stroke engine, first built and patented in 1876.

Otto's four-stroke cycle and motor meant a huge technological shift from previous thermal machines (i) in terms of power with respect to size and (ii) in scalability (Amengual and Sáiz, 2007: Table 1.2). The key idea, derived from constant experimentation with gas engines, consisted of compressing the mixture of air and gas in the same cylinder in which combustion and expansion took place. Despite lack of interest from his partners—especially Daimler, who believed that nothing could emerge from such an idea—Otto believed a new engine configuration would compress and burn the charge in a single cylinder. After months of experimentation, he finally accomplished this by expanding the intake–compression–ignition–expansion–exhaust cycle over four piston strokes (or two crankshaft revolutions). This was a disruptive concept with respect to the established practices in previous steam or gas engines, in which each stroke contributed its share of useful work. To run correctly, the new engine required accurate control over both the stratified charge of the mixture and combustion. This led Otto to make key modifications in the functioning and timing of the valves for charge and exhaust as well as in the ignition system. Once properly tuned, the engine turned a true revolution. The direct ancestor to all modern reciprocating combustion engines, and the one that pushed the technological trajectory forward, is represented in Figure 1. The engine's efficiency and cross-sectorial possibilities opened up new and powerful business opportunities for Otto and his partners.

Otto had been a particularly successful trader in his youth, and his business and commercial skills were as significant as his mechanical skills. This key combination helps explain the successful entrepreneurial results of his projects. With N. A. Otto & Company, Otto contributed his patents and workshop and Langen his financial support. After a successful demonstration at the 1867 Paris International Exposition, they needed additional capital to enlarge their business. This funding occurred through an association with Ludwig August Roosen-Runge, creating in 1869 a new firm: Langen, Otto, and Roosen. The partners built their factory in the Cologne suburb of Deutz. With an ever-increasing demand for capital, in 1872, the company incorporated as Gasmotoren-Fabrik Deutz AG (hereafter Deutz) through new investments made by capitalist partners. The partners hired more engineers, including Daimler

3 Beau de Rochas described the cycle in a lengthy patent registered in France on January 16, 1862 (Institut National de la Propriété Industrielle [INPI], Patent No. 52,593) for "nouvelles recherches et perfectionnements sur les conditions pratiques de la plus grande utilisation de la chaleur et en général de la force motrice, avec application aux chemins de fer et à la navigation" (research and improvements on the practical conditions of the extended use of heat and, generally, motive power, applied to railways and navigation), in which he presented a mix of inventions but also ramblings on unrelated issues. On page 48 of this patent, he thoroughly explained the theoretical four-stroke engine cycle.

4 This was a coal gas engine patented by Jean-Joseph Etienne on January 24, 1860, in France. It was a "moteur à gaz et à air dilaté" (gas and expanded air engine) (INPI, Patent No. 43,624). It inaugurated the internal combustion era on the basis of burning a noncompressed mixture of gas and air that was ignited by sparks. However, the lack of charge compression restricted the engine's efficiency and limited sales and later developments (Payen, 1963).

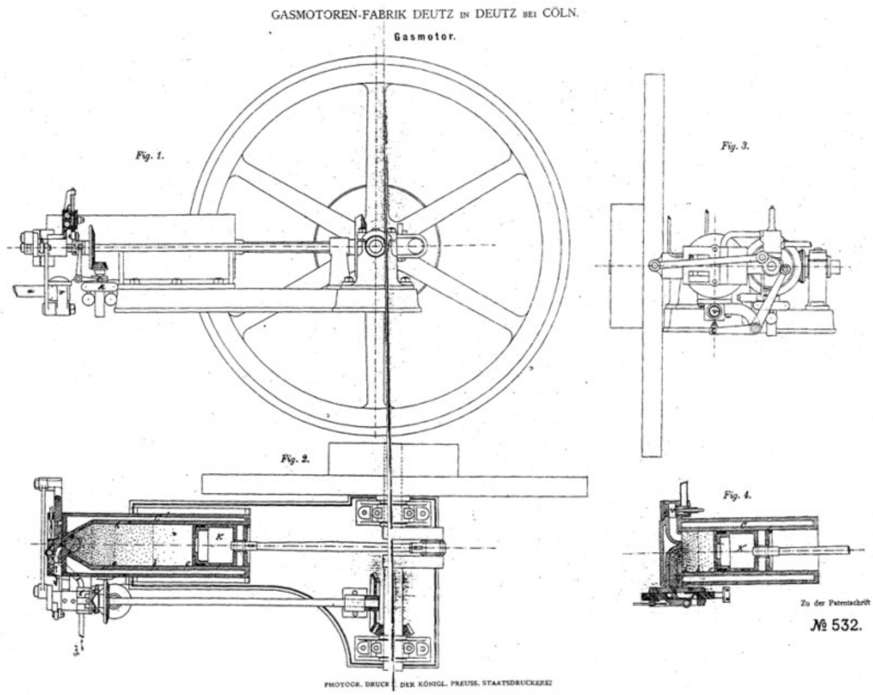


**Figure 1**. Drawings of the four-stroke engine, invented by Nicolaus August Otto, included in the 1876 German, French, and Spanish patents.

*Source*: Deutsches Patent- und Markenamt, Patent No. 532, applied for June 5, 1876, as a "gasmotor," by Gasmotoren-Fabrik Deutz.

and Maybach. Otto, who invested his patents in the business but not money, obtained a long-term contract as the technical director (Cummins, 1989: 139, 144–146).

After Otto's four-stroke engine was developed in 1876, Otto and Deutz immediately patented it and widened their business through international agreements to build the new engines. Previously, Langen, Otto, and Roosen had negotiated with the English manufacturers Crossley Brothers, who acquired the license for the British patent on atmospheric engines in 1869, and then with the French Edouard Sarazin in 1872—the same year that they established an Austrian subsidiary, Langen and Wolf, Gasmotorenfabrik.[5] Starting in 1876, as Deutz, they created subsidiaries, licensed patents and fought imitators in many other countries. Deutz continued in partnership with Crossley Brothers in the UK, extended its connections through the Compagnie Parisenne d'Éclairage et de Chauffage par le Gaz in 1879 (incorporated into Compagnie Française des Moteurs à Gaz. Système Otto) in France, established Schleicher, Schumm, & Company in 1876 (then as Otto Gas Engine Works in 1894) in the United States, concluded deals with Fetu & De Liege in 1877 in Belgium (later becoming the Société Anonyme des établissements Fetu-Defize), signed agreements with J. G. A. Eickhoff in 1880 in Denmark, and licensed its technology to Bauer & Company in 1888 in Italy (later becoming Societa Italiana Langen & Wolf). The evolution of Otto's business is depicted in Figure 2.

The most significant of the manufacturers were Deutz's own Gasmotoren-Fabrik (8300 engines manufactured by the mid-1880s), its American subsidiary (25,000 units), and the licensee Crossley Brothers (more than 5000 units). The Crossley Brothers had been authorized to build and sell worldwide except, obviously, in Germany (Cummins, 1989: 162). The British firm quickly developed during the last decades of the nineteenth century to become a great engine exporter before World War I. Consequently, they opened agencies in 30 countries and competed with domestic manufacturers everywhere, especially starting in the 1890s, when Otto's original 1876 patent expired and Crossley registered improved engine versions (Ortiz-Villajos, 2014: 655). In small markets (i.e., those with limited

5 Created in association with Carl Otto Langen and Richard Lothar Wolf.

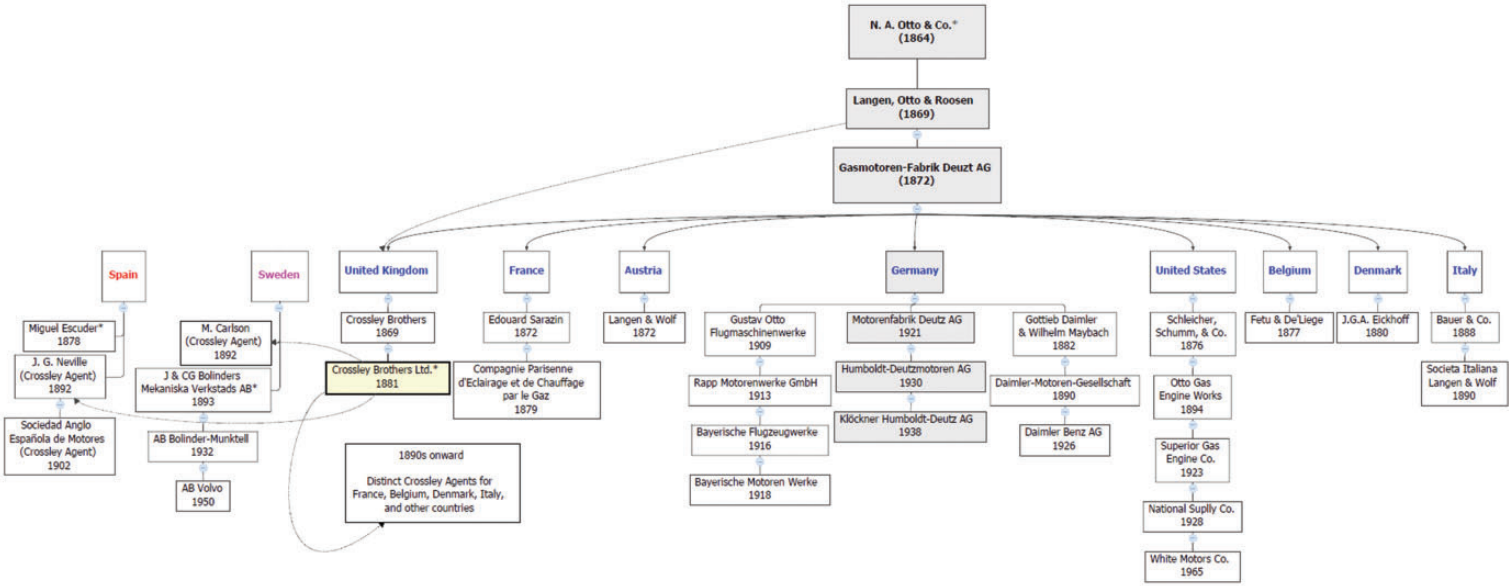


**Figure 2.** International licensees, subsidiaries, and entrepreneurial evolution, starting with N. A. Otto & Co.

*Notes:* * Deutz's evolution in Germany is shaded and centered. Deutz licensed the patent to British-based Crossley Brothers, which would become a significant manufacturer and worldwide exporter with agents in many countries. The first Spanish manufacturer Miguel Escuder was not authorized. The Swedish manufacturer J & CG Bolinders Mekaniska Verkstads AB developed its own patented combustion engines in 1893.

*Sources*: Cummings (1989: 152–160); Cabana (1992: vol. 1: 129, 130); Ortiz-Villajos (2006: Table 2); Thomson and Baden-Fuller (2010: 102, 103). Also see Volvo Construction Equipment, "About Us" page, https://www.volvoce.com/global/en/this-is-volvo-ce/our-history/

populations or low industrialization levels) such as Sweden and Spain, importations were the main source for the extension of the new technology, largely through the work of Crossley Brothers' agents, although domestic manufacturers also had opportunities to manufacture engines.

In Sweden, for instance, J & CG Bolinders Mekaniska Verkstads AB began to manufacture its own designed four-stroke paraffin engines in 1893. The experience led the firm to develop two-stroke compression–ignition crude oil engines in 1897, which turned into a tremendous success, for example, with a global market share of 80% of fishing boats by the 1920s. In Spain, the first manufacturer of Otto's four-stroke engine entered into the business without license. As is well documented (Cabana, 1992, vol. 1: 129, 130; Amengual, 2008: 100, 101), a Catalonian manufacturer, Miguel Escuder, produced approximately 300 engines between 1878 and 1900 that were mainly sold in the most industrial areas of Spain, such as Barcelona and the Basque Country. It was a small quantity as compared with the main producers, and the undeveloped Spanish market was quickly supplied by engine importations from Crossley Brothers (Ortiz-Villajos, 2014: 654–657, Figure 1).

In sum, Otto's revolutionary invention definitively contributed to the expansion and technical trajectory of the reciprocating internal combustion engine, and his business savvy contributed to worldwide business opportunities that he and Deutz rapidly grew. Otto's new engine was the keystone of the second industrial revolution in that it gave birth to an entire industrial sector that remains important today. Patent management was always a strategic challenge in a competitive sector in which reverse engineering made keeping industrial secrets difficult. First-generation inventors and companies required patents to block competitors, license technologies, and fight imitators, depending on the extent and scope of their monopoly protection. Follower and latecomer firms had to get used to patent rights—by either respecting, challenging, or bypassing them—often depending on distinct management strategies and the character of institutional arrangements concerning patent treatment in each nation. Patents were strategic and complex issues, especially considering the range of diverse national patent institutions, the absence of international agreements until 1883, the rise of protectionist and nationalistic attitudes toward industrialization, and the birth of the first globalization process.

## 3. Radical innovations, patent institutions, and legal strategies for four-stroke engine protection

A technological trajectory begins with key radical innovations from a few inventors and enterprises that push forward both technology and business. If an invention is successful, clusters and waves of incremental technical advances usually follow both established and new technical fields, which, in turn, can improve the efficiency, scope, and range of the technology. The same process can be tracked and analyzed for patent management. A pioneer innovator or firm registers a patent at a crucial moment at the beginning of a trajectory in an attempt to monopolize and organize their business. This step is essential to move into a strong position in marketplaces (van Rooij, 2012: 1136). Both pioneers and followers will also use patent systems to protect incremental and complementary innovations, filing thousands of patent applications. As business possibilities grow, agreements, licenses, imitations, conflicts, and lawsuits increase.

The aim of this section is to thoroughly analyze the first key patents filed internationally for the four-stroke engine as registered by Otto and Deutz at the start of the reciprocating internal combustion engine trajectory. We do not include long-term patent activity so as to be able to delve into the initial strategies concerning technical disclosure and the key intangible assets in Deutz's first international expansion. For this analysis, we selected six countries with different patent regimes and industrialization levels in which Otto or Deutz filed patents: Germany (Deutz's homeland), the UK, France, the United States, Sweden, and Spain.

In 1876, when the four-stroke engine was developed, there were no international agreements concerning IPRs beyond those specified in bilateral accords linked to commercial treaties, although foreign patent activity was usually allowed everywhere. Furthermore, the 1883 Paris Convention for the Protection of Industrial Property did not suppose radical changes, and each nation retained its own way of organizing its patent system.[6] With respect to the

6 The consensus over the last decades of the nineteenth century did not go beyond several basic agreements regarding national treatment for foreigners and 3- to 6-month priority rights for granting previous patents. The Paris Convention did include clauses regarding (i) the security that importing one's own patented objects from abroad would not forfeit the monopoly, and (ii) the guarantee of temporal protection in international exhibitions (Penrose, 1951: 60–87).

targeted countries in this article, France, Spain, and the UK signed the Paris Convention in 1883–1884, Sweden in 1885, the United States in 1887, and Germany in 1903. Thus, in 1876, Otto and Deutz had no other way to protect their initial invention and subsequent developments but to attend to national legislation in each country. Patent lawyers, international agencies, and other intermediaries in markets for technology were thus crucial in their process of monopoly extension (Guagnini, 2002, 2012; Lamoreaux and Sokoloff, 2003; Galvez-Behar, 2006; Pretel and Sáiz, 2012).

Based on contemporaneous manuals and the writings of several patent attorneys, we have created a legal snapshot of the basic differences among the six patent systems for the years 1876 and 1877 (Table 1). The practitioners themselves easily recognized and warned of such dissimilarities regarding, for instance, whether there were previous technical exams, high fees, installment payments, compulsory working clauses, and patents of introduction or importation. At that time, the US and German systems clearly stood out because they were only countries with strong previous novelty exams[7] designed to reject valueless inventions and with special administrative jurisdiction to revoke patents. In addition, both systems published printed descriptions and drawings to properly spread technical information, called for opposition before granting patents, and did not allow patents of introduction (which rewarded first introducers of foreign inventions). The United States went further by recognizing IPRs only to the true inventor and giving priority rights for 2 years (Thompson, 1882: 74, 75). However, the German and the US systems had also significant differences as related to their particular politico-economic practices. The main difference was the cost for a full-extent patent: it was extraordinarily expensive in Germany and quite cheap in the United States. There were also significant differences in patentees' rights, such as the German constraint concerning compulsory working and licensing that did not exist in the United States. Some scholars have argued that, on the one hand, the US patent system was quickly democratized and that it allowed the birth of an active market for innovations (Khan, 2005). On the other hand, the German system may have been influenced by national, industrial, and corporate governmental strategies than focused on individual rights to favor scientific, technological, and innovative spillovers (Streb *et al*., 2006).

The French and the Spanish patent systems had many things in common in the mid-1870s (Table 1). Both had simple registration systems with no previous exams, opposition proceedings, priority rights, specific patent jurisdiction, or publication of specifications and drawings, and they had similar fees (international prices) as well as compulsory working requirements to maintain monopolies. In addition, France did not allow the patentee to import the protected object, and Spain granted patents of introduction to bring in foreign technology without being the first inventor (Sáiz, 2014). Therefore, at first impression, these two systems seem weaker than the German and, especially, the US systems, at least for defending patent holder's rights. Once again, political and institutional determinants clearly encouraged domestic industrialization and technology transfers over IPRs (Ortiz-Villajos, 1999, 2002; Sáiz, 2002; Galvez-Behar, 2008).

Finally, the British and the Swedish patent systems in 1876 had some common characteristics with the aforementioned countries, but they also had unique attributes that led to an intermediate level of protection. In the UK, obviously based on English common law tradition, there were no novelty exams, although there were calls of opposition and specifications and drawings were published. Like the German system, the British one was quite expensive; like the US system, no compulsory working or licensing requirements were implemented; like the Spanish system, the first *importer* of a new technology did not file for a 5-year patent of introduction but instead filed for a full-extent invention patent without being the first and true inventor. It was the only system that could exceptionally allow extensions after the patent's full term and that had a payment system with three installments at the first, third, and seventh years (MacLeod *et al*., 2003).

The Swedish system did not have officially established previous exams, but, like the British and the German systems, it called for opposition before granting a patent and it also published drawings and specifications. The fees were as inexpensive as in the United States, although Sweden's Department of Commerce determined the patent extension in each case, from a minimum of 3 years to a maximum of 15 years, depending on the scope and importance of the invention. This department had full jurisdiction on patent granting with no further possibility of appellation in

7 Exams existed in the United States starting in 1836 and were introduced in Germany in 1877.

**Table 1.** Legal characteristics of patent systems, six countries, 1876 and 1877

| Snapshot | Germany | The UK | France | The United States | Sweden | Spain |
|---|---|---|---|---|---|---|
| Law in force to grant Otto's patent | 1877 | 1852 | 1844 | 1861 | 1856 | 1826 |
| Previous novelty and technical exam | Yes | No | No | Yes | No[a] | No |
| Opposition proceedings | Yes | Yes | No | No | Yes | No |
| Priority rights to previous patents | No | No | No | Yes[b] | No | No |
| Maximum patent term (years) | 15 | 14 | 15 | 17 | 15[c] | 15 |
| Patent extension beyond maximum term | No | Exceptionally 7 years[d] | No | No | No | No |
| Payment system | Annual installments | Three installments[e] | Annual installments | In advance | In advance | In advance |
| Fees for a full-term patent[f] | 5300 marks | 180 pounds | 1500 francs | 35 dollars | 144 crowns | 6000 reals |
| Fees in 1876 British pounds[f] | 260 | 180 | 60 | 7 | 8 | 60 |
| Patents of addition | Yes (no annual taxes) | No[g] | Yes (no annual taxes) | No | No | No |
| Patents of introduction or importation | No | Yes[h] | No | No | No | Yes (5 years) |
| Compulsory working clauses | Yes (within 3 years) | No | Yes (within 2 years) | No | Yes (within 2–4 years)[i] | Yes (within 1 year) |
| Compulsory licenses | Yes[j] | No | No | No | No | No |
| Importation prevention of patented item | Yes | Yes | Yes | Yes | Yes | Yes[k] |
| Patentee importations void the patent | No | No | Yes | No | No | No |
| Publication of patent specifications/drawings | Yes | Yes | No | Yes | Yes | No |
| Specific patent jurisdiction | Yes[l] | No | No | Yes[l] | Yes[m] | No |

*Notes:*

[a]According to Andersson (2016: Ch. 4), Sweden's Department of Commerce may have conducted a short novelty exam (driven by a single technical assistant) that could lead to patent rejections.

[b]Priority rights to previous patents occurred except if the invention was in public use in the United States for more than 2 years.

[c]The extension was determined by Sweden's Department of Commerce for each patent (minimum 3 years, maximum 15 years).

[d]Patent extension was allowed in the UK only in special cases through a formal petition to the queen and a report from a Judicial Committee.

[e]The UK allowed three installments at or before the end of the first, third, and seventh years.

[f]Fees shown (in domestic currencies or in British pounds) were for full-term patents. The final cost may have included several things in each country (drawings, translations, patent attorney fees, payments for publication in the official Gazettes, etc.).

[g]In the UK, additions and improvements had to be made between the time of the application and grant, that is, between provisional and final specifications.

[h]Although nominally there were no patents of introduction or importation in the UK, patents could be taken by the first person to introduce an invention into the country, which is, for all intents and purposes, the same thing.

[i]In Sweden, the patentee had to use the invention within 2 years, which could be extended to 4 years (having applied previously). The patentee had also to prove that the patent was in use each year of the patent term.

[j]In Germany, compulsory licenses had to be offered if the patent was not used or it was of public interest.

[k]Importation prevention was allowed in Spain except for patents of introduction, which could not block importations by third parties.

[l]The patent offices in Germany and the United States might revoke applications on the grounds of a lack of patentability or novelty with no further appellation except to the country's individual Supreme Court.

[m]Sweden's Department of Commerce's decisions on patent granting carried no further possibility of appellation.

*Sources*: Information from manuals of patent practitioners and experts, including Webster (1853); Johnson and Johnson (1866); Hunter (1880); Thompson (1882); Gordon (1908). See also Pakuscher (1986: 90); Lerner (2000: Tables 1–5, 2005: Tables 1–4); Khan (2001); Sáiz (2002: Table 1); Galvez-Behar (2008, 2010); Khan and Sokoloff (2009: Table 10.1); Maestrejuan (2009: 131); Andersson (2014: Table 1, 2016: Ch. 4). Exchange rates among currencies for the year 1876 based on the Swedish SEK (Lobell, 2010: Tables A6.1, A6.2, A6.4; Historical Statistics, http://www.historicalstatistics.org; see table for Sweden), except for Spain (Martín and Pons, 2005: Table 9.19).

courts. Patents of introduction or importation were not allowed, and the Swedish system required inventors to manufacture their invention within Sweden itself (Andersson, 2014: 8–9, 2016: Ch. 4).[8]

Some questions immediately arise: Did these disparities in patent systems influence Otto's or Deutz's protection strategies? How did Otto, Deutz, and their agents manage the patent internationalization process? Were there distinct disclosure levels, patent claims, and technical breadth for distinct countries and systems? Were there dissimilar economic returns, problems, or business strategies depending on the particular characteristics of each patent system? Is it possible that this diversity did not influence Otto's and Deutz's decisions?

Otto's international patents were filed in a short period of time in 1876 (Table 2). The German patent[9] was applied for on June 5; the French patent[10] was registered on June 9; the Spanish patent[11] was stamped on June 27; the provisional specifications of the British patent[12] were dated May 17, although it was not sealed until August 1; and the US patent[13] appears signed by Otto on June 1, although the official application was not filed until July 13. The power of attorney for the Swedish patent[14] was signed by Otto on September 16, although the patent was not applied for until November 1. Thus, these close dates and order clearly mean that Otto and Deutz, as duly advised by their patent attorneys,[15] developed a unified strategy to patent the four-stroke engine internationally. Deutz filed for the German and the Spanish patents; meanwhile, Otto filed for the French, British, Swedish, and US patents. This probably was an intentional policy product of internal agreements among Deutz's partnerships as well as a consequence of distinct domestic patent requirements.[16] Their schedule of patent extensions began with the British document: between the presentation of the British provisional and final specifications (May and August, respectively), they applied for the other patents, with the exception of the Swedish, which was filed last. These actions were a carefully prepared strategy, as shown in the following quote from a US patent agent on how to patent in the UK:

> Application should be made prior to the publication of the invention, even by prior foreign patent specifications. … It is usual on application to file merely a provisional specification setting forth the general character of the invention, but omitting its minor details, as from the result of experiment it may be desirable to modify these to some extent during the six months granted by provisional protection. The final specification may be filed at first but this course is not desirable. (Hunter, 1880: 44, 45)

Hence, it seems that Otto and Deutz were well advised during their internationalization process, or at least were well informed. Except for the aforementioned Swedish extension, which took 5 months, the patent coverage was widened country by country in nearly only a month and a half. The costs of translations, technical drawings, and practitioner commissions, among other expenditures, had to be paid and managed, which certainly did not make the process inexpensive. Otto's invention was thus rapidly protected in the most significant markets of the world. The following includes our careful analysis of each of the six countries selected for original patent files, and we especially

8 Note that Table 1 is only a snapshot for the years 1876 and 1877 and that the nineteenth-century patent legislation was continuously changing and adapting to social, political, and industrial realities. For example, there were distinct patent laws in pre-1877 German states; and in 1878, Spain changed to a new and less expensive system that extended patents to 20 years and recognized 2-year priority rights. France and Spain passed new patent statutes in 1902; the UK included compulsory licenses in 1883, a previous novelty exam in 1905, and compulsory working clauses in 1907; and Sweden passed a new patent law and established rigorous previous novelty exams in 1884.

9 Deutsches Patent- und Markenamt (DPMA), Patent No. 532. Although the patent was presented in 1876, it fell under the 1877 German law.

10 INPI, Patent No. 113,251.

11 Oficina Española de Patentes y Marcas (OEPM), Privilege No. 5479.

12 BL, Patent No. 2081.

13 United States Patent and Trademark Office, Patent No. 194,047.

14 Patent- och Registreringsverket (PRV), Patent Application No. 2310.

15 Patent agents and agencies were internationally linked from the beginning of patent systems; however, starting in the 1870s, linking was essential (Galvez-Behar, 2006; Pretel and Sáiz, 2012: 100–108). For instance, Otto and Deutz presented their patents through well-known patent attorneys, including Maison Armengaud Aîné, in France; Charles Denton Abel, in the UK; and Bernardo García Abad (later Pedro Rigalt y Fagell), in Spain.

16 A corporate patent is a firm's asset; in the case of a limited liability company, a patent granted to a partner is the partner's private property. At that time, some patent systems, such as in the United States or Sweden, allowed only individual inventors to file, who could later assign the patent to a firm.

**Table 2.** Otto's and Deutz's first patents, by country

| First patent | Germany | The UK | France | The United States | Sweden | Spain |
|---|---|---|---|---|---|---|
| Patent number | 532 | 2081 | 113,251 | 194,047 | 2310 | 5479 |
| Application date (1876) | June 5 | May 17 (sealed August 1) | June 9 | July 13 (signed June 1) | November 1 (signed September 16)[a] | June 27 |
| Applicant | Deutz | Otto | Otto | Otto | Otto | Deutz |
| Patent attorney | n.a. | Charles Denton Abel | Armengaud Aîné | Charles Sydney Whitman | L. A. Groth[b] | BernardoGarcía Abad |
| Patent term (years) | 15 | 14 | 15 | 17 | 9–15[c] | 15 |
| Document characteristics | Original text and drawings | Partially related text and same drawings as US patent | Same text and drawings as German patent | Partially related text and same drawings as UK patent | Partially related text and same drawings as UK patent | Same text and drawings as German patent |
| Typewritten | Yes | Yes | No | Yes | No | No |
| Number of words in the technical description (approximately)[d] | 1231 | 3154 | 1600 | 3082 | 1123 | 1700 |
| Number of drawings | 4 | 13 | 4 | 13 | 13 | 4 |
| References to previously owned patents[e] | None | None | None | None | None | None |
| Invention disclosure level | Low | Medium-high | Low | High | Medium | Low |
| Claims quality | Not adequate | Not adequate | Not adequate | Partially adequate | Not adequate | Not adequate |
| Court litigation | Yes | Yes | Yes | Yes | Unknown[f] | Yes |
| Patent revocation | Yes | No | Yes | No | No | Yes[g] |

*Notes:*

[a]Sweden's power of attorney signed September 16.

[b]In 1887 in Sweden, Fredrik L. Enquist replaced L. A. Groth. Enquist undertook the task of asking for the patent extension.

[c]Sweden's Department of Commerce established an initial patent term of 9 years. A new patent law was passed in 1884, at which time Otto asked to have the patent assigned under the new rules (a 15-year term). He was granted an extension until 1891 (a total period of 15 years from the original application).

[d]This is an approximate number of words as related to the entire technical description in each patent specification.

[e]Although priority claims were not internationally established until the 1883 Paris Convention, the patent description could quote previous patents abroad. The US law specifically recognized previous patents.

[f]There appears to be no sign of litigation in Sweden's patent record.

[g]The patent was revoked in Spain for not properly demonstrating that the engine was in use, but this was later reestablished. Nevertheless, Otto could not stop production from the nonlicensed manufacturer Miguel Escuder, which held several patents of introduction on Otto's engine (Amengual, 2008: 100, 101).

*Sources*: Otto's patent original files. Litigation data according to Cummins (1989: 172–178); Flink (1990: 11). We thank David E. Andersson for his considerable help in analyzing the Swedish patent system and Otto's patent.

scrutinized the technical information paragraph by paragraph and drawing by drawing. There is strong evidence of specification fine-tuning and careful editing of details among the patents, and, thus, of strategic patent management that we had to disentangle.

We found that all the patents that we studied lacked certain valuable information and that several contained considerably insufficient disclosures. For instance, no patent offered sufficient thermodynamic data for the full and complete understanding of the engine without experimentation. Furthermore, in three of the patents, there were not enough details to allow an engineer of the time to build the engine. This means that Otto and Deutz purposefully did not reveal essential information of the four-stroke engine, and that the details offered varied by country and patent system characteristics. As stated in the introduction, in exchange for a monopoly, innovators *should* completely reveal new information to competitors and society. In reality, they often keep essential information to themselves. This is a difficult choice because inventors need their patents to be granted and for their inventions to be properly protected in case of litigation, but they also want to protect their work from being legally or illegally used. Therefore, it was—and it still is—hard to find the tipping point in the art of tight writing of patent specifications and claims—an art that is offered only by good patent advisors knowledgeable about inventors and firms. In words of a contemporaneous professional patent agent:

> [The profession's main duties are] to collect the inventor's ideas, to arrange them in an intelligible form, and ultimately to embody them in a specification, which will not only stand the scrutiny of the Law Court, but which will effectually prevent any rival manufacturer from doing anything in the direction of the patent. [...] At the same time, he must be careful that the boundary is not so indefinitely drawn as to overlap existing rights, or to interfere with rights of new-comers." (Newton, 1882: 159, 160)

We can also undoubtedly state that there were clear and deliberate differences among the patent specifications and drawings in the six countries analyzed, especially between most European documents as compared with American and British documents. On the one hand, the German patent was theoretically subject to previous technical and novelty exams. This means that a low disclosure level might have turned into a serious problem. Examination was a new requirement of the 1877 German law, under which Otto's patent fell, notwithstanding that he applied for the patent in 1876. We examined the patent specifications and figures and found that the engine is described in a wide and simple manner, mixing two distinct modalities (with and without previous compression), and includes just four drawings with a general view of the engine (see Figure 1). Hence, the German patent lacked significant disclosure. Furthermore, the French and Spanish patents, granted by simple registering systems, were literal translations from the German file, thus sharing similarly limited specifications and identical figures. These three European patents can be considered matching documents with the same insufficient disclosure levels and wide technical claims.

On the other hand, the patents filed in the United States and UK were much more concrete and offered a more thorough invention description and claims. Both the UK and the US patents shared the same 13 detailed drawings (Figure 3) and doubled in words the German patent technical specifications (see Table 2), which helped with a better understanding of the four-stroke engine's functioning and characteristics. Both patents described (and included specific drawings for) two key devices not present in the aforementioned continental patents, and without which it was almost impossible to develop the engine: (i) the charge motion within the cylinder, through a cam for valve control, and (ii) the spark-ignition system regulation (Table 3 and Figure 4).[17] The Swedish patent, based on and partially translated from the British, showed these two significant drives and the same 13 drawings, which turned it into the stronger continental document, although the technical description reached neither the extension nor the clarity of the UK or US patents. What is important to note is that the presence of clear drawings was an outstanding point in all these patents. Hunter point out, "In many law suits the complainant or defendant has often lost his case for want of drawings explicit in detail, attached to his patent. Nothing sets off a patent so well, makes it clear of comprehension, and invariable produces the sale of the same, as a good set of drawings finely executed. Fine drawings attached to an application always induces an examiner to take more interest in the invention" (Hunter, 1880: 14, 15).

Even so, the valve control and the ignition regulation systems were not properly described in any of the patent documents; as a consequence, there is not enough information to replicate the engine with total certainty. None of

17 The shape of the cam ("R" in Figure 4) is a key issue for valve control. Any modification in the shape would involve changes in the timing for opening and closing valves and, therefore, would generate distinct engine performances. Similarly, although old-fashioned as compared with current devices, the ignition regulation system had a key communication channel between the combustion chamber and an ignition flame, which allowed the connection of the mixture of compressed gas and fuel to the flame and, therefore, the combustion.

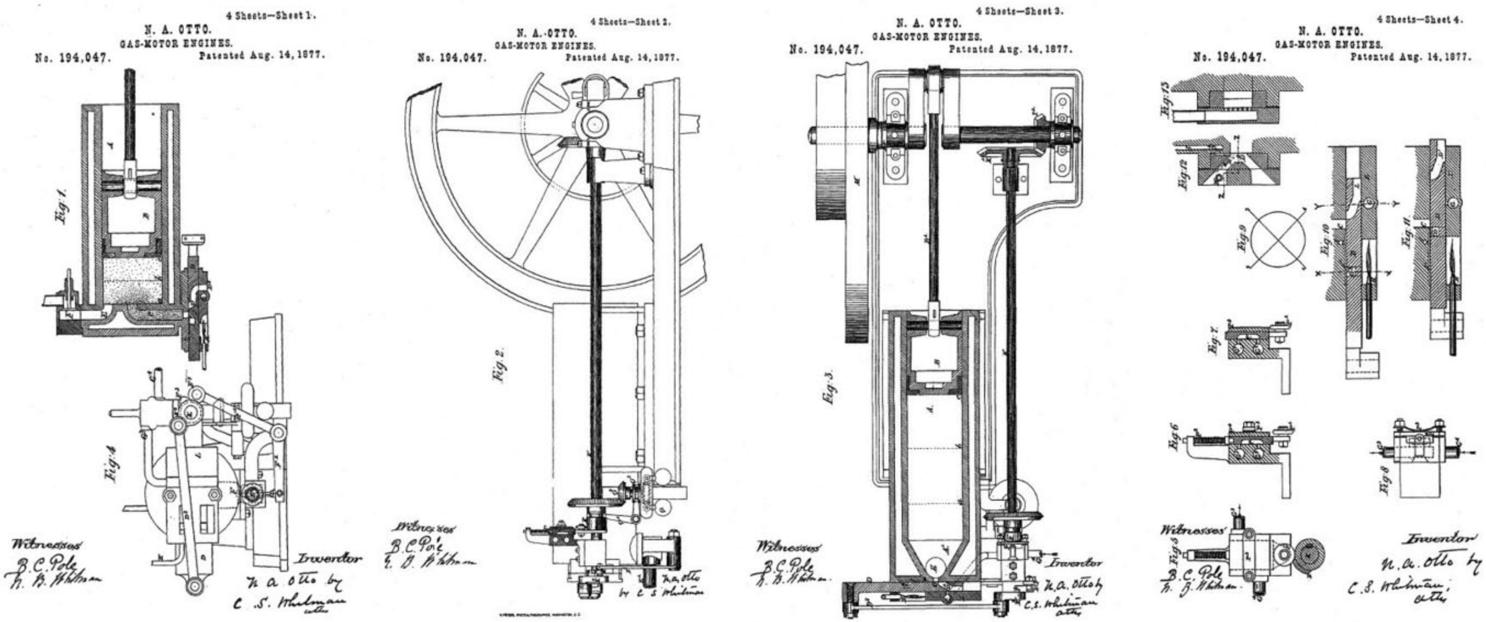


**Figure 3.** Drawings included in Otto's American, British, and Swedish patents, 1876.

*Source*: United States Patent and Trademark Office, Patent No. 194,047.

**Table 3.** References to key topics in Otto's and Deutz's first international patents

| | Charge motion control | | | Spark-ignition system regulation | | | Four-stroke references |
|---|---|---|---|---|---|---|---|
| | Text | Drawings | Claims | Text | Drawings | Claims | Claims |
| GB 2081 | Page 5, Lines 26–45 | Figure 5 | – | Page 6, Lines 3–11 | Figures 10 and 11 | – | Claim 1 (admission) Claim 2 (compression, combustion, exhaust) |
| DE 532 | – | – | – | – | – | – | Claim 4 (the four-stroke cycle) |
| FR 113,251 | – | – | – | – | – | – | Claim 4 (the four-stroke cycle) |
| ES 5479 PR | – | – | – | – | – | – | Claim 4 (the four-stroke cycle) |
| US 194,047 | Page 3, left column, Lines 15–20 | Figure 5 | Claims 5 and 6 | Page 3, right column, Lines 9–26 | Figures 10 and 11 | – | Claim 2 (admission) Claim 3 (compression, combustion, exhaust) |
| SE 2310 | Page 5, Lines 4–32 | Figure 5 | – | Page 6, Lines 11–29 | Figures 10 and 11 | – | Claim 1 (admission) Claim 2 (compression, combustion, exhaust) |

*Sources*: Otto's patent original files.

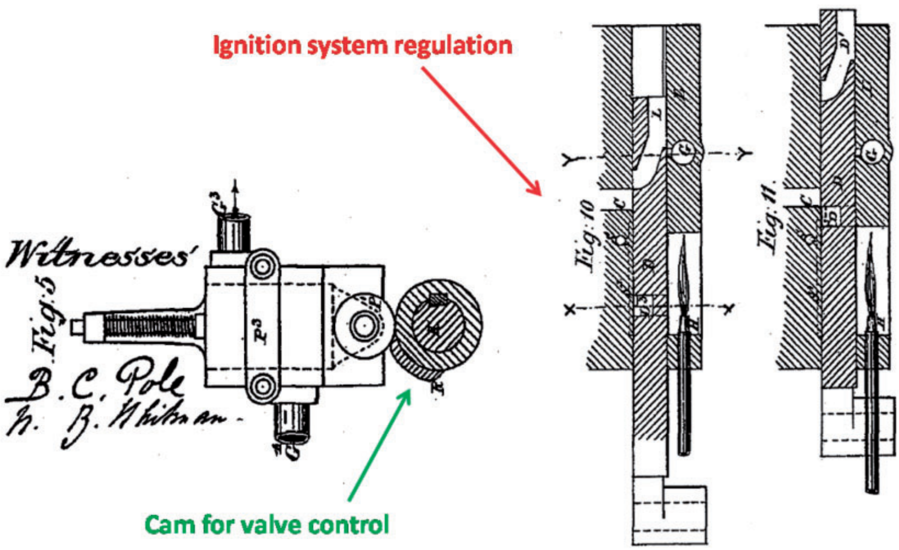


**Figure 4.** Essential devices to fully understand function of Otto's four-stroke engine.

*Sources:* United States Patent and Trademark Office, Patent No. 194,047, detail of Figures 5, 10, and 11.

the patents provided information or data on how the cam's shape would affect the process of opening and closing the valves or on the "connecting law" that governed the link between the combustion chamber and the ignition flame. Thus, although a nineteenth-century skilled engineer could replicate the engine using the US or UK patents, its later and proper function could not be assured without further experimentation or knowledge concerning these two key devices. Indeed, reverse engineering from an original engine would be the faster way to understand how it functioned.

Despite the similarities in the disclosure levels of the United States, UK, and Swedish patents, we also found significant differences among them. The Swedish patent, written after the other two, was the most vague of the three because of its shorter technical description (less than half words of the British and American patents), and it was in part literally translated from the British specifications. Thus, the British and American patents were written during the same period, included the same figures, and matched closely in the extent of specifications, except for the description of the engine. The UK patent was worded in a slightly broader manner than the US patent, and it highlighted and developed the possibility of the engine working at atmospheric pressure, which was not the key point of the four-stroke invention. Although the UK patent also included this, the description of the engine working in upper atmospheric pressure—that is, with previous compression—was the only issue on the US patent. Indeed, the US specifications concerning the engine were more solid and detailed. Furthermore, when we focused our attention on the final claims in these three files—significant legal and juridical parts related to later patent enforcement—the American, British, and Swedish documents were different. The US patent contained much more rigorous claims for the four-stroke cycle and for the key devices of the engine. The claims on the British and Swedish patents were not adequate, as they were written vaguely and in a wider manner, for instance with no reference to the aforementioned cam for valve control for the charge motion. The absence of previous strong technical exams in the British and Swedish patent systems may have influenced these differences with the American patent. An English practitioner reported about the United States Patent and Trademark Office (USPTO) at that time: "The American Patent Office is the most perfect institution of the kind in the world. ... Each application in America is rigidly examined as regards novelty; there being a staff of one commissioner, one assistant commissioner, one hundred and two examiners and assistant examiners, and a large number of clerks and copyists. Every applicant must produce a specification and drawing made according to the rules of the Patent Office, which are very exacting" (Thompson, 1882: 73).

We can conclude that the US patent contained the highest level of knowledge disclosure, included the clearest description in relationship with the drawings, and offered the most specific claims. Even without the thermodynamic information but with complete references to key devices, this patent revealed the basic information needed to understand the concept of the new engine. This may have reduced the breadth of the patent, but it clarified the essential points of the invention. This lead to the longest patent, at 17 years, which was nearly double the amount of time of the Swedish patent.[18] In addition, the US patent system was the least expensive and the US judicial system strongly supported private IPRs. Thus, our findings fit well with what has been long stated by scholars and specialists concerning the higher commercial and social value of US patents, and the quick birth of an active market for innovations and technologies (Sokoloff and Khan, 1990; Khan, 1995, 2005, 2013; Lamoreaux and Sokoloff, 2001; Khan and Sokoloff, 2004; Lamoreaux *et al*., 2013).

Based on this case study, we conclude that the UK's patent system was very close in disclosure level as well as perhaps in enforcement capacity and patent value to the system in the United States, despite some strong contradictions (e.g., the lack of previous technical exams, the possibility of patents for importers, and the high costs of protection). The Swedish patent system seems to have been established on a solid foundation from its start, regardless of the serious absence, as in the British case, of hard technical exams, although these were rapidly introduced in 1884. In comparison, despite previous exams and other modern characteristics, the German patent system showed, at least in Otto's case, the same weaknesses as some other European patent institutions at that time, such as the French and the Spanish patent systems.

This section has demonstrated that Otto and Deutz intentionally left out key knowledge from their patent specifications and followed a unified patent strategy focused on adapting the disclosure levels and the scope of the technical claims to distinct international requirements, with the US patent system being the most demanding. This patent fine-tuning was certainly influenced by the character of the different patent institutions. However, this left us with questions that clearly needed to be addressed. For example, if Otto and Deutz acknowledged weaknesses in certain patent systems such as in Spain or France, why did they invest in registering the engine in those places? Did they want a tool to fight imitators or in case of lawsuits? If so, why then did they not include complete disclosure? Furthermore, if high-quality essential information was revealed in one patent, why hide it in others? Even in a pre-Internet era, such public information could cross internationally in 6 or 12 months. Was that delay enough to justify filing different patents? Or were these strategies a simple result of patent agency practices, routines, and businesses? Were Otto's and Deutz's productive and commercial plans affected in some way by the relative scope and strength (or weakness) of their patents? Can we learn something about how different patent institutions and policies affected technology

18 As noted earlier, the Swedish patent was originally granted for 9 years, which was extended to 15 years after passage of an 1884 Swedish patent law.

diffusion and industrialization processes? In the next section, we try to answer these questions by analyzing patent litigation and the evolution of Otto's and Deutz's businesses during the last quarter of the nineteenth century.

## 4. Patent international litigation and business results

As we demonstrated in Sections 2 and 3, the rapid globalization of the internal combustion engine's technology and business was linked to Otto's and Deutz's international patent strategy and disclosure management. There were three main manufacturers of this kind of engine (see Figure 2): Deutz in Germany, their subsidiary in the United States for the domestic and American markets, and their licensees in the UK as the main exporters in Europe. The engine was also produced on a small scale in many other countries, both by authorized and unauthorized manufacturers, although the main three captured the most significant part of the business. Original patent rights were enforced and defended everywhere from the beginning. Patent infringements by any unauthorized manufacturer were automatically pursued and litigation (or threats of such action) was common.[19] The initial patent-document fine-tuning for each institutional system and the concealment of key technological information when it was possible meant that Otto, Deutz, and its main partners were ready to firmly use IPRs to fight and eliminate competition involving not only the four-stroke cycle but any similar compression engine, such as the two-stroke engine (Torrens, 1992: 248). The claims were written so as to widen the patent scope as much as possible, especially in France, Spain, and Germany, and to a certain extent also in the UK and Sweden. This was a common strategy then and now for blocking as many competitors as possible and a key factor when litigation occurs (Merges and Nelson, 1990; Usselman and John, 2006).

After Otto's breakthrough technology, Deutz used not only the power of innovation *per se* to acquire competitive leadership but also the power of patents, attorneys, and other legal instruments to establish and defend the monopoly and, thus, to control the markets. These too were common strategies used by other corporations (van Rooij, 2012: 1118). In this framework, it made sense to register the patent everywhere regardless of the character of local patent institutions or final results. Again, this was a common strategy used by multinationals during the end of the nineteenth century and the first half of the twentieth century (Sáiz and Pretel, 2014). This may explain the concealment of key technological information when possible, especially during the first stages of Otto's innovation and internationalization; pioneers "dislike disclosure because it lowers the cost of rivals who want to enter the protected market" (Scotchmer, 2012: 104; see also Gans and Murray, 2012). Moreover, the level of patent disclosure is inversely linked to patent scope. The more generally an invention is described and the wider the claims are written, the greater the monopoly potential, which extends to litigation and risks.[20] The easiest way to file for a patent would be to use the same document everywhere; thus, patent fine-tuning and strategic management had to be worth the time and cost. A few years, or even months, might be long enough to allow the inventor a strong start and a secure distance from imitators, who, in the absence of full disclosure, would be forced to reverse engineer the invention and create practical tests to reach the technological frontier. The pioneer firm's rapid growth and high returns would also allow it to allocate resources for launching legal battles, blocking competitors, and maintaining the monopoly.

As mentioned earlier, the American, British, and German patents were the main pillars for Deutz's business, although the patents also faced legal conflicts. The first serious threat began in Germany in 1882, when Deutz unsuccessfully fought a patent application by Gerhard Adam, a Munich competitor (Cummins, 1989: 173–175). Christian Reithmann, a witness in the case, claimed to have previously built a four-stroke device, which led Deutz to sue him in 1883 for his damaging testimony. Despite a significant lack of evidence, the court ruled in favor of Reithmann in 1884, although further appellation to a higher court reversed that decision. Otto's patent blocked many competitor firms wanting to manufacture similar devices, and Deutz systematically pursued competitors claiming four-stroke engine inventions. However, the hunting season had been opened. In 1884, for example, C. Wigand, a German patent attorney, uncovered and published Beau de Rochas' 1862 patent, which, as mentioned earlier, described a theoretical

19 See, for instance, a letter sent by Crossley Brothers, the licensees in the UK, to the editor of a contemporaneous specialized journal (*Engineering*, April 27, 1883, 391): "It may be of more than passing interest to some of your readers to know that Mr. Otto has been obliged again to take action against several firms for infringing his patent. . . . The public should know, that after the action of *Otto v. Linford* (in which Linford was defeated and ordered to pay costs and cease to manufacture), purchasers and users of the Linford engine were obliged to pay royalty to Mr. Otto."

20 For several cases at the US Supreme Court concerning patent scope during the 1870s and 1880s, see Usselman and John.

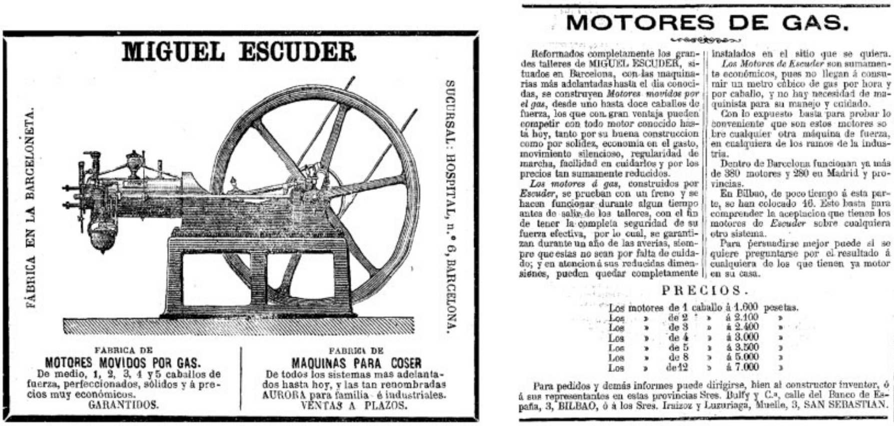


**Figure 5**. Two advertisements in Spanish newspapers for four-stroke engines, produced by Miguel Escuder in Barcelona.

*Sources*: Left: *La Vanguardia*, February 2, 1881, 14. Right: *El Fuerista: periódico católico, Dios, Patria, Rey*, No. 512, October 4, 1889.

four-stroke cycle, although no engine had been built and, thus, there were no thermodynamic or experimental data. Ernst and Berthold Körting, significant manufacturers from Hannover, Germany, used this information to file suits against Deutz's monopoly. The Körting Brothers won their first case in January 1886, as they also did when faced with further appellations.

Otto's patent, pride, and, especially, his business monopoly were officially broken in his own country. Adam and Körting openly competed with Deutz by manufacturing similar engines. Moreover, the same conflict extended to the French, American, and British patents, and other problems arose in Spain. For example, an engine designed in 1884 by M. M. Delamare-Deboutteville and Maladin, called "Simplex," and manufactured by M. M. Matter and Cie., in Rouen, competed with Otto's four-stroke engine in the French market. Immediately, Deutz sued them (Donkin, 1896: 135). Others sources note that there were several court actions for patent infringements during those years in Paris, such as *Otto v. Frères Rouart* (Marbach, 2013: 80). Deutz lost these court battles, first in August 1885 and again in November 1888.[21] The "French" Beau de Rochas cycle was again the key issue. Meanwhile, in neighboring Spain, the situation was as complex as it was interesting. According to Spain's 1826 patent law, under which Otto's patent had been granted, compulsory working of the invention was required (i.e., manufacturing the engine in the country) within 1 year of the grant date, which in this case was December 1876. A mechanical engineer certified the existence of a Deutz four-stroke engine in June 1878 in a button factory in Madrid, and Otto's patent attorney in Spain declared that this engine had been built in a mechanical workshop in Barcelona. Nevertheless, the patent office required more information, which was sent by another mechanical engineer a month later, in July 1878. However, he reported that the button factory in Madrid was not an engine workshop and that the engine had been manufactured in Germany, according to its label (Amengual, 2008: 97, 98). Thus, in October 1878, the patent in Spain was canceled and the four-stroke technology entered into public domain.

This may be how Miguel Escuder, a Catalonian engine factory owner, was able to manufacture and even repatent Otto's invention. The Spanish patent law was designed to encourage industrialization by requiring compulsory working clauses and by granting 5-year "patents of introduction" to anyone ready to locally manufacture others' inventions, provided that such technology was not already being manufactured in Spain (although importations could never be blocked). Escuder applied for two patents of introduction concerning four-stroke engines (basically Otto's model) in December 1878,[22] just as Otto's patent had been voided. Thus, while Otto lost his rights in Spain, a local manufacturer began to produce and sell the engine. Deutz's response was quick. First, court actions were filed to void Escuder's patents of introduction and destroy the engines he had built. Second, Deutz's new patent attorney in Spain lobbied and then applied for a patent rehabilitation to the Spanish patent office by arguing that the previous

21 *Le Génie civil. Revue générale des industries françaises et étrangères*, June 25, p. 544.
22 OEPM, Patents of Introduction Nos. 157 and 158.

mechanical engineer had made significant mistakes: the engines were indeed manufactured in Barcelona, starting in 1876. In the first tactic, Otto lost in the courts because patents of introduction were apparently legal and Otto's original rights were voided—even though by the time judgment was handed down in 1885, Escuder's 5-year patents had expired (Cabana, 1992, vol. 1: 129, 130). With the second tactic, Otto succeeded. After receiving a new certificate signed by another mechanical engineer in July 1879, assuring that Otto's engines were manufactured in a workshop in Barcelona, the patent was readmitted by the Spanish patent office and declared into practice in 1880. However, with or without patents, Otto could not stop Escuder, whose company continued to sell four-stroke engines until 1910 (Figure 5). Escuder offered machines from one horsepower to 12 horsepower at lower prices, but he produced no more than 300 engines before closing his firm. Escuder was not "defeated" by Otto's patents in Spain, but by the Crossley Brothers, Otto's licensees, who dominated the Spanish market via exportations from the UK (Ortiz-Villajos, 2014: Figure 1). Therefore, Escuder and his engine were defeated by competition in the international market.

Deutz's intangible assets held in the United States—where the most significant subsidiary of Deutz was established—or in the UK—from where the Crossley Brothers flooded Europe with four-stroke engines—were more relevant than the Spanish or French patents. Undoubtedly, the loss of the German monopoly was difficult, but Deutz had the rights for 10 years (as also occurred in France), which allowed enough time to collect significant benefits and continue business expansion even after the patent was over (Feldenkirchen, 2013: Table 2). Thus, it seems that the lower the disclosure levels and wider patent breadth filed in Germany, France, and Spain meant more legal conflicts, eventually leading to shorter patent terms in these countries. What, then, of the British and American contexts? These patent systems required higher disclosure levels and narrower technical breadth, but did this guarantee stronger property rights and greater valuable intangible assets for Otto's firm in return?

Many followers, in Schumpeterian terms, rapidly filed patents around the key technology, which inevitably landed them in court. For example, during the early years, the Crossley Brothers sued, through Otto, several unauthorized coal gas engine makers in the UK, including Charles Linford in 1880, in one of the most well-known and documented cases.[23] The court case was decided in Linford's favor, but Otto appealed in January 1882.[24] In the second case, Linford was forced to pay judicial costs and cease manufacture, and purchasers and users of Linford's engine were obliged to pay royalties to Otto.

Because of the Beau de Rochas issue, which had led to Otto losing his patent in Germany, a new judicial case occupied the engineering journals in the UK.[25] Crossley Brothers and Otto took action against Robert Steel, an engine manufacturer, whose lawyers used the new information about Beau de Rochas to invalidate Otto's patent in England. However, as published in *The Engineer*, Otto won in 1885.[26] The sentencing included mention of the *Linford* case and the previous decision of the Court of Appeal concerning Otto's patent novelty. The most significant determination in the *Steel* case was to reject the admission of the publication of the Beau de Rochas patent, meaning that the technological information was considered not available when Otto registered his engine. Although the library at the British Museum had received a single printed copy of the handwritten tract in 1864, "inasmuch as the book was not in the reading-room, but in a part of the library not accessible to the public, and could only be obtained by a written order for the book, which would be a written order under the name of the author,"[27] the information was considered not published in the UK.

Thus, every claim related to Otto's British patent was upheld.[28] The Crossley Brothers retained the monopoly on four-stroke engines in the UK until the expiration of the licensed patent in the early 1890s. Furthermore, they continued advertising in specialized journals the superiority of Otto's engine, the validity of the British patent, and the appellation against Körting Brothers in Germany. The Körting Brothers, however, publicly answered by highlighting that the German courts had established that Otto really made no invention but used a combination of known parts,

23 *Otto v. Linford* (1880), High Court of Justice, Chancery Division, before Vice-Chancellor Sir James Bacon.

24 Several specialized journals meticulously followed the case. See, for example, *The Engineer*, April 1, 1881, 233–235, 238, 239 and February 3, 1882, 75–78, 85, 86.

25 *Otto v. Steel* (1885), High Court of Justice, Chancery Division, before Mr Justice Pearson.

26 See *The Engineer*, December 25, 1885.

27 *The Engineer*, January 29, 1886, 91–93.

28 The detailed description of the court case can be found in *The Engineer*, 1886: January 1, 6–9; January 8, 28 and 35, 36; January 15, 47; January 22, 62, 63; February 19, 156, 157.

and that there were no foundation to call Körting's engine an infringement of Otto's German patent. In *The Engineer*, the Körting Brothers wrote, "Anyone can bring actions for infringements of his patents if he has money enough to pay the costs, but it is only possible for him to win such actions when he has law and right on his side. . . . The bare fact that Dr. Otto is attacking us again proves nothing."[29] Indeed, Otto and Deutz extensively and consistently used legal battles to block competitors; after all, business is business and monopoly is monopoly.

This strong patent enforcement in the UK forced other engine makers to develop (and even patent) peculiar mechanisms to get around the Crossley Brothers' claims and its monopoly; this led to a waste of R&D efforts (Gallini, 1992). In 1882, the editor of *The Engineer* complained that within the past 2 years, several firms had applied for more than 250 patents for improvements to that class of machinery, and that the court decisions supporting the Crossley's monopoly could affect a very large amount of capital.[30] After Otto's patent expired, the original engine configuration was rapidly adopted by competing manufacturers that abandoned their other less-efficient devices that had been developed only to avoid infringing the original patent (Donkin, 1896: 120).

After Otto lost the German appellation, he fought the Körting Brothers in the United States by filing a lawsuit in 1887 against Körting's subsidiary, the Körting Gas-Engine Company Limited, for patent infringement. This subsidiary had been established in New York in 1886 to manufacture vertical gas engines to sell to the vast American market mainly occupied by Deutz's US subsidiary, Schleicher, Schumm & Co. As had previously occurred, defendants brought the Beau de Rochas patent before the USPTO. The US patent system was the only system that guaranteed patents to first and true inventors, not to first applicants. Thus, the Beau de Rochas patent posed a significant danger. However, the case never even made it to trial because the USPTO stressed that an inventor had to show "diligence in reducing his invention to practice" (Cummins, 1989: 176) and, as we have already shown, that was not the case with Beau de Rochas. Therefore, other inventors may be granted American patents for the same theoretical cycle provided that they improved the idea by actually building the machine, which Otto had done.[31] Although 100 Körting engines were manufactured and delivered along the East Coast, it seems that Körting Gas-Engine Company Limited halted manufacture after the patent conflict. Some sources blamed the poor quality of US-made Körting engines as compared to the German-made originals,[32] but the legal strength of American patents, and thus of Otto's intangible assets, also may be the main reason for such a decline.

The British and especially American patent systems—the ones that required higher disclosure levels and more accurate novelty claims—proved to provide valuable intangible assests also for other innovators. For example, there is some evidence in the literature that confirms that British patents were stronger than Belgian and German patents in protecting Wilhelmus van Berkel, a significant Dutch inventor and business man (van Rooij, 2012: 1136), and that the United States successfully recognized and licensed the patent for Joseph Day's two-stroke engine, even though Day encountered constant opposition and court battles in the UK (Torrens, 1992: 259). In Otto's case, both patent systems strongly supported his rights, although the US system was superior. The USPTO's previous technical exams required a higher lever of disclosure and concretion, but in return US patents were both less expensive and more enforceable. This led to the development of a consolidated market for technology in which Otto had few legal problems. Nonetheless, in both countries, competitors were blocked and Deutz's subsidiaries, the British Crossley Brothers and the American Schleicher, Schumm & Co. (later, the Otto Gas Engine Works) grew, expanded, and turned into central pillars of the mechanical engineering and motor industries.

Moreover, even in the countries in which Otto's rights were weakened, the patents remained key assets for the company. The industrial, corporate, and nationalistic Germany invalidated Otto's patent, allowing competitors to enter the market, but only after 10 years of successful monopoly. This head start also allowed Deutz to retain significant market share and continue entrepreneurial development. Similarly, in France and Spain, where, on the one hand, the Beau de Rochas patent, and on the other hand, compulsory working clauses and patents of introduction,

29 See Crossley's letter and Lindeman's retort (on behalf of the Körting Brothers) to the editor, *The Engineer*, 1886: April 2, 265, and April 9, 278, respectively.

30 *The Engineer*, February 3, 1882, 85.

31 *Nicolaus August Otto v. the Körting Gas-Engine Company Limited: George W. Sillcox, Maxemo E. Mora, William J. Dougherty, Frederick S. Blackall, and Elija S. Parker*, Complainant's Record (Prima Facie Proofs) (1889), Allen, Lane & Scott: Philadelphia.

32 See description and figure in Vintage Machinery, "Korting Gas Engine Co., Ltd." http://www.vintagemachinery.org/mfgindex/imagedetail.aspx?id=7665 (December 2015).

led to a monopoly interruption, Otto was able to initially maintain exclusive rights, after which he initiated ongoing litigation in defense of his patents. In France, competitor manufacturers emerged, as occurred to a lesser degree in Spain. However, in the latter case, Crossley Brothers' exportations and leadership helped to wipe out what little competition arose.

We have not discussed Sweden because we have not been able to find litigation evidence in that country. It seems Otto's patent had similar enforcement as in other parts of Europe. The Swedish patent system required compulsory working within either 2 or 4 years, and the patent office required demonstration of it throughout the patent term. For Otto's patent, there are official certifications between 1878 and 1889 that proves that the patent was in practice. In 1881 a report signed by two engineers, Carl Gerner and J. A. Holmgren, stated that Otto's invention was being manufactured in Malmö.[33] We must remind readers here that Otto's first 9-year patent in Sweden was extended to 15 years after 1884, and that Sweden's patent's technical disclosure was similar to that of the United States and UK. Indeed, as occurred in these two countries, Otto retained his rights in Sweden until the end of 1891.[34]

## 5. Conclusion

> Patents are supposed to spread knowledge by obliging holders to lay out their innovation for all to see; they often fall, because patent-lawyers are masters of obfuscation. Instead the system has created a parasitic ecology of trolls and defensive patent holders, who aim to block innovation.[35]

Two of the most significant issues for the historical justification of patents have been that they enable disclosure and an open science system through which knowledge spreads, and without which inventors and firms would not be stimulated to conduct research and new ideas would be secreted, leading to a decline in technological progress. However, from the innovator's perspective, disclosure is always a problem because it immediately facilitates competition by both blatant imitation and true developments based on the original knowledge. Although patent institutions can force disclosure through compulsory previous technical exams, innovators can also fine-tune their specifications and drawings in order both to keep key knowledge outside of the patent and widen the potential monopoly's scope. Such strategies have certain risks, both when facing previous technical exams or court litigation, depending on the character of each patent system and enforcement frameworks. However, the innovators' dilemma when dealing with disclosure may have a strong bias toward concealment.

Although scholars agree that patent disclosure is essential, the topic has attracted very little academic research. There are few empirical studies on the levels of patent disclosure and the distinct strategies followed by inventors and innovative firms with respect to knowledge management. The initial example of Watt's 1769 separate condenser, a true revolution in steam engines technological trajectory, demonstrates how a patent with vague specifications and no drawings was successfully and broadly enforced for more than 31 years, which certainly damaged competitors and society and blocked further innovation. Moreover, evidence suggests that without previous technical exams and institutional controls, eighteen-century and early nineteenth-century inventors systematically left off essential parts of their inventions from patent specifications (Johns, 2009: 258, 259). That was the reason why the United States introduced technical exams, which eventually if slowly spread across other developed countries throughout the late nineteenth and twentieth centuries. Evidence from previous business history case studies suggests that multinationals also carefully managed patents as legal weapons to control markets (van Rooij, 2012).

In this article, we explored the emergence of a significant nineteenth-century radical innovation and disruptive business: the four-stroke engine invented by Nicolas August Otto in 1876. The new technology provided a large commercial opportunity, which is why it was immediately patented and licensed worldwide and imitated worldwide too. When Otto registered his invention globally, national patent systems differed considerably; for instance, whether previous technical exams were required. We studied the original patents on Otto's four-stroke engine in the United States, UK, Germany, France, Sweden, and Spain to disentangle the process of patent internationalization followed by Otto and Deutz. Our research and analysis found specific findings: (i) there was a lack of key disclosure in all the documents, and no patent offered sufficient thermodynamic data or complete explanations of the key devices; (ii)

33 Malmö is also where Gerner founded his engineering firm, AB Carl Gerner.

34 Riksarkivet, Kommerskollegium, Ingående diarium för patent, Vol. 1877, Otto, 121.

35 *The Economist*, "Time to Fix Patents," August 8, 2015, 9.

there was no disclosure included in the German, French, and Spanish patents, which offered Otto wide patent breadth, but demonstrated less enforceability over the long-term; (iii) the US patent required the most detailed specifications, claims, and drawings, followed by the UK and Swedish patent systems; and (iv) Otto and Deutz followed a coherent and meticulously planned international patent extension program that used distinct timing, specifications, and drawings according to the different systems but always constraining as much key information as possible.

Regardless of system requirements, all these patents were immediately used, licensed, legally enforced, and defended by all means necessary during Deutz's worldwide expansion. Infringements and legal battles were common, but Otto, Deutz, and their licensees were proactive in pursuing legal actions against all possible competitors. Otto's patent was finally defeated in Germany, France, and Spain, where his monopoly did not exceed 10 years. In the United States and the UK, two of the main producers of four-stroke engines, the patents remained valid and stopped direct competitors throughout the terms of the patents (17 and 14 years, respectively), as well as in Sweden, where the original 9-year patent was extended to 15 years. Otto's business also flourished in Germany, and to a lesser degree in France and Spain through imports from the UK.

Several lessons can be learned from this case study with respect to innovators' disclosures, multinationals' protection strategies, and patent institutions' economic consequences. First, as occurred with Watt a hundred years prior, Otto's case demonstrates that innovators have a strong tendency to conceal important aspects of their inventions. For example, Otto and Deutz widely used fine-tuning tactics in their disclosures to control knowledge and capture markets. The easiest way to patent internationally is to translate the same specifications; thus, their disclosure strategy was deliberately designed to gain time and market share by making competition difficult. Second, their initial high returns allowed allocation of resources to launch legal battles worldwide to retain their monopoly. Indeed, Otto and Deutz were quite successful in strategically managing worldwide patents and their subsidiaries; this demonstrates a careful knowledge of both international patent institutions and the engine sector, which led to long-lasting, globally favorable results. Third, as economic theory predicts (Scotchmer and Green, 1990), as well as evidence from other case studies (Torrens, 1992: 259; van Rooij, 2012: 1136), the patent systems that required higher disclosure levels (the United States, the UK, and Sweden) offered Otto and Deutz strong protection against imitators and, therefore, facilitated their international monopolies. Finally, as also in the case of Watt, when patents do not enable disclosure and are used as legal weapons against competitors, they induce heavy social costs not only by selling the new technology at prices above factor's marginal cost and by blocking fair competition but also by wasting R&D efforts related to changing the patented technology enough to qualify as a new invention.

This case study has demonstrated that corporations, inventors, and agents can obtain patent monopolies without total patent disclosure, and that such lack of disclosure is more than usual, even in patent systems with difficult previous technical exams. Although mechanical devices may be disentangled through reverse engineering, chemical inventions cannot be. For example, the US administration expropriated patents from the German chemical industry after World War I through creation of the Chemical Foundation, which first bought and then managed the confiscated intangible assets from German corporations. The purpose behind this process (Steen, 2001, 2014) was to launch and support the American synthetic organic industry, previously dominated by Germany. It was believed that the German patented information would give essential technical knowledge to US manufacturers, but prominent chemists at American universities and at chemical firms testified[36] that patent specifications systematically excluded vital information, making it impossible to produce dyes and other chemical products: "Industrial chemists were required to invest an extraordinary amount of time conducting additional research to obtain commercial products supposedly covered by patents. In no case did the manufacturers make a commercially viable product from the patents without gaining supplementary information." In many cases, the only way to transfer knowledge was to employ chemists from defeated Germany because patents did "not have any practical value without the know-how." The conclusions are straightforward: the United States aided its synthetic organic chemicals industry not by diffusing technical knowledge from German patents but by using confiscated patent rights against the German firms, for example, through the collection of royalties on imported German products (all from Steen, 2014: 376–379).

Although total disclosure has always been the point behind patent protection, scholars specialized in IPR studies affirm that, even today, it is "usually impossible to build a functioning device or software program from a modern patent application" (Boldrin and Levine, 2013: 9). Patentees had—and still have—a strong tendency to conceal vital

36 *United States v. The Chemical Foundation, Inc.*, 272 U.S. 1 (1926), US District Court of Delaware, before Judge Hugh M. Morris (1923). See Steen, 2014: 368.

knowledge, fine-tune specifications, and use patents as legal weapons. More historical case study analyses, such as the one carried out in this article, are needed, because research may shed light on the consequences of allowing (i) long-term patents that do not include total disclosure, and (ii) strategies that block competition and corner markets for the patentee holder. These are harmful efforts in which corporations usually succeed but also in which expensive and usually pointless R&D occurs for other companies; important knowledge remains hidden, and societal costs in the way of advancement can mount.

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