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KNOWLEDGE DISCLOSURE, PATENT
MANAGEMENT, AND THE FOUR-STROKE
ENGINE BUSINESS

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**DEPARTAMENTO DE ANÁLISIS ECONÓMICO:
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Knowledge Disclosure, Patent Management, and the Four-Stroke Engine Business

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ABSTRACT:

The appropriateness of patent systems has been largely discussed and has led to substantial theoretical debates and empirical analyses. One of the most significant arguments in favor of patents is that they enable knowledge disclosure, which would compensate their social cost. Through an evolutionary approach to a key case study based on a radical innovation and business –the four-stroke engine invented by the German Nicolaus August Otto in 1876– we provide new and fresh insights on the disclosure issue, on patent management hidden strategies, and on patent institutions and controversies.

JEL: N70, N83, O32, O33, O34

Keywords: Patent Disclosure, IPR Management, Thermal Machines, Four-Stroke Engine, Otto

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1. Introduction

During the last two hundred years, intellectual property rights (IPRs) and patent systems have spread unstoppably throughout the world, from nineteenth-century North Atlantic industrialist economies to the twenty-first-century poorer countries of Africa. At the same time that old *Ancien Regime* privileges were avoided in the name of freedom, property, competitiveness, and markets, intellectual monopolies were justified by the own fathers of liberalism and economics, including Smith, Bentham, Say or Mill. Step by step patent regimes extended and consolidated while classical economics accepted them as the less damaging solution for promoting innovation. However, then as now, there were also harsh patent opponents that did not accept any of the defendant's justifications: that there is a natural right to (intellectual) property; that this kind of monopolies facilitates appropriation and reward creators for the social benefit contributed; that without these monopolies there would not be any incentive for technological progress; and, as a consequence, that they are granted in exchange for secrets facilitating an open-science world (Machlup, 1958: 20–1). And now as then, challengers point at the harmful and blocking effect of patent monopolies, which would diminish social benefit; question the incentive argument, arguing that free competitiveness would drive technical progress; and doubt that patents encourage total disclosure (Boldrin and Levine, 2005, 2008a). Notwithstanding, patents remain in our globalized economy stronger than ever.

In the course of the nineteenth century, IPR opponents gave rise to the so-called “patent controversy”, that still emerges from time to time and that reached a significant peak between the 1850s and 1870s in the United Kingdom, France, Germany, Holland or Switzerland. An anti-patent movement that caught the eye of contemporary journals and magazines and that –with “honorable” exceptions such as the lack of any patent system in Switzerland until 1888 or, more remarkable, the abolition of patents in Holland between 1869 and 1912– did not succeed (Machlup and Penrose, 1950). On contrary, firms and corporations progressively poured and took over patent systems everywhere while international agreements arose to globalize IPRs (Penrose, 1951). The second industrial revolution (SIR) led to an exponential increase of patent and trademark grants while first multinationals extended and worldwide exercised their brand-new rights. Recent research demonstrates that such IPR enforcement led to a “patent litigation explosion” between the 1870s and 1890s even bigger than today (Beauchamp, 2016). During the twentieth century, patent systems and corporate patenting were generally accepted while the academy avoided any economic discussion.

However, during the last decades patent studies have flourished in many theoretical and applied areas and the controversy has arisen again, especially when discussing or testing the incentive effect of patents on invention activity, the balance between social benefits and damages, and the disclosure issue. Indeed, the latter argument has attracted little scholars' interest, and when it did it has been mainly focused in the trade-off between patents and secrecy, assuming that patents reveal technological information otherwise not available (Dasgupta, 1994; Gans and Murray, 2012). Thus, IPRs would play a key role as long-term technological progress and optimal allocation of research resources would depend on the rapid disclosure of new findings, in order to be quickly confirmed or rejected, which would maximize the rate of growth (David, 2003). For this and other economic reasons, such as cost reduction for rivals trying to achieve further progress around the invention, disclosure would be essential for the social welfare (Scotchmer, 2012: 105). However, how much information do patents really disclose? If technology is not just a synonym of information and it requires tacit knowledge to be properly implemented, then patent specifications would always provide insufficient disclosure levels (Pavitt, 1987: 185; Nelson, 1989: 236).

Furthermore, in specific circumstances such as in sequential innovation processes and patent races, innovators may be very reluctant to disclose because it directly make

competition more potent. Patent institutions and practices can influence disclosure levels by, for instance, establishing previous technical exams for novelty and patentability. Indeed, there is a permanent tension between novelty and patent claim requirements, on the one hand, and disclosure on the other. The absence of technical exams or its low quality might lead to concealment, but if inventors and firms are forced to disclose then patent protection should be increased and reinforced to avoid negative externalities on research investment levels (Scotchmer and Green, 1990). The strength of such protection will depend on patent enforceability, monopoly duration or life (patent length), and technical scope (patent breadth) –that is, whether similar technologies can be blocked or not; to which we should also add the innovation market size. Several scholars think that patent breadth should be wide enough when there is strong innovative competition with the possibility of a rapid turnover in the market, and highlight the necessity of allocating strong patent rights to the first inventor to encourage disclosure, which would facilitate new generations of innovations, although they are aware that a very broad patent scope may be not optimal for opposite reasons (Scotchmer, 1991; O'Donoghue et al., 1998). Notwithstanding, other scholars outline that, as total disclosure and perfect claims are difficult to guarantee, broad-in-scope patents and strong property rights will really damage the social welfare by diminishing further innovation and expanding litigation (Merges and Nelson, 1990). Another negative effect may be R&D waste caused by an inefficient allocation of resources when competitors invest in ways of bypassing the key patent, developing unproductive or less-suitable devices. Combining enough patent breadth with short duration would diminish competitor's incentives to invent around (Gallini, 1992).

Thus, despite the theoretical, applied, and even historical research carried out during the last decades, conclusions are not definitive and we still deal with the same paradoxes. As can be found in almost any manual of industrial organization, by blocking competitors and selling at prices above factors' marginal cost the patentee obtains a significant part of the social benefit of the invention in exchange of technological information disclosure (see, for instance, Carlton and Perloff, 2000: Chapter 16). However, as the patent length, technical breadth, and market size increase so would do social damage (Boldrin and Levine, 2009), very especially if patents are not enabling disclosure. Furthermore, the nowadays much-reviled patent trolls, patent thickets, or the extension of IPR litigation, are not recent phenomena and date back to the second half of the nineteenth century (Beauchamp, 2016). For the most critic scholars, legal suits, law firms, and court costs have completely distorted innovation processes (Bessen and Meurer, 2008).

Therefore, the discussion on patent systems is as complex as unresolved. The main questions are still unaddressed: Are patent monopolies necessary to promote and facilitate innovation? Are they indispensable in all economic sectors? If invention prizes and other similar initiatives that are recently gaining supporters are not really serious alternatives to IPRs –as historical evidences demonstrate (Khan, 2015)–, then how much time must patents last and how wide in scope must the protection be? Could IPRs generate wastefulness and more social costs than benefits? And our essential research questions: Do patents really encourage technological disclosure? How do corporations and multinationals really manage such monopolies and intangible assets? To which extent are patents more legal weapons to be launched against monopoly challengers than justified prizes to compensate R&D expenditures? And, eventually, could technological progress emerge solely from market competition in a world without patents?

In this work, we aim to shed some more light to all these issues by focusing on a key case study: the emergence and first evolution of the four-stroke engine technology and business. When the German Nicolaus August Otto built the first prototype in Cologne –a

radical innovation that opened a long-term technological trajectory on which we still live—several firms were created to commercialize the new invention. In doing so, patents were perceived as a key tool to secure intangible assets at the dawn of the SIR, when international IPR agreements were also being developed. Herein we meticulously analyze such innovation process and patent activity driven by Otto and his firms, as well as its ups and downs in several pioneer, first follower, and lagging countries, in order to find out how domestic and international IPRs were managed and what patent strategies, institutional constraints, and business results were respectively followed, faced, and obtained. Thus, besides theoretical, applied, and statistical approaches the case-study methodology would be appropriate as a complementary support for the understanding of such a complex social phenomena as patent institutions and strategies, which are totally linked to organizational and managerial processes—where this methodology can be really useful (Yin, 2009: 1)—and to business studies in general—where is one of the most powerful methods employed (Dul and Hak, 2007; Woodside, 2010).

Our findings disentangle patent management hidden strategies, deepen into the disclosure problem, assess the effects of distinct international patent institution, and offer new and fresh insights into the current “patent controversy”. Results deploy throughout the article as follows: Section 2 investigates thermodynamics and the four-stroke engine technology from an evolutionary approach, indispensable for the understanding of the process of technical advance in the sector and the display of further inquiries and findings; Section 3 shows how the gas-engine business emerged and worldwide internationalized in a few decades; Section 4 demonstrates the key role of patents in the internationalization process and how Otto and his agents tuned specifications and drawings according to different patent systems; Section 5 provides evidence on how Otto used IPRs to globally monopolize the business, suit imitators, and extent patent litigation, as well as on its consequences for the sector; finally, Section 6 concludes.

2. Thermodynamics and the internal combustion engine technology

If we consider thermodynamics as a *technological axiom* based on heat and its relation to energy and work, then we could establish at least four main technological paradigms and trajectories (Dosi, 1982, 1984: 2.2; Teece, 1988) concerned with clearly distinct thermal machines: 1) reciprocating steam engines, 2) reciprocating internal combustion engines, 3) steam turbines, and 4) gas turbines. Though they were thermodynamically related, each one required for its development of specific theories, particular thermal cycles, key radical innovations, and certain technological convergences from other scientific and technical fields that led to distinct timings and evolutionary paths.

The Newcomen’s atmospheric engine (1712) and Watt’s advances on steam machines (1769-1782) pushed upward the first of those technological trajectories that would feed the nineteenth-century impressive industrial and economic shift. The evolution of the reciprocating steam engine reached its maturity between 1870 and 1914, progressively entering into technological diminishing returns (Wolf, 1912; Kuznets, 1930: 11; Freeman et al., 1982: 70; López-García, 1997: 86–95; Perez, 2009: 186)¹ and favoring research and developments of new thermal machine specimens. Before WW I, the internal combustion engine and the steam turbine trajectories had been totally arisen through key radical

¹ Julius Wolf was the first author in raising the significant notion of technological diminishing returns at the beginning of the twentieth century (the “Wolf Law”).

innovations that spread at the heat of the SIR². Likewise, during the 1930s, previous knowledge on turbo compressors (Meher-Homji, 2000: 290–1)³ and gas turbine first prototypes⁴ converged with metallurgical and aerodynamic advances into the last thermal machine trajectory: the industrial and aviation gas turbine.⁵

Table 1. Power provided by the key radical innovations in the four trajectories of thermal machines and some data related to its size (1712-1939)

Trajectory	Engine	Year	Power (kW)	Piston Diameter (cm)	Piston Stroke (cm)
<i>Steam Engines</i>	Newcomen	1712	4.1	53.3	233.8
	Watt	1769	12.7	127.0	96.5
<i>Internal Combustion Engines</i>	Lenoir	1860	0.7-1.0	18	10
	Otto	1876	2.3	16.1	30.0
	Diesel	1897	13.3	25.0	40.0
<i>Steam Turbines</i>	Parsons	1890	350.0	--	--
	Rateau	1901	220.0	--	--
	Curtis	1900	500.0	--	--
<i>Gas Turbines</i>	Brown & Boveri Co.	1939	4,000.0	--	--

Source: Amengual (2008: Tables 10 and 11)

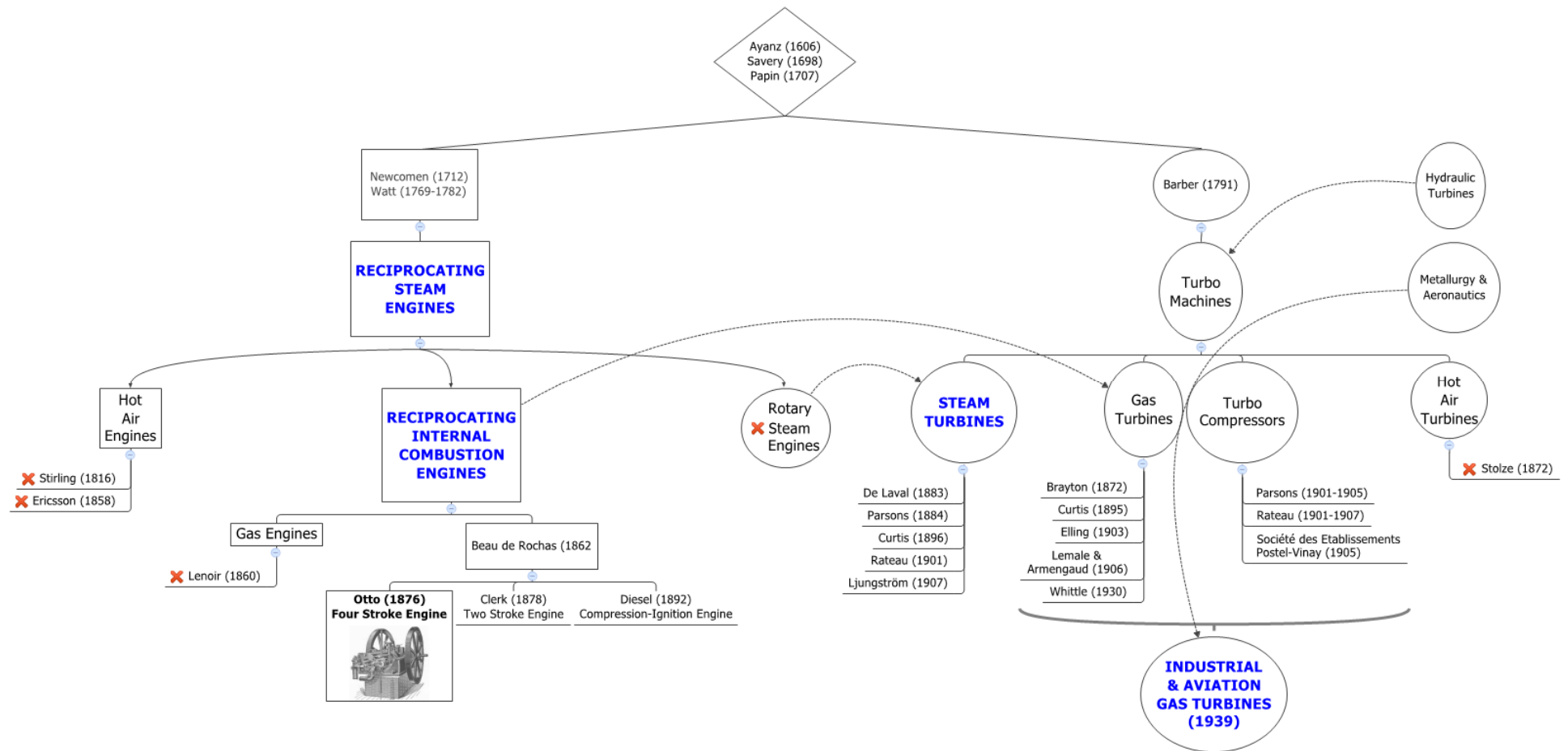
² The scientific knowledge and radical innovations that opened and widen the reciprocation-internal-combustion-engine trajectory (Lenoir, Beau de Rochas, Otto, Clerk, and Diesel) are detailed further in this section. The steam-turbine trajectory was spread by key innovations such as the impulse and reaction turbines, designed by Gustaf De Laval in 1883 and Charles Algernon Parsons in 1884 respectively, and subsequent compound devices such as the multi-speed impulse turbine devised by Charles Gordon Curtis in 1896, the multi-stage impulse turbine built by Auguste Camille Edmond Rateau in 1901, and the radial reaction turbine designed by Birger and Fredrik Ljungström in 1907.

³ Strictly speaking, an industrial or aviation gas turbine is composed by two machines: the turbo compressor and the own gas turbine. Although not-yet-achieved significant advances in metallurgy and aerodynamics were required for developing and building efficient turbo compressors, the previously mentioned Parsons and Rateau also pioneered research in such devices and built the first prototypes during the 1900s.

⁴ George Bailey Brayton established the theoretical cycle of gas turbines in 1872. The first designs raised through the work of the aforementioned Charles Gordon Curtis, who proposed and patented a gas turbine in 1895, of Aegidius Elling, who built in 1903 a first working prototype, of René Armengaud and Charles Lemale, who also built a gas turbine in 1906, and overall of Frank Whittle, whose radical innovations concerning the turbojet engine, in 1930, would facilitate the actual extension of the gas turbine trajectory.

⁵ In 1939, the first industrial gas turbine (in the strict sense of the term) for generating electricity was installed in Neuchâtel (Switzerland) built by Brown Boveri & Co and developed by several engineers such as Claude Seippel, Georges Darrieus, Jean von Freudenreich, Kurt Niehus, Hans Pfenninger, and Willy Burger.

Figure 1. Basic diagram of the thermal machine evolution (1712-1939)



Note: ✗ indicates ended or non-developed evolutionary paths. The four main thermal machine technological trajectories are highlighted in CAPITAL letters. The arrows indicate links and influences among distinct trajectories. Source: See Amengual (2008) for a full explanation based on detailed analyses of each trajectory and (Greiner, 1918: 139–40) for data on hot air turbines.

Although the four trajectories deserve being deeply scrutinized, and the last three remain currently integrated in distinct significant technology systems in our techno-economic paradigm (Freeman, 1994; Perez, 2009),⁶ herein we will only focus on the reciprocating internal combustion engine and, overall, on Nicholas August Otto's four-stroke motor, firms, patents, partners, and vicissitudes. As it is schematized in Figure 1, once the reciprocating steam engine had extended and matured research and experimentation led to substitute the steam –as the working fluid within the cylinder- first with hot air, then with a mixture of air and coal gas, and finally with other petrol gas explosive combinations. Hot air engines were developed and built by Robert Stirling⁷ and John Ericsson⁸ during the first half of the nineteenth century and were limitedly commercialized during the following decades for domestic or workshop low-power applications as well as for maritime transport (Stouffs, 2011; Duffett, 2014). The coal gas engine patented by Jean-Joseph Etienne Lenoir⁹ in 1860 was much more relevant because it inaugurated the internal combustion era on the basis of burning a non-compressed mixture of gas and air ignited by sparks. Notwithstanding, the lack of charge compression restricted the engine efficiency and limited sales and later developments (Payen, 1963). In fact, by the end of the nineteenth century both hot air and coal gas engines had been totally surpassed by new alternatives and formally condemned to extinction.

The actual development of the reciprocating internal combustion machine primarily required of new scientific knowledge that was facilitated by Alphonse Eugène Beau de Rochas in 1862, when he accurately detailed in a patent document the four-stroke engine thermodynamic cycle (intake, compression, combustion, and exhaust).¹⁰ Nonetheless, Beau de Rochas neither included any technical drawing in the description nor built or developed any engine, at least to the extent of current knowledge. That is the reason for what Nicolaus August Otto remained in the history of technology as the true designer and builder of the four-stroke motor, to such a point that its theoretical cycle is also known as the “Otto cycle”. However, whether or not Beau de Rochas built any engine, the fact is that his 1862 patent would cause Otto and his business a lot of problems, as we will see further on.

Born in Germany in 1832, Otto did not have any engineering education although he was trained in mechanics and extensively experienced in both technological and business issues. He was a real “tweaker” (Meisenzahl and Mokyr, 2012). While working as a trader he knew about the Lenoir's gas engine and was totally convinced of the virtues and commercial possibilities of the new technology. Thus, he immediately began to work in coal gas engines until building his first prototypes in 1861 and 1862. In 1864 Otto went in partnership with Eugen Langen, a well-trained mechanical engineer, with whom he improved and patented new atmospheric gas engine arrangements, and with whom he would build and sell hundreds of

⁶ Technology systems formed by distinct innovations and technological trajectories economically related through several sectors, which also led to long-duration techno-economic paradigms (usually originated by technical revolutions).

⁷ The first Stirling's patent for a “Heat Economiser” was presented in November 6, 1816 in England (The British Library [BL], The Patent Office [PO], patent n. 4,081).

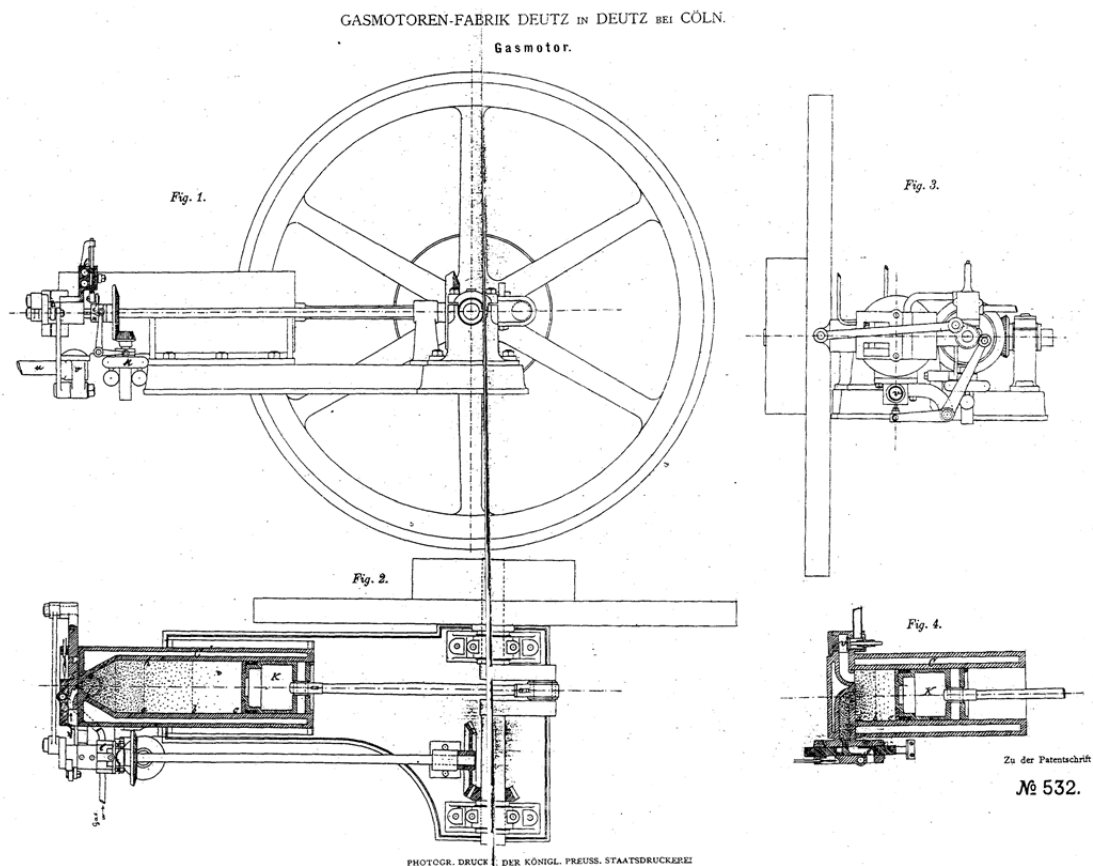
⁸ Although Ericsson worked between the 1830s and 1850s in “Caloric Engines”, his first patent for an improved “Air Engine” was applied for in December 14, 1858 (United States Patent and Trademark Office [USPTO], patent n. 22,281).

⁹ Lenoir registered his first patent in France as a “moteur à gaz et à air dilaté” in January 24, 1860 (*Institut National de la Propriété Industrielle* [INPI], brevet n. 43,624)

¹⁰ Beau de Rochas described the cycle in a lengthy and unusual patent presented in France in January 16, 1862 (INPI, brevet n. 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”, in which he presented a real mix of inventions and also ramblings around non-related issues. In the page 48 of such a patent, he perfectly explained the four-stroke engine theoretical cycle.

such kind of machines (Cummins, 1989: 138–43). In 1872 two other experienced engineers, Gottlieb Daimler and Wilhelm Maybach, joined Otto and Langen, which in fact gave birth to one of the best and more creative technical teams specialized in thermal engines at that time. With Otto in charge the partnership facilitated the improvement of atmospheric gas engines, the expansion of the business, and the exploration of new paths. However, each one of these engineers had their own styles and intuitions and it was Otto who finally invented the first four-stroke engine patented by the firm in 1876.

Figure 2. 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* (DPMA), patent n. 532, applied for in June 5, 1876 as a “Gasmotor” by Gasmotoren-Fabrik Deutz.

Otto’s four-stroke cycle and motor meant a huge technological shift from all previous thermal machines and internal combustion engines both in terms of power with respect to size and of scalability (Table 1). In fact, the motor represented in Figure 2 was the actual direct ancestor to all kind of modern reciprocating combustion engines and the one which really pushed upwards the technological trajectory. Two other later developments and theoretical cycles completed the paradigm: the two-stroke engine built by Dugald Clerk in 1878¹¹ as well as the compression-ignition engine designed by Rudolf Diesel in 1892¹², who achieved a low-consuming machine that increased the thermal efficiency of previous four-stroke engines. Although Diesel’s developments were originally based on the 1824 Sadi Carnot’s ideal

¹¹ Clerk’s first patent was presented in the United Kingdom in August 1, 1878 (BL, PO, patent n. 3,045).

¹² The first Diesel’s patent was presented in Germany in February 28, 1892 (DPMA, patent n. 67,207)

thermodynamic cycle¹³ (unworkable in practice) he finally shifted to a constant pressure combustion cycle, today known as the “Diesel Cycle”. Thus, from 1876 onwards, the modern trajectory of the reciprocation internal combustion engine opened new and strong business opportunities that these pioneers (and especially Otto) would take full advantage of.

3. Pioneers, entrepreneurship, and the gas engine business

In fact, all the technological paradigms and trajectories described in the previous section created new business opportunities for innovators and sharp entrepreneurs and adventurers, such as James Watt and Matthew Boulton to begin with. This particular partnership was formed for exploiting Watt’s patents on steam engines, a successful undertaking at the core of the British Industrial Revolution (Nuvolari, 2004: 22-45-121). Therefore, IPRs played a significant role in the engine business from the very beginning and firms involved had to learn how to deal with them. In an increasingly complex and internationally connected nineteenth century, and in a sector in which reverse engineering made not easy keeping industrial secrets for much time, first inventors and companies required patents for blocking competitors, signing agreements, licensing technologies, or fighting imitators, depending on the extent and scope of IPR enforcements. Likewise, follower and latecomer firms in the business also had to get used to patent rights, either for respecting, challenging, or bypassing them, which often depended on distinct management strategies and on the character of institutional arrangements concerning IPR treatment in each nation.

Hence, almost all radical innovators in each thermodynamic trajectory (Figure 1) started up pioneering firms and dealt with patent issues, as occurred with *Boulton & Watt* in the reciprocating steam engine path during the last quarter of the eighteenth century. Similarly, brand new companies were created by creative engineers working in steam turbines at the turn of the nineteenth to the twentieth century, such as *AB de Laval’s Ångturbin*, founded by Gustaf De Laval¹⁴ in 1893 (Schön, 2012: 163–4); *C. A. Parsons and Company* and *Parsons Marine Steam Turbine Company*, established by Charles A. Parsons in 1889 and 1897 respectively (Parsons, 1946); *Curtis Electric Manufacturing Company*, set up by Charles G. Curtis in 1888¹⁵ (Dickinson, 2010: 215); *Société pour l’Exploitation des Appareils Rateau*, founded by Auguste C. E. Rateau in 1903 (Delouche, 1994); or *AB Ljungströms Ångturbin* and *Svenska Turbinfabriks AB Ljungström*, organized by Fredrik and Birger Ljungström in 1908 and 1913 (ASME, 1995: 4). The same process can be tracked concerning gas turbines. Georges B. Brayton was such an enterprising man as quick-witted inventor, since he started up *The New York and New Jersey Ready Motor Company* in 1875, *The Pennsylvania Ready Motor Company* in 1876, and *The Brayton Petroleum Engine Company* in 1882 (Cummins, 1989: 194); Ægidius Elling founded *A/S Elling Compressor Company* in 1902 (Bakken et al., 2004); Charles Lemale and Rene Armengaud (jointly with the aforementioned Rateau) established the *Société des Turbo-moteurs* in 1903 (Smil, 2010: 85); and Frank Whittle founded *Power Jets Limited* in 1936.

¹³ Sadi Carnot developed the “closed cycle” analysis, by which all heat-engines can be investigated for their efficiency and power. He found that the maximum efficiency is based on the temperature difference between the beginning and end of an expansion stroke. He also indicated the need for compressing the air to be burned prior to actual combustion (the true Diesel’s innovation). See Cummings (1989: 30–3) for further information.

¹⁴ Who patented more than 90 inventions and started 37 companies related with distinct topics, many unsuccessful.

¹⁵ Where he developed and patented his steam turbine, whose rights were sold to *General Electric* in 1897, and other innovations related to gas turbines.

Finally, the engineers employed in *Brown Boveri & Company* built the first industrial gas turbine in 1939.¹⁶

Even in short evolutionary paths, such as hot air engines, pioneers set up or participated in companies for commercializing their inventions: So did Robert Stirling in association with his brother James during the first half of the nineteenth century; or John Ericsson with the *Massachusetts Caloric Engine Company* founded in 1857 (later *Rider-Ericsson Engine Company*, which would become the major producer of caloric engines in the United States) and other early licensees of his patent¹⁷ (Duffett, 2014: 11; Cummins, 1989: 23–5). In the same way, Lenoir founded the *Société des Moteurs Lenoir-Gautier et Cie.* in 1859 for selling his gas engine through the world (Ray, 2009: 90), although the success of Otto's four-stroke motor quickly outshone it. Thus, with respect to reciprocating internal combustion engines we must certainly and extensively focus on Otto's business.

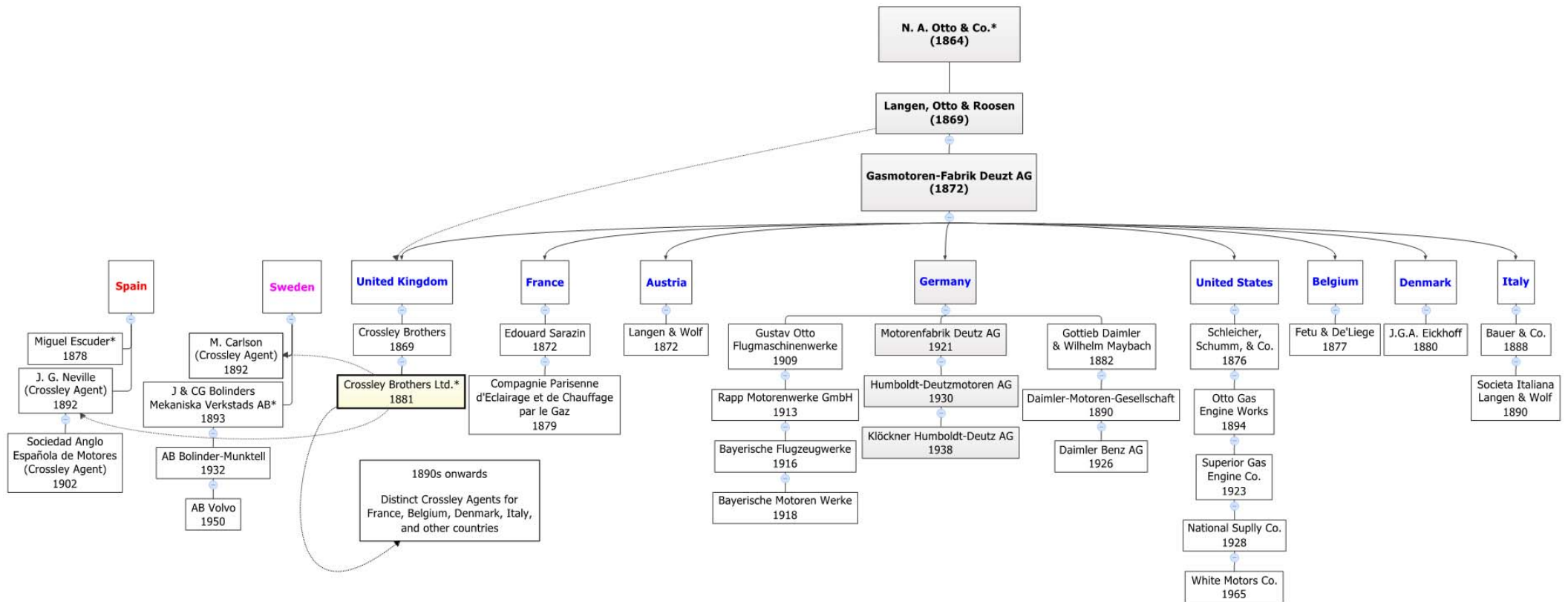
As occurred with many of the aforementioned innovators, who also acquired and developed business experience, Otto was a particularly successful and experimented trader and businessman during his youth. His business and commercial skills, therefore, were as significant as his mechanical formation as a "tweaker". That was a key combination that could help to explain the entrepreneurial positive results of his projects. After Otto's first trials with gas engines, he undertook an industrial adventure with Langen, setting up the *N. A. Otto & Company* in 1864. Otto contributed with his patents and workshop and Langen with financial support. After a successful demonstration in the 1867 Paris International Exposition, they needed new capital for enlarging their business, money that entered through an association with Ludwig August Roosen-Runge into a new firm, *Langen, Otto, and Roosen*, created in 1869, when they moved their factory to the Cologne suburb of Deutz. In an increasing demand for capital, the company finally became into the incorporated *Gasmotoren-Fabrik Deutz AG* through new investments made by capitalist partners in 1872 and through the employment of new engineers, such as the aforementioned Daimler and Maybach. Otto, who had never invested other thing than his patents in the business, obtained a long-term contract as a technical director (Cummins, 1989: 139, 144–6).

Once Otto's four-stroke engine developed in 1876, the firm immediately patented it (Figure 2) and widened its business' international scope. In fact, Otto and Langen –and then *Deutz*– had already tried the global market through agreements for the building of their previous atmospheric gas engine. They went first into negotiation with the English manufacturers *Crossley Brothers* –who acquired the license for the British patent in 1869– and with the French *Edouard Sarazin* in 1872, the same year that they established an Austrian subsidiary called *Langen and Wolf*. From 1876 onwards, the German firm set up subsidiaries, licensed patents, and fought imitators in many other countries. As it is depicted in Figure 3, *Deutz* carried on with their Crossley-Brother partnership in the United Kingdom; extended their French connections through the *Compagnie Parisienne d'Eclairage et de Chauffage par le Gaz* in 1879 (incorporated in *Compagnie Française des Moteurs à Gaz. Système Otto*); established a US branch called *Schleicher, Schumm, & Company* in 1876 (then *Otto Gas Engine Works* in 1894); concluded deals with *Fetu & De Liege* in Belgium in 1877 (later *Société Anonyme des établissements Fetu-Defize*); signed agreements with *J.G.A. Eickhoff* in Denmark in 1880; and licensed their technology to the Italian *Bauer & Company* in 1888 (then *Società Italiana Langen & Wolf*).

¹⁶ See note 5.

¹⁷ Such as the Newark Machine Company (see *Banner of Liberty*, April 6, 1859, Middletown, New York, p. 109)

Figure 3. International licensees, subsidiaries, and entrepreneurial evolution from Otto's 1864 first firm.



*Deutz's evolution in Germany is shaded and centered. Deutz licensed the patent to the British 'Crossley Brothers' who would become a significant manufacturer and worldwide exporter with agents in many countries. The first Spanish manufacturer, Miguel Escuder, was a non-authorized maker. The Swedish manufacturer J & CG Bolinders Mekaniska Verkstads AB developed their own patented combustion engines in 1893.

Source: Cabana (1992: 1, pp. 129-130), Cummings (1989: 152-60), Ortiz-Villajos (2006: Table 2), Thompson and Baden-Fuller (2010: 102-3), and information available at <http://www.volvoce.com/constructionequipment/corporate/en-gb/aboutus/history>.

In Germany, the *Gasmotoren-Fabrik Deutz AG*, after changing its name in 1921, merged with *Maschinenbau Humboldt AG* into the *Humboldt-Deutzmotoren AG* in 1930, remaining always as a central pillar of the German engine industry. Furthermore, indirect branches derived, somehow, from *Deutz* experience would also become into strong firms in the business. That was the case when Daimler and Maybach split from *Deutz* in 1882 and formed their own company, which changed in 1890 to *Daimler-Motoren-Gesellschaft*, the antecessor of *Daimler-Benz AG* (1926) that introduced the famous Mercedes-Benz automobile brand. On the other hand, Gustav Otto, the son of Nicholas August, founded an aircraft firm called *Gustav-Otto-Flugmaschinenwerke* in 1909, linked later to the engine manufacturer *Rapp Motorenwerke GmbH*. The former company was absorbed by *Bayerische Flugzeugwerke AG* (BFW) in 1916 and the latter transformed into *Bayerische Motorenwerke AG* (BMW) in 1918. After stopping production in 1919, BFW moved the engine section to BMW. This process gave birth to such a significant German automobile brand.

The most significant manufacturers were eventually the *Gasmotoren-Fabrik* in Germany (8,300 engines towards the mid-1880s), its American subsidiary (25,000 units), and the licensee Crossley Brothers Ltd. in the United Kingdom (more than 5,000) (Cummins, 1989: 162), who had been authorized to build and worldwide sell the engine except, obviously, into Germany. In fact, the British firm quickly developed during the last decades of the nineteenth century, becoming a great engine exporter before WW I. Consequently, they opened agencies in 30 countries and competed with domestic manufacturers everywhere, especially from the 1890s, when the original 1876 patent expired and they registered improved engine versions (Ortiz-Villajos, 2013: 6). In small markets (low population or low industrialization level) such as Sweden or Spain, importations were the main source for the extension of the new technology, largely through the work of Crossley agents, although domestic manufacturers also had their chance. In Sweden, for instance, *J & CG Bolinders Mekaniska Verkstads AB* began to manufacture their 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 with a global market share of 80% in fishing boats by the 1920s.

In Spain, the first manufacturer of Otto's four-stroke engine entered into the business without license. As it is well-documented (Cabana, 1992: 129–30; Amengual, 2008: 100–1), a Catalan manufacturer called Miguel Escuder produced and, as we will see in the next sections, even re-patented the motor while Otto temporary lost his IPRs. From 1878 to 1900, Escuder manufactured approximately 300 engines that were mainly sold in the most industrial areas of Spain such as Barcelona or the Basque Country. As it is shown in Figure 6 Escuder's workshop offered engines from 1 to 12 horsepower at restrained prices. It was a short quantity compared to the main producers, but Escuder's strategies constitute an extraordinary example for reflecting on the consequences of distinct patent institutions. In fact, Escuder was the first and only domestic manufacturer because the short and undeveloped Spanish market would be quickly occupied by engine importations from Crossley Brother agents (Ortiz-Villajos, 2013: 5–8 and Figure 1).

To sum up, Otto's revolutionary approach definitively contributed to the expansion of the reciprocating internal combustion engine technological trajectory and to the opening of a worldwide business opportunity that the German inventor and his firm rapidly took. This new engine turned into a key stone of the SIR that would give birth to a whole industrial branch of fundamental importance still today. At the beginning of that process, IPR management was a strategic challenge in a competitive sector in which reverse engineering was not only feasible but a reality. Furthermore, it was not only strategic but a complex issue, if we take into account the existence of diverse national patent institutions, the absence of international

agreements until 1883, the rise of protectionist and nationalistic attitudes towards industrialization, and, at the same time, the birth of the first globalization process.

4. Radical innovations, IPR institutions, and the four-stroke engine patent strategies

A technological trajectory begins with key innovations from a few inventors and enterprises that pushed forward both the technology and the business. If the invention succeeds, then it is usually followed by clusters and waves of incremental technical advance, that may be achieved from a much wider spectrum and that normally improve the efficiency, scope, and range of the technology. The same process can be tracked and analyzed as to IPR management. Pioneer innovators and firms use to take out the first key patents in a crucial moment at the beginning of the trajectory, trying to monopolize and organize the business. These pioneers' first steps are essential in order to move into the market and establish a good position. In the long run, both pioneers and followers will also use IPR systems to protect incremental and complementary innovations, filling in thousands of patent applications. As the business possibilities grow, agreements, licenses, imitations, conflicts, and court fights also extend.

The particular aim of this section is to thoroughly study and compare those first key patents concerning the four-stroke engine that were internationally registered by Otto and *Gasmotoren-Fabrik Deutz AG* at the very beginning of the reciprocating internal combustion engine trajectory, leaving aside long-term patent activity in the sector.¹⁸ The motive for doing so is to delve into the initial strategies followed by the inventor and the firm concerning technical disclosure, as well as to find out the role of such key intangible assets in Deutz's first international expansion. Hence, for that purpose, we have selected six target countries with different patent regimes and industrialization paces, such as Germany (Deutz's homeland), the United Kingdom, France, the United States, Sweden, and Spain.

In 1876, when the four-stroke engine was developed, there was not any international agreement concerning IPRs beyond those specified in bilateral accords linked to commercial treaties, although foreign patent activity was usually allowed everywhere.¹⁹ Furthermore, although the attempt to harmonize distinct systems ended in the 1883 *International Union for the Protection of Industrial Property*, this did not suppose radical changes and each nation retained its own way of organizing IPRs. The consensus during the last decades of the nineteenth century did not go beyond several basic agreements regarding national treatment for foreigners and three to six-month priority rights for granting previous IPRs, as well as some interesting clauses regarding the security that importing own patented objects from abroad would not forfeit IPRs and the guarantee of temporal protection in international exhibitions (Penrose, 1951: 60–87). With respect to our targeted countries, France, Spain, and the United Kingdom signed the international agreement in 1883–1884, Sweden in 1885, the United States in 1887, and Germany in 1903. Thus, in 1876 Otto and *Gasmotoren-Fabrik Deutz* had no other way than to protect their initial inventions and subsequent developments attending to national legislation constraints. Patent practitioners, international agencies, and other

¹⁸ A complete analysis of long-term pre-1914 patent activity concerning thermodynamics and internal combustion engines in Spain can be found in Amengual and Sáiz (2007) and Amengual (2008).

¹⁹ In some countries there were constraints for foreign IPRs during certain periods. The United States restricted patents to US citizens from 1790 to 1836 and imposed discriminatory patent fees until 1861 (Khan, 2013: 45). Similar measures against foreigners existed in the Japanese patent law from 1871 to 1899 (Diebolt and Pellier, 2011: 13). Furthermore, several scholars had argued that Japan, Germany, the United Kingdom, and the United States used subtle discriminatory measures against foreigners even during the twentieth century, such as delaying or rejecting more applications on purpose (Kotabe, 1992; Richter and Streb, 2011: 1021–1022 and Table 1).

intermediaries in markets for technology were usually crucial in such an IPR extension process (Guagnini, 2002, 2012; Galvez-Behar, 2006; Lamoreaux and Sokoloff, 2003; Pretel and Sáiz, 2012).

Based on contemporary manuals and writings of several of those patent attorneys, we have depicted a legal snapshot for the years 1876-1877 with the basic differences among the six patent systems analyzed (Table 2). The practitioners themselves easily recognized and warned about such dissimilarities regarding, for instance, whether or not 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. They were the only ones with strong previous novelty exams²⁰, designed for rejecting valueless inventions, and special administrative jurisdiction for revoking patents. In addition, both systems published printed descriptions and drawings in order to properly spread technical information, call for oppositions before granting patents, and did not allow patents of introduction (the way for rewarding first introducers of foreign inventions). The United States went further only recognizing IPRs to the true inventor and giving a priority right for two years (Thompson, 1882: 74–5). Notwithstanding, the German and the US regimes had also significant differences related to their particular political-economy practices. The main one was the cost for a full-extent patent, extraordinarily expensive in Germany and cheap in the United States. There were also high differences in patentees' rights, such as the German constraints concerning compulsory working and licensing that did not exist in the United States. Thus, some scholars have argued that the US IPR 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 more influenced by and focused on national, industrial, and corporate governmental strategies than on individual IPRs, in order to favor scientific, technological, and innovative spillovers (Streb et al., 2006).

The French and the Spanish patent regimes had also many things in common in the mid-1870s, as it can also be checked in Table 2. Both were based in simple registration systems with neither previous exams, nor opposition proceedings, nor priority rights, nor specific patent jurisdiction, nor publication of specifications and drawings, and similar fees (in international prices) as well as compulsory working requirements in order to maintain the monopoly. In addition, France did not allow the patentee to import the object protected, and Spain granted patents of introduction to bring in foreign technology without being the first inventor (Sáiz, 2014). Therefore, at first sight, these two systems seem weaker than the German and, very specially, the American ones, at least for defending patent holder's IPRs. Again, political and institutional determinants for encouraging domestic industrialization, technology transfer, and economic growth clearly emerged (Galvez-Behar, 2008; Ortiz-Villajos, 1999, 2002; Sáiz, 2002).

²⁰ From 1836 in the United States and just introduced in 1877 in Germany.

Table 2. Patent regime characteristics in Germany, the United Kingdom, France, Spain, the United States, and Sweden. Legal snapshot for 1876-1877.

LEGAL SNAPSHOT (years 1876-1877)	GERMANY	UNITED KINGDOM	FRANCE	UNITED STATES	SWEDEN	SPAIN
<i>Law in force to grant Otto's patent</i>	1877	1852	1844	1861	1856	1826
<i>Previous novelty and technical exam</i>	Yes	No	No	Yes	No ⁽¹⁾	No
<i>Opposition proceedings</i>	Yes	Yes	No	No	Yes	No
<i>Priority rights to previous patents</i>	No	No	No	Yes ⁽²⁾	No	No
<i>Maximum patent term</i>	15 y.	14 y.	15 y.	17 y.	15 y. ⁽³⁾	15 y.
<i>Patent extensions beyond maximum term</i>	No	Exceptionally 7 years ⁽⁴⁾	No	No	No	No
<i>Payment system</i>	Annual installments	Three installments ⁽⁵⁾	Annual installments	In advance	In advance	In advance
<i>Fees for a full-term patent</i> ⁽⁶⁾	5,300 marks	180 pounds	1,500 francs	35 dollars	144 crowns	6,000 reals
<i>Fees in 1876 British pounds</i> ⁽⁶⁾	260	180	60	7	8	60
<i>Patents of addition</i>	Yes (no annual taxes)	No ⁽⁷⁾	Yes (no annual taxes)	No	No	No
<i>Patents of introduction or importation</i>	No	Yes ⁽⁸⁾	No	No	No	Yes (5 y.)
<i>Compulsory working clauses</i>	Yes (within 3 y.)	No	Yes (within 2 y.)	No	Yes (within 2-4 y.) ⁽⁹⁾	Yes (within 1 y.)
<i>Compulsory licenses</i>	Yes ⁽¹⁰⁾	No	No	No	No	No
<i>Importation prevention of patented object</i>	Yes	Yes	Yes	Yes	Yes	Yes ⁽¹¹⁾
<i>Patentee importations void the patent</i>	No	No	Yes	No	No	No
<i>Publication of patent specifications / drawings</i>	Yes	Yes	No	Yes	Yes	No
<i>Specific IPR jurisdiction</i>	Yes ⁽¹²⁾	No	No	Yes ⁽¹²⁾	Yes ⁽¹³⁾	No

⁽¹⁾ According to Andersson (see sources) the Department of Commerce may have conducted a short novelty exam (driven by a single technical assistant) that could lead to patent rejections.

⁽²⁾ Except if the invention was in public use in the United States for more than 2 years.

⁽³⁾ The extension was determined by the Department of Commerce for each patent (minimum 3, maximum 15 years).

⁽⁴⁾ Only in special cases through a formal petition to the Queen and a report from a Judicial Committee.

⁽⁵⁾ Three installments at or before the end of the 1st, 3rd, and 7th year.

⁽⁶⁾ Only fees for a full-term patent. The real cost may include several other things in each country (drawings, translations, patent-attorney fees, payments for publication in the official Gazettes, etc.)

⁽⁷⁾ Additions and improvements must be made between application and grant, i.e. between provisional and final specifications.

⁽⁸⁾ Although nominally there were no patents of introduction or importation in the United Kingdom, patents could be taken by the first person to introduce an invention into the country, which is actually the same.

⁽⁹⁾ The patentee must work the invention within two years, which could be extended to four (applying for it previously). The patentee had also to prove that the patent was in use each year of the patent term.

⁽¹⁰⁾ Compulsory licenses had to be offered if the patent was not worked or it was of public interest.

⁽¹¹⁾ Except for patents of introduction, that cannot block importations by third parties.

⁽¹²⁾ The Patent Office might revoke applications on grounds of lack of patentability or novelty with no further appeal except to the Supreme Court.

⁽¹³⁾ The Department of Commerce's decisions on patent granting had no further possibility of appeal.

Sources: Information extracted from manuals of patent practitioners and experts such as Webster (1853), Johnson and Johnson (1866), Hunter (1880), Thompson (1882), and Gordon (1908). See also Andersson (2014: Table 1), Gálvez-Behar (2008, 2010), Khan (2001), Khan and Sokoloff (2009: Table 10.1), Lerner (2000: Tables 1 to 5, 2005: Tables 1 to 4), Maestrejuan (2009: 131), Pakuscher (1986: 90), and Sáiz (2002: Table 1). Exchange rates among currencies for the year 1876 have been obtained through the Swedish SEK (Lobell, 2010: Tables A6.1, A6.2, and A6.4 and <http://www.historicalstatistics.org>, table for Sweden), except for Spain (Martín and Pons, 2005: Table 9.19).

Finally, the British and the Swedish patent systems in 1876 had both some common characteristics with the aforementioned groups of countries and unique attributes, which made them reach an intermediate protection level. In the British case, strongly based on English common law tradition, there were not novelty exams although oppositions were called and specifications and drawings published. Like the German system, the British was quite expensive; in the same way that the American regime, no compulsory working or licensing requirements were implemented; but as in the Spanish case, the first importer of a new technology could obtain not just five-year patents of introduction but full-extent invention patents without being the first and true inventor. It was the only system that could exceptionally allow extensions after the patent full term and that had a singular payment system with three installments at the first, third, and seventh year (MacLeod et al., 2003). The Swedish regime did not officially establish previous exams either (see Table 2, footnote 1) but, as the British or the German, it called for oppositions before granting and it also published drawings and specifications. The fees were as cheap as in the United States, although the Department of Commerce determined the patent extension in each case, from a minimum of 3 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 appeal in courts. Although patents of introduction or importation were not allowed, the Swedish system also required to work the invention within the country (Andersson, 2014: 8–9).²¹

Thus, some questions immediately arise: Did these IPR regime disparities influence Deutz's patent strategies in any sense? How did Otto, Deutz, and their agents manage the IPR 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? Or did this diversity not influence in Otto's and Deutz's decisions at all?

Otto's first patents were presented in a short period of time during the 1876 summer. The German file²² was applied for in June 5; the French application²³ was registered in June 9; the Spanish patent²⁴ was stamped in June 27; the provisional specifications of the British patent²⁵ were dated in May 17 –although it was sealed in August 1; and, similarly, the US patent specification²⁶ appeared signed by Otto in June 1, although the official application was filed in July 13. The power of attorney for the Swedish patent²⁷ was signed by Otto in September 16 although the patent was applied for in November 1. Thus, these close dates and order clearly mean that Otto and *Gasmotoren-Fabrik*, duly advised by their patent attorneys,²⁸

²¹ We must remind here that the picture depicted in Table 2 is just a snapshot for the years 1876–1877 and that the nineteenth-century patent legislation was continuously changing and adapting to social, political, and industrial reality. In fact, just for enumerating several examples, there was distinct patent laws in pre-1877 German states; Spain changed to a new and cheaper system that extended patents to twenty years and recognized two-year priority rights in 1878; France (and also Spain) passed a new patent statute in 1902; the United Kingdom 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.

²² DPMA, patent n. 532. Although the patent was presented in 1876 it was dealt with under the 1877 German law.

²³ INPI, patent n. 113,251.

²⁴ *Oficina Española de Patentes y Marcas* (OEPM), privilege n. 5,479.

²⁵ BL, PO, patent n. 2,081.

²⁶ USPTO, patent n. 194,047.

²⁷ *Patent- och Registreringsverket* (PRV), patent application n. 2,310.

²⁸ Patent agents and agencies were internationally linked since the beginning of the patent business, however from the 1870s on it became an essential issue (Galvez-Behar, 2006; Pretel and Sáiz, 2012: 100–8). For instance, Otto and Deutz presented their patents through very well-known patent attorneys

developed a unified strategy to patent internationally. The German and the Spanish patent were taken by the firm, while the French, British, Sweden, and the US files were applied for by Otto, which probably was an intentional policy product of internal agreements among Deutz's partnership but also a consequence of distinct domestic patent requirements.²⁹ The release of the British patent provisional specifications was just the starting signal for the process. Between the provisional and the complete specification the rest of patents were applied for, with the exception of the Swedish, which was presented afterwards. In general, this responded to a carefully prepared strategy, as denotes the following fragment from an American patent advisor on how to patent in the United Kingdom:

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: 44–5).

Hence, it seems that Otto and Deutz were very well advised during the internationalization process or, at least, very well informed and coordinated. Except for the aforementioned Swedish extension, that took five months, the patent coverage was widened country by country practically in a month and a half, regardless of cost. Translations, technical drawings, or practitioner commissions, among other expenditures, had also to be paid and managed, which certainly did not make the process inexpensive. At any rate, the invention had been rapidly protected in the most significant markets of the world. Furthermore, we have completely and thoroughly analyzed each of the aforementioned six selected original patent files, specially scrutinizing the technical information, paragraph by paragraph and drawing by drawing, and there are strong evidences of cautious specification devising and editing and, therefore, of a strategic IPR management that can be disentangled. In doing so, we have joined efforts from distinct academic areas such as economics, economic history, thermodynamic engineering, and professional patent examination. Based on this fresh research, we have been able to conclude some new findings.

such as Maison Armengaud Aîné in France, Charles Denton Abel in the United Kingdom, or Bernardo García Abad (later Pedro Rigalt y Fagell) in Spain.

²⁹ Basically, a corporate patent is part of the firm's assets while an individual patent, granted to one of the partners, is his/her private property in case of limited liability. Some patent systems such as the US or the Swedish allow only individual inventors at that time (who may afterwards assign the patent to a firm).

Table 3. Otto-Deutz's first patents in Germany, the United Kingdom, France, the United States, Sweden, and Spain.

FIRST PATENT	Germany	United Kingdom	France	United States	Sweden	Spain
<i>Number</i>	532	2,081	113,251	194,047	2,310	5,479
<i>Application date (1876)</i>	June 5	May 17 (sealed August 1)	June 9	July 13 (signed June 1)	November 1 (signed Sept. 16) ⁽¹⁾	June 27
<i>Applicant</i>	Deutz	Otto	Otto	Otto	Otto	Deutz
<i>Patent Attorney</i>	n.a.	Charles Denton Abel	Armengaud Aîné	Charles Sydney Whitman	L. A. Groth	Bernardo García Abad
<i>Patent term</i>	15	14	15	17	9 ⁽²⁾	15
<i>Document Characteristics</i>	Original text and drawings	Partially related text and same drawings than the US pat.	Same text and drawings than the German pat.	Partially related text and same drawings than the UK pat.	Partially related text and same drawings than the UK pat.	Same text and drawings than the German pat.
<i>Typewritten</i>	Yes	Yes	No	Yes	No	No
<i>Specification number of words (approx.)⁽³⁾</i>	1,231	3,154	1,600	3,082	1,123	1,700
<i>Number of drawings</i>	4	13	4	13	13	4
<i>References to previous own patents⁽⁴⁾</i>	None	None	None	None	None	None
<i>Invention disclosure level</i>	Low	Medium-High	Low	High	Medium	Low
<i>Claims quality</i>	Not adequate	Not adequate	Not adequate	Partially adequate	Not adequate	Not adequate
<i>Court litigation</i>	Yes	Yes	Yes	Yes	Unknown ⁽⁵⁾	Yes
<i>Patent revocation</i>	Yes	No	Yes	No	Unknown ⁽⁵⁾	Yes ⁽⁶⁾

⁽¹⁾ Power of attorney signed in Deutz the 16th of September.

⁽²⁾ The extension was established by the Department of Commerce for each patent (in this case 9 years).

⁽³⁾ Number of words of the whole technical description in each patent specification.

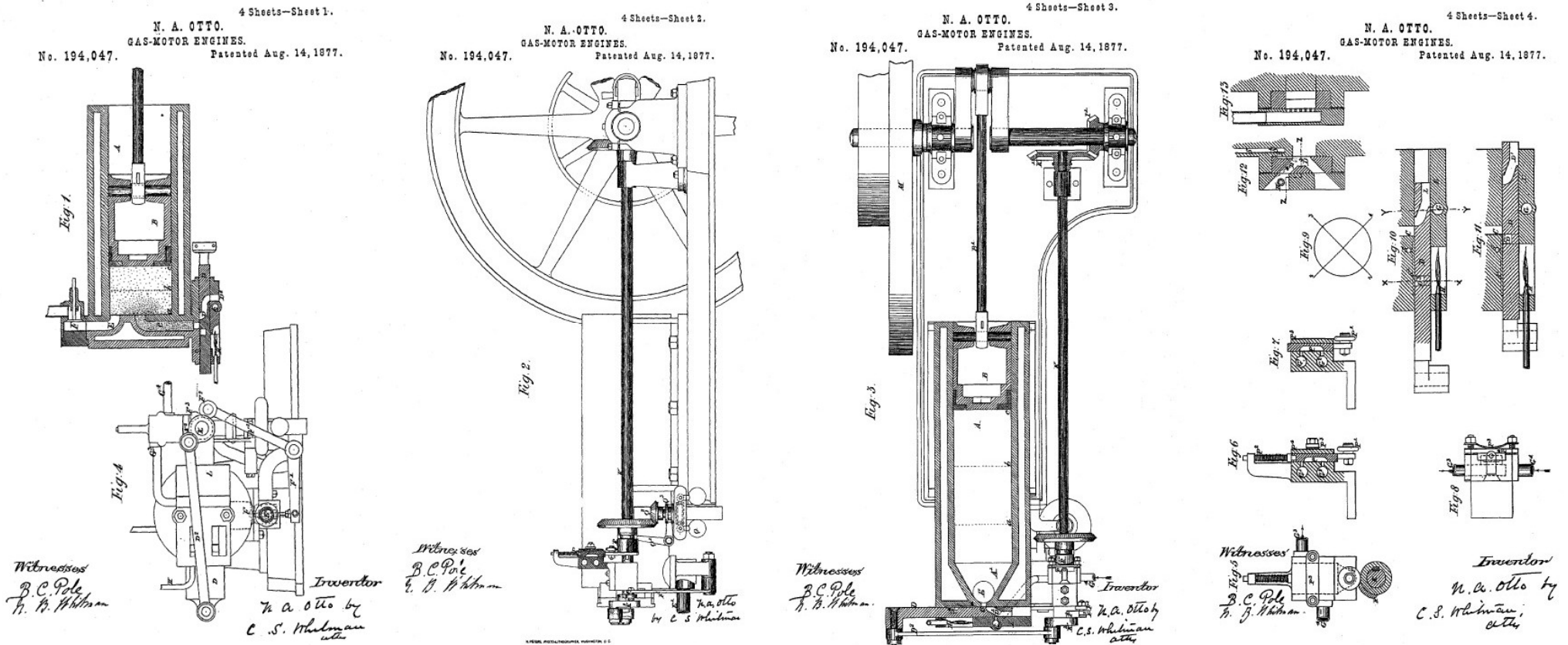
⁽⁴⁾ Although priority claims were not internationally established until the 1883 Paris International Union, the patent description could quote previous patents abroad. The US law specifically recognized previous patents (see Table 2).

⁽⁵⁾ Apparently there is no sing of litigation or revocation in the patent record.

⁽⁶⁾ The patent was revoked for not properly demonstrate that it was in practice, but it was later re-established. Nevertheless, Otto could not stop production from the non-license manufacturer Miguel Escuder who hold several patents of introduction on Otto's engine (Amengual, 2008: 100–1).

Sources: Otto's patent original files (see notes 22 to 27). These six patents are available at [reference details omitted for review purposes]. Litigation data according to Cummins (1989: 172–8) and Flink (1990: 11). The Swedish patent was facilitated by David E. Andersson, to whom we earnestly acknowledge the help for analyzing the Swedish patent system and Otto's patent.

Figure 4. Drawings included in Otto's American, British, and Swedish patents in 1876.



Sources: USPTO, patent n. 194,047

Firstly, we claim that all the patents studied lacked certain valuable information and that several definitively provided very insufficient disclosure. For instance, no patent offered enough 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 the building of the machine. This means that Otto and Deutz did not totally reveal essential information of the four-stroke engine on purpose and that this varied depending on the country and patent regime characteristics. In fact, as we have stated in the introduction, a patent is no other thing than a contract between the author of new significant information and the society that is going to benefit from it, in order to create appropriability through a temporal monopoly that rewards the inventor and enables disclosure. In other words: in exchange for the monopoly, the inventor must completely reveal the new information to the competitors and the society. Thus, if a firm or inventor is able to get and maintain a monopoly at the same time that they keep essential information out from the hands of others, they will certainly accord with such a deal. Nevertheless, this may be a difficult thing to do, because they need the patent to be passed and granted, and the invention to be properly protected in case of litigation. If you hide very significant and key information looking for a wider patent technical scope, you may have serious problems if others register or manufacture similar devices based in such hidden characteristics, because you might not be able to demonstrate that you had previously discovered and protected them. Therefore, it was an art –and it still is– to find out where the tipping point is: the art of tight writing and drawing patent specifications and claims; the art of good patent practitioners and advisors in tune with well-informed inventors and firms. In words of a contemporary professional patent agent:

The profession's main duties were "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)

Secondly, we can undoubtedly state that there were clear and deliberate differences among the distinct patent specifications and drawings in the six countries analyzed (see Table 3), especially between the overseas documents and the others. On the one hand we have the German patent that, as we already know, 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 was dealt with notwithstanding that it was applied for in 1876. However, once examined the patent specifications and figures it can be noticed that the engine is described in a wide and simple manner, mixing two distinct modalities (with and without previous compression), and including just four drawings with a general view of the engine, as it is shown in the aforementioned Figure 2. Hence, despite previous exams if there was any, the German patent had very significant lack of disclosure. Furthermore, the French and Spanish patents, granted by simple registering systems, were just literal translations from the German file and shared similar specifications and identical figures. Therefore, these three European patents can be considered matching documents with the same insufficient disclosure level and wide technical claims.

On the other hand, the Anglo-American patents were much more concrete and offered a better invention description and claims. Both the British and the American shared the same thirteen detailed drawings (Figure 4) and doubled in words the German patent technical specifications (Table 3), which helped to a better understanding of the four-stroke engine functioning and characteristics. For instance, both patents described (including specific

drawings) two key devices that are not present in the aforementioned continental patents, and without which it was almost impossible to develop the engine: a) the charge motion within the cylinder, throughout a cam for valve control, and b) the spark-ignition system regulation (Table 4 and Figure 5).³⁰ Similarly, the Swedish patent, based on and partially translated from the British, showed also these two significant drives and shared the same thirteen drawings, which turned it into the stronger continental document, although the technical description neither reached the extension nor the clarity of the overseas patents. At any rate, the presence of clear drawings was an outstanding point in all these patents.

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: 14–5)

Notwithstanding, the valve control and the ignition regulation systems are not properly described in any of the patent documents and, as a consequence, there is not enough information to replicate the engine with total certainty. No patent provide information or data either 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 be able to replicate the engine using the American or English patents, its later and proper function could not be assured without further experimentation or knowledge concerning these two key devices. Indeed, reverse engineering from original engines would be the faster way to disentangle its functioning.

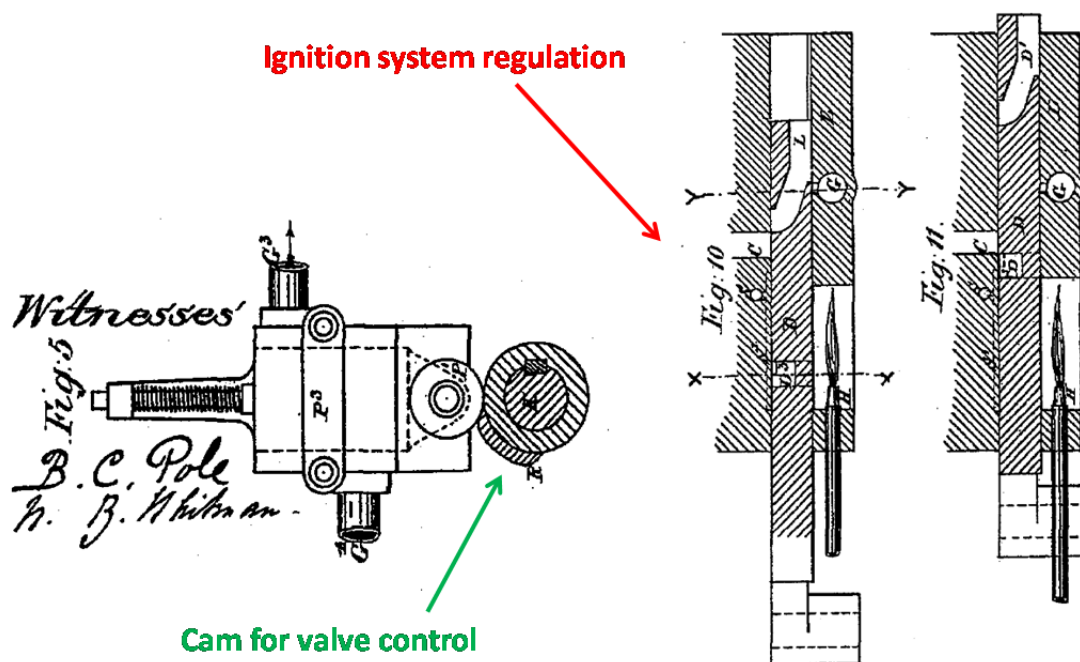
³⁰ The shape of the cam "R" in Figure 5 is a key issue for the valve control. Any modification in such shape would involve changes in the timing for opening and closing valves and, therefore, would generate distinct engine performances. Similarly, although old-fashioned compared to current devices, the ignition regulation system had a key communication channel between the combustion chamber and an ignition flame, which allow the connection of the mixture of compressed gas and fuel to the flame and therefore the combustion.

Table 4. References to key topics in Otto-Deutz's first international patents

	CHARGE MOTION CONTROL			SPARK-IGNITION SYSTEM REGULATION			FOUR-STROKE REFERENCES
	<i>Text</i>	<i>Drawings</i>	<i>Claims</i>	<i>Text</i>	<i>Drawings</i>	<i>Claims</i>	<i>Claims</i>
GB 2081	Page 5, lines 26-45	Figure 5	--	Page 6, lines 3-11	Figures 10 & 11	--	Claim 1 (admission) & Claim 2 (compression, combustion, exhaust)
DE 532	--	--	--	--	--	--	Claim 4 (the four-stroke cycle)
FR 113251	--	--	--	--	--	--	Claim 4 (the four-stroke cycle)
ES 5479 PR	--	--	--	--	--	--	Claim 4 (the four-stroke cycle)
US 194047	Page 3, left column, lines 15-20	Figure 5	Claims 5 & 6	Page 3, right column, lines 9-26	Figures 10 & 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 & 11	--	Claim 1 (admission) & Claim 2 (compression, combustion, exhaust)

Sources: Otto's patent original files (see notes 22 to 27). These six patents are available at [reference details omitted for review purposes].

Figure 5. Essential devices to fully understand the Otto's four-stroke engine functioning



Sources: USPTO, patent n. 194,047, detail of figures 5, 10 and 11.

Thirdly, despite the interesting disclosure level of the Anglo-American and Swedish patent, we can also state that there were significant differences among them. Subsequently written, the Swedish one was the vaguest of the three as it had the shorter technical description (less than half words than the British or American) and it was in part literally translated from the British specifications. Thus, the British and American patents were written during the same period, had the same figures, and practically coincided in the specification extent, although the engine description was non-identical. The British patent was worded in a slightly broader manner than the US one and it highlighted and developed again the possibility of an engine working at atmospheric pressure, which was not the key point of the four-stroke invention. Although the British patent also explained the engine working upper atmospheric pressure, i.e. with previous compression, such key version was the only and central issue of the US patent. Indeed, the US specifications concerning the engine were more solid and detailed. Furthermore, if we focus on the final claims within these three files –a significant legal and juridical part for later patent enforcement– the American and the British (also the Swedish) documents were also different. The US patent had much more rigorous claims for the four-stroke cycle and for the key devices of the engine (Table 4 and Figure 5). However, the claims of the British and Swedish patents were not adequate and were written in a much vaguer and wider manner, with no reference, for instance, 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 in such differences, according to what an English practitioner reported about the 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).

Eventually, we can conclude that the US patent reached the highest level of knowledge disclosure, the clearest description in relationship with the drawings, and the best written claims. Notwithstanding the lack of thermodynamic information and of complete references to the aforementioned key devices, this patent revealed the basic information needed for the understanding of the new engine concept. This apparently may reduce the patent breadth, clarifying the essential points of the invention, which was compensated by the highest patent length (17 years), practically doubling the Swedish one. In addition, the US patent system was the cheapest and the US judicial system strongly supported private IPRs. Thus, our findings fit well with what has been long stated by American scholars and specialists concerning the higher commercial and social value of patents and IPRs, and the quick birth of a very active market for innovations and technologies (Sokoloff and Khan, 1990; Khan, 1995; Lamoreaux and Sokoloff, 2001; Khan and Sokoloff, 2004; Khan, 2005; Lamoreaux et al., 2013; Khan, 2013). Based on this case study, we can also conclude that the English patent system was very close in disclosure level and probably in patent enforcement capacity and IPR value, despite some strong contradictions such as the lack of previous technical exams, the possibility of patents for importers, or the high cost of protection, which, as some scholars have demonstrated, did not impede the granting of non-viable technologies and the abandonment of valuable ones (MacLeod et al., 2003). Likewise, the Swedish patent system seems to have been established on solid basis from its beginnings regardless of the absence, as in the British case, of hard technical exams, which would be serious- and rapidly introduced in 1884. On the contrary, despite such previous exams and other modern characteristics, the German patent system showed, at least in the Otto's case, the same weaknesses than other continental and peripheral European patent institution at that time, such as the French and the Spanish.

This section has demonstrated that Otto and Deutz intentionally maintained key knowledge out of patent specifications and followed a unified patent strategy focused on adapting the disclosure level and the scope of the technical claims to distinct international requirements, being the US one at that time the most demanding. This patent tuning tactic was certainly influenced by the character of such different patent institutions. However, some puzzle pieces are still not well-addressed. If Otto and Deutz perceived and acknowledged the weaknesses and difficulties of certain patent systems: Why did they invest for registering the engine there? Did they want just a tool to fight imitators or to face further judicial problems? Why then did not they enable disclosure completely? Furthermore, if high-quality essential information was revealed just in one of the aforementioned contemporary patents: Why to hide it in the rest? Even in a pre-Internet era such public information could cross the sea in, let's say, six or twelve months. Was that enough for justifying different patents? Were these strategies just a simple consequence of patent agency practices, routines, and businesses? And the most significant issues: Were Otto's and Deutz's productive and commercial plans affected in some way by the relatively strength, scope, or weakness of their patents? Can we learn something on how different patent institutions and policies affected technology diffusion and industrialization processes? In the next section, we will try to shed some light on these questions by analyzing patent litigation and the evolution of Otto's and Deutz's business during the last quarter of the nineteenth century.

5. IPR international litigation and business results

As has been demonstrated in sections 3 and 4, the rapid globalization of the internal combustion engine technology and business was totally entangled with Otto's and Deutz's international patent strategy. Three were the main producers of this kind of engines in the world: the headquarters in Germany, their subsidiary in the US and American market, and their licensees in the United Kingdom and also main European exporters (see Figure 3). The engine was also small-scale produced in many other countries, both by authorized and unauthorized manufacturers, although the three mentioned upwards captured the most significant part of the business. Original patent rights were enforced and defended everywhere since the beginning. Patent infringements by any unauthorized builder were automatically pursued and litigation (and threats of such action) was common.³¹ Thus, besides the initial patent-document adaptation to each institutional system, concealing key technological information when it was possible, the firm and its main partners firmly use IPRs to fight and eliminate competition involving not only the four-stroke cycle but any similar compression engine. As Table 4 demonstrates the claims were written to widen the patent scope as much as possible, especially in France, Spain, and Germany, and to certain extent also in the United Kingdom and Sweden, a usual strategy then and now for blocking as many competitors as possible and a key issue when litigation comes up (Merges and Nelson, 1990; Usselman and John, 2006)

Therefore, once such a break-through technology and business arisen, Otto and his partners in Deutz used not only the power of innovation *per se* for acquiring competitive leadership, but also the power of IPRs, attorneys, and other legal instruments for establishing and defending the monopoly. In this framework, it makes sense to register the patent everywhere regardless of the character of local patent institutions or final results. Furthermore, this was a common strategy followed by multinational corporations when spreading during the end of the nineteenth century and the first half of the twentieth (Sáiz and Pretel, 2014). Similarly, this may also explain the will of concealing key technological information when possible, especially during the first stages of innovation, as 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, patent disclosure level is inversely linked to patent scope. The more generally an invention described and the wider the claims written, the greater will be the monopoly potential, which will also extend litigation and risks.³² The easy way of patenting would have been to present the same document everywhere; thus, as the opposite had costs, patent tuning and strategic management had to be worth. A few years, or even months, may be enough to allow a strong take off and to set up secure distance from imitators, who in the absence of full disclosure were forced to reverse engineering and practical tests for reaching the technological frontier. Pioneer firm's rapid growth and high returns would allow then to allocate resources for launching legal battles, block competitors, and enduring the monopoly.

Hence, the American, the British, and the German patents were main pillars for Otto's and Deutz's business, being the two former the documents with higher level of disclosure, although all of them keep significant information out of the technical description. During the

³¹ See for instance a letter to the editor sent by Crossley Brothers, the licensees in the UK, to a contemporary specialized journal (*Engineering*, April 27, 1883, p. 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."

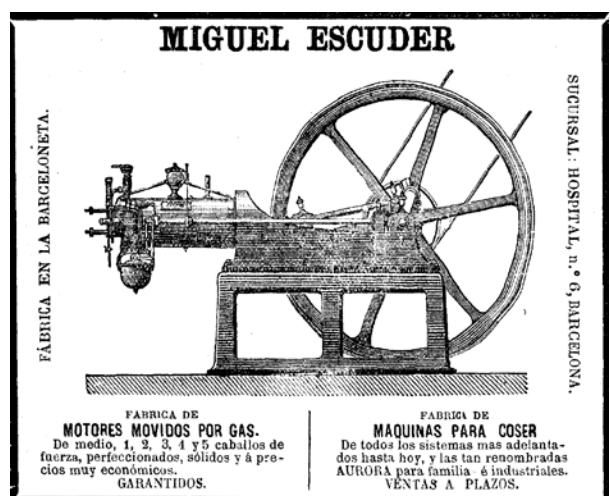
³² Several cases at the US Supreme Court concerning patent scope during the 1870s and 1880s were solved in distinct manner even by the same judge: see Usselman and John (2006: 116–8).

first years, Otto was able to keep such a cherished intangible asset in the three countries although facing distinct legal conflicts. First serious threats began in Germany in 1882, when Deutz unsuccessfully objected to a patent applied for by Gerhard Adam, a Munich competitor (Cummins, 1989: 173–5). A witness, Christian Reithmann, assured to have previously built a four-stroke device, which led Deutz to sue him in 1883 for his damaging testimony. Despite significant lack of evidence, the court ruled in favor of Reithmann in 1884, although further appeal to a higher court finally reversed this decision. However, the season was opened. Otto's patent was blocking many competitor firms aiming to manufacture similar devices who were systematically pursued under the four-stroke claims. Indeed, that same year of 1884, a patent attorney called C. Wigand uncovered and published the Beau de Rochas' 1862 patent, which theoretically described a four-stroke cycle although no engine was ever built and, thus, there was no thermodynamic or experimental data (see Figure 1 and footnote 10). At any rate, Ernst and Berthold Körting, significant manufacturers from Hannover, rapidly used the new available information to suit in courts Deutz's monopoly. Despite the defendant efforts, Körting Brothers won in January 1886 as they also did when facing with further appellations.

Otto's patent, pride, and –especially– business monopoly were officially broken in his own land. Other similar engines such as those manufactured by Adam or Körting would openly compete with Deutz. Moreover, the same conflict immediately extended to the French, American, and British patents, while other problems came up in the Spain. In the former case, an interesting engine brought about by M.M. Delamare-Deboutteville and Maladin and called "Simplex", competed with Otto's firm in the French market, who went to courts against the proprietors in 1884 (Donkin, 1896: 135). Others sources point out that there were several court actions for patent infringements during those years in Paris, such as Otto vs. Frères Rouart (Marbach, 2013: 80). At any rate, all agree that Otto's patent was defeated, which occurred in the first instance in August 1885 and definitively in November 1888.³³ The "French" Beau-de-Rochas cycle was again the key issue. Meanwhile, in the neighboring Spain the situation was as complex as interesting. The Spanish 1826 patent law, under which the Otto's patent was granted, required compulsory working of the invention (meaning manufacturing the engine in the country) within one year since the grant date (i.e. December 1876). Although a mechanical engineer certified the existence of a four-stroke engine in June of 1878 in a button factory in Madrid, and although Otto's patent attorney in Spain declared that such engine had been built in a mechanical workshop in Barcelona, the patent office required more information, which was sent by another mechanical engineer a month later, in July 1878. In this case, he reported that the button factory in Madrid was not an engine workshop and that the motor had been manufactured in Germany as its label read (Amengual, 2008: 97–8). Thus, in October 1878 the patent was cancelled and the four-stroke technology entered in public domain.

³³ *Le Génie civil. Revue générale des industries françaises et étrangères*, June 25, p. 544.

Figure 6. Advertisements in Spanish newspapers concerning four-stroke engines produced by Miguel Escuder in Barcelona (1881 and 1889).



MOTORES DE GAS.

Reformados completamente los grandes talleres de MIGUEL ESCUDER, situados en Barcelona, con las maquinarias más adelantadas hasta el día conocido, se construyen *Motores movidos por el gas*, desde uno hasta doce caballos de fuerza, los que con gran ventaja pueden competir con todo motor conocido hasta hoy, tanto por su buena construcción como por solides, economía en el gasto, movimiento silencioso, regularidad de marcha, facilidad en cuidarlos y por los precios tan sumamente reducidos.

Los motores a gas, construidos por Escuder, se prueban con un freno y se hacen funcionar durante algun tiempo antes de salir de los talleres, con el fin de tener la completa seguridad de su fuerza efectiva, por lo cual, se garantizan durante un año de las averías, siempre que estas no sean por falta de cuidado; y en atención á sus reducidas dimensiones, pueden quedar completamente instalados en el sitio que se quiera.

Los *Motores de Escuder* son sumamente económicos, pues no llegan á consumir un metro cubico de gas por hora y por caballo, y no hay necesidad de maquinista para su manejo y cuidado.

Con lo expuesto basta para probar lo conveniente que son estos motores sobre cualquier otra máquina de fuerza, en cualquiera de los ramos de la industria.

Dentro de Barcelona funcionan ya más de 380 motores y 280 en Madrid y provincias.

En Elburo, de poco tiempo á esta parte, se han colocado 16. Esto basta para comprender la aceptación que tienen los motores de Escuder sobre cualquiera otro sistema.

Para persuadirse mejor puede si se quiere preguntarse por el resultado á cualquiera de los que tienen ya motor en su casa.

PRECIOS.

Los motores	de 1 caballo	á 1.000 pesetas.
Los	» de 2	» á 2.400 »
Los	» de 3	» á 2.400 »
Los	» de 4	» á 3.000 »
Los	» de 5	» á 3.500 »
Los	» de 8	» á 5.000 »
Los	» de 12	» á 7.000 »

Para pedidos y demás informes puede dirigirse, bien al constructor inventor, ó á sus representantes en estas provincias Sres. Bulfy y C.ª, calle del Banco de España, 3, BILBAO, ó á los Sres. Irujo y Luzuriaga, Muelle, 3, SAN SEBASTIAN.

Source: Left: *La Vanguardia*, February 2, 1881, p. 14; Right: *El Fuerista: periódico católico. Dios, Patria, Rey*, n. 512, October 4, 1889

That may be the reason for the understanding of how a Catalanian engine manufacturer, Miguel Escuder, was able to factory and even re-patent 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 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 1878,³⁴ just when the original Otto's patent had been voided. Thus, while Otto lost his rights in Spain a local manufacturer began to sell the engine. Otto's and Deutz's answer was quick and accurate. 1) As usual, he took court actions against Escuder applying for voiding the patents granted and destroying the engines built; and 2) Otto's new attorney applied for (and lobbied for) a patent rehabilitation to the Spanish patent office arguing that the previous agent had made significant mistakes and that the engines were being manufactured in Barcelona since 1876. In the first case Otto lost in the courts because patents of introduction were apparently legal and the original Otto's IPRs had been cancelled, although when the judgment was set up in 1885 Escuder's 5-year patents had also expired (Cabana, 1992: 129–30). With the second tactic Otto succeeded. Not only because the patent was readmitted by the Spanish patent office but because it was also declared into practice in 1880, after receiving a new certificate signed but another mechanical engineer in July 1879 assuring that engines of that kind were being manufactured in a workshop in Barcelona. However, with or without patents, Otto was not able to stop Escuder's business, who went on building four-stroke engines until 1910 (see Figure 6). As we have previously stated at the end of the section 3, he produced more than 300 engines before closing the firm. If defeated it was not by Otto's IPRs in Spain but by his licensees' exportations from the United Kingdom, the Crossley Brothers, who totally occupied the Spanish market (Ortiz-Villajos, 2013: Figure 1). Therefore, it was defeated by competition in the international market.

Thus, other intangible assets such as those held in the United States –where the most significant subsidiary of the German firm was established– or in the United Kingdom –from where the aforementioned licensees flooded Europe with four-stroke engines– could be more

³⁴ OEPM, patents of introduction n. 157 and 158.

relevant for Otto's and Deut's businesses and results than the Spanish or even the French IPRs. Undoubtedly, the loss of the German patent was harsh, but at least they kept the rights during 10 years (as also occurred in France), time enough to collect huge benefits and to get on leading the sector afterwards. Thus, it seems that in these three European countries, the wider the patent breadth the bigger the conflict and, eventually, the shorter the patent term. What did occur then in the Anglo-American context? These patent systems required higher disclosure levels and narrower technical breadth somehow, but did they guarantee strong property rights in return and then more valuable intangible assets for Otto's firm? As had occurred in Germany, many followers, in Schumpeterian terms, rapidly came up and patented around the key technology which inevitably ended in court litigation. During the first years, Crossley Brothers sued, through Otto, several unauthorized gas engine makers in the United Kingdom such as Charles Lindford in 1880, one of the most popular and documented cases won first by Lindford but lastly and after appealing by Otto in January 1882.³⁵ While Lindford was condemned to pay cost and cease to manufacture, purchasers and users were obliged to pay royalties to the plaintiffs.

When the Beau-de-Rochas issue arose and Otto suffered his legal demise in Germany, a new judicial case (Otto v. Steel) occupied the engineering journals in the United Kingdom. Crossley and Otto had taken actions against another engine manufacturer, Robert Steel, whose lawyers strongly used the new information available in Germany for invalidating Otto's patent. However, Otto won in 1885.³⁶ The sentence brought Lindford's case up and reminded the previous decision of the Court of Appeal concerning Otto's patent novelty. Yet, the most significant decision was to reject the admission of the publication of Beau de Rochas patent, meaning that the technological information was considered not available when Otto registered his engine. Although the British Museum library 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"*,³⁷ the information was considered not published in the United Kingdom.

Thus, all of the claims in the Otto's British patent were upheld.³⁸ Crossley Brother's would retain their monopoly on four-stroke engines in the United Kingdom until the expiration of the patent in the early 1890s. Furthermore, they went on advertising in specialized journals the superiority of Otto's devices, the British patent validity, and the appellation against Körting Brothers in Germany; who also publicly answered highlighting that German courts had established that Otto really made no invention, but a combination of known parts, and that there were no foundation to call Körting's engine an infringement of Otto's German patent. *"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."*³⁹ Indeed, it proves how Otto and Deutz extensive and consistently used IPRs and legal fighting for blocking competitors. Monopoly is monopoly just as business is business.

³⁵ Several specialized journals meticulously followed the case. See, for instance, *The Engineer*, April 1, 1881, pp. 233-235 and 238-239; February 3, 1882, pp. 75-78 and 85-86. See also footnote 31.

³⁶ The sentence in *The Engineer*, December 25, 1885.

³⁷ *The Engineer*, January 29, 1886, pp. 91-93.

³⁸ The detailed description of the Court case can be followed in *The Engineer*, 1886: January 1, pp. 6-9; January 8, pp. 28 and 35-36; January 15, p. 47; January 22, pp. 62-63; February 19, pp. 156-157.

³⁹ See F. W. Crossley's and Otto Lindeman's (on behalf of Körting Brothers) letters to the editor in *The Engineer*, 1886: April 2, p. 265; and April 9, p. 278.

Once the German appellation lost, Otto got ahead of Körting Brothers in the United States by suing the *Körting Gas-Engine Company Limited* in 1887 for patent infringement. This subsidiary was established in New York in 1886 for manufacturing vertical gas engines, looking for the vast American market mainly occupied by Deutz's subsidiary. As had previously occurred, the Beau de Rochas's patent was brought before the USPTO by the defendants. The US patent system was the only one that guaranteed patents to first and true inventors, instead of first applicant. Thus, the Beau de Rochas issue was apparently a significant danger. However, the case *Otto v. Körting* was solved before celebrating the trial because the own patent office stressed that an inventor had to show "diligence in reducing his invention to practice" and, as we already know, that was not the case of Beau the Rochas. Therefore, other inventors may be granted American patents for the same theoretical cycle provided that they improved the first idea by building the machine, which Otto did (see *Nicolaus August Otto vs. the Körting Gas-Engine Company*, 1889). Although a hundred of Körting engines may be manufactured and delivered in the East coast, it seems that the company lapsed after the patent conflict. Some sources blame the poor quality of American-made Körting engines compared to German-made originals⁴⁰, but the legal strength of American patents and thus of Otto's intangible assets may be the main reason for such a decline.

Hence, the British and the American patents, the ones with higher disclosure level and better claims, especially in the US case, also proved to be significant intangible assets for Otto an Deutz's business and thus for his licensees and subsidiaries. Both patent systems strongly supported Otto's IPRs, again very especially in the United States, which with previous technical exams, cheap payments, and determined enforcement of patentees' property rights led to the development of a consolidated market for technology. In both countries, competitors were blocked and both the British *Crossley Brothers Ltd.* and the American *Schleicher, Schumm & Co* (later *Otto Gas Engine Works*) grew, expanded, and turned into the central pillars of the engine industry. Moreover, even in the other countries herein analyzed, where Otto's IPRs were weakened, patents still were key issues for the company. The industrial, corporate, and nationalistic Germany finally favored the competitors invalidating Otto's patent, but after ten years of monopoly which also allowed *Gasmotoren-Fabrik Deutz AG* to retain a big piece of the pie and to continue with its entrepreneurial development. Similarly, in France and Spain, where the Beau de Rochas issue on the one hand and compulsory working clauses and patents of introduction on the other led to a monopoly interruption, Otto was able to initially maintain the exclusive rights and then initiate hard litigation in defense of his IPRs. In France competitor manufacturers emerged, as to a lower degree occurred in Spain, although Crossley Brothers' exportations and leadership contributed to totally extinguish the fire, at least in the Spanish case. Finally, although we have not been able to find any litigation evidence in Sweden, Otto's patent was enforced there with similar insistence as in other parts of Europe. As the Swedish patent system required compulsory working within two-to-four years (Table 2), the original patent file keeps a certification dated in 1881 and signed by two engineers stating that Otto's invention was being manufactured in Malmö. We must remind here that Otto obtained just a 9-year patent in Sweden, which means that the invention was theoretically in public domain by 1885 or 1886.

⁴⁰ See brief details in <http://www.vintagemachinery.org/mfgindex/imagdetail.aspx?id=7665> (December 2015).

6. Conclusion

In August 2015, *The Economist*, which had supported IPR abolitionists during the mid-nineteenth-century patent controversy,⁴¹ returned to the attack again: “*patents are supposed to spread knowledge, by obliging holders to lay out their innovation for all to see; they often fail, 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...*” and stated that, at least, patent term should be strongly reduced and compulsory working clauses reintroduced (use it or lose it).⁴²

One of the most significant issues for the historical justification of patents, therefore, has 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 research or would keep new ideas in secrecy, prompting technological progress to decline. This discussion has attracted very little academic research, although scholars agree that disclosure is essential. Thus, in the long run, patent institutions would have reinforced monopoly protection to encourage disclosure and established previous technical exams to guarantee it. Notwithstanding, even with strong property rights, innovators have very little incentives to disclose because it directly benefits competitors, who can, firstly, imitate and copy, and/or, secondly, learn and overcome the original idea even reaching a patentable level. The extension of patent litigation and transaction costs could then rocket. Although these are essential topics, we really lack of empirical studies on the level of patent disclosure and on the distinct patent and legal strategies followed by inventors and innovative firms. Moreover, historical evidence suggests that without previous technical exams and institutional controls eighteenth- and early-nineteenth-century inventors systematically left the essential parts of their inventions aside of the patent specifications (Johns, 2009: 258–9). That was the reason of the early introduction of technical exams in the United States and –slow and eventually– in the rest of the developed countries throughout the late-nineteenth and twentieth century.

Did previous technical exams and patent reinforcement finish with disclosure problems? Are patents then the best and unique way for encouraging technological progress? A set of similar related research question has been stated in the introduction to this article, which deals with such a complex phenomenon throughout a detailed case study (Yin, 2009) based on the four-stroke engine technology invention and business. In doing so, an evolutionary approach has been adopted for the understanding of the socio-technological framework within which the internal combustion engine technology emerged, as well as the relationships with other thermodynamic trajectories. When the steam-engine technology reached its maturity, attempts to improve it led to the relatively quick development of new ideas and devices to transform heat in work more effectively: from the steam to the gas turbine trajectories through hot-air engines and different reciprocating internal combustion machines (Figure 1). Otto’s 1876 four-stroke motor was a radical advance in the middle of this evolutionary process that provided a large business opportunity and that was immediately patented and commercialized worldwide. In a few decades, Otto’s original manufacturing firm in Germany had internationalized through a set of subsidiaries and patent licensees that covered the whole industrial world (Figure 3).

Despite the progressive efforts to internationalize IPRs during the late-nineteenth century, national patent systems still differed considerably among them when Otto’s invention was registered (Table 2). While the US patent system had early evolved to introduce previous technical exams, as Germany did in 1877, the rest of countries were still based upon simple

⁴¹ See, for instance, *The Economist*, February 1 and July 26, 1851.

⁴² “Time to Fix Patents” *The Economist*, August 8, 2015, p. 9.

registration systems. Many other issues concerning patent fees, term, or compulsory working clauses had also very different treatments. Hence, in this article we have deeply studied the original patents on the four-stroke engine in the USA, the UK, Germany, France, Sweden and Spain in order to disentangle the process of patent internationalization followed by Otto and his firm, Deutz, in 1876 (Table 3). After a thoroughly reading of the specifications and a professional analysis of the drawings executed by a mechanical engineer, trained in patent examination and industrial history, straightforward findings come up (Table 4): 1) there is a lack of key disclosure in all the documents and no patent offer enough thermodynamic data and complete explanations of the key devices; 2) there is a total lack of disclosure in the German, the French, and the Spanish Otto's first patents; 3) the US patent is the one with the best specifications, claims, and drawings, followed by the UK document and the Swedish, both less clear than the first; and 4) the analysis reveals that Otto and Deutz followed a coherent and meticulously planned international patent extension that implied distinct timings, specifications, and drawings according to different patent systems, always constraining as much key information as it was possible.

At any rate, all these patents were immediately used, licensed, legally enforced, and defended by all the means during the worldwide expansion undertaken by the new multinational. Infringements and legal battles were common everywhere and Otto and his licensees proved to be very proactive pursuing legal actions against any possible competitor. Otto's patent was finally defeated in Germany, France, and Spain, and the monopoly did not exceed ten years either in these three countries or in Sweden, where it was granted for just nine years. Only in the US and the UK the right remained valid and with enough technical scope to stop direct competitors during the whole patent term (17 and 14 years respectively). Notwithstanding, along with the US subsidiary and the UK licensee, which were two of the main producers of four-stroke engines, the business also flourished in the headquarters in Germany and to a less degree in France, Sweden, or Spain (through imports from the UK).

Then, what lessons can we learn from this case study in order to answer the question stated in the introduction? Were patents necessary to promote innovation and pioneer businesses? Were they justified prizes to compensate R&D expenditure? Undoubtedly, they were an interesting incentive for many inventors such as Otto, who were seeking for and testing new gas engines at the time. However, once the invention reached and the patent arranged, as others did previously and do nowadays, Otto and Deutz widely used disclosure tuning tactics and IPRs to block any kind of competitor everywhere in order to totally monopolize the business. Patents turn then in a strong legal weapon and may induce heavy social costs, especially when they do not enable total disclosure. Thus, perhaps the question must be settled in another way: How much time must last a patent monopoly? Could long-term or broad patents generate more social costs than benefits? Supposing that patents are necessary as an incentive, if we follow Otto's case in Germany, France, Sweden, or Spain it seems that even ten-or-less-year patents could be more than enough for rewarding pioneers in certain industries as recent economic theory has highlighted, especially when the market size increases (Boldrin and Levine, 2008b, 2009). Furthermore, what would have occurred with the four-stroke engine in a world without patents? In a sector with strong competition and opportunity of high returns, soon or later the invention would have probably occurred taking into account the Lenoir and Beau de Rochas precedents and the evolutionary path depicted in Figure 1. "All useful inventions depend less on any individual than on the progress of society."⁴³ If we accept this supposition, that no patents or, better, short-term patents would have not discouraged Otto or others, then one only thing is sure: gas engine prices would have progressively dropped.

⁴³ *The Economist*, July 26, 1851, p. 812.

Correspondingly, social benefits would have increased, to the detriment of monopolist's high returns, and R&D waste for skipping Otto's patent would have been avoided. Thus, long-term patents and broad technical scope not only may discourage second-generation innovation on the one hand, but encourage inefficient allocation of R&D resources on the other. As Otto's claims on the four-stroke cycle were wide enough in many countries, in those with strong patent enforcement other engine makers were forced to develop (and even patent) peculiar mechanisms for surrounding the claims. That was the case in the United Kingdom, for instance, where many manufacturers tried to border Crossley's monopoly. In 1882, the editorial of the prestigious journal *The Engineer* complained that within the last two years more than 250 patents had been taken by several firms for improvements in that class of machinery and that the Court decisions supporting Crossley's monopoly could affect a very large amount of capital.⁴⁴ However, once the Otto's patent expired, the original engine configuration was rapidly adopted by competing manufacturers who abandoned other less-efficient devices that had been developed in order to avoid infringing the patent.⁴⁵

Eventually, how did corporations, inventors, and their agents really manage IPRs and the enabling disclosure requirement? How was it possible to obtain patent monopolies without total disclosure? Because it seems that the lack of disclosure was (and is) more than usual even in patent systems with previous technical exams. Although mechanical devices could be more easily disentangled through reverse engineering, chemical inventions did not. When the US administration expropriated patents from the German chemical industry after WW I, *The Chemical Foundation, Inc.* was created first to buy and then to manage such confiscated intangible assets from German corporations. The point behind this process—largely and thoroughly studied by Kathryn Steen (2001, 2014)—was to launch and support the American synthetic organic industry, previously dominated by Germany. It was supposed that patents would release essential technical knowledge to American manufacturers but prominent chemist from American universities and chemical firms testified that all patent specifications systematically excluded vital information and that it was impossible to produce dyes and other chemical products following the descriptions. *“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 the defeated Germany because patents did “not have any practical value without the know-how”. The conclusions are straightforward: The United States only aided its synthetic organic chemicals industry by using confiscated patent rights against the own German firms (!) and therefore “temporarily weakening a segment of the national patent system” (all the quotations from Steen, 2014: 376–9).

Although total disclosure is the essence of patent justification, scholars specialized in IPR studies affirm the same nowadays: that it is “usually impossible to build a functioning device or software program from a modern patent application” (Boldrin and Levine, 2013: 9). The case study on the four-stroke engine presented herein leads to similar findings concerning what was a key mechanical device. Therefore, the evidence suggests that shorter and narrower patents would not have stopped the innovation and the business and would have increased the social benefit, as patentees had—and have nowadays—a strong tendency to

⁴⁴ *The Engineer*, February 3, 1882, p. 85.

⁴⁵ *“To avoid infringing the patent, makers had recourse to various devices to alter the working method, most of which were abandoned as soon as the Otto engine became public property. At the same time the sudden and universal competition reduced the price of gas engines, and increased their sale. Some makers had long been prepared, as soon as the patent expired, to bring out engines using the Beau de Rochas or Otto cycle.”* (Donkin, 1896: 120)

conceal vital knowledge, to tune specifications, and to widely use patents as legal weapons. Moreover, the relation between patents and innovation remains unclear, even in key fields such as medicine and pharmaceuticals where scholars usually claim that IPRs are essential. Critics suggest that even supporting such firm's research expenditures would be cheaper for the States than guaranteeing patents and paying monopoly prizes for the medicines (Baker, 2005). Besides theoretical and empirical insights, more carefully-analyzed historical case studies, such as the one carried out in this article, are needed, because they may help to shed new light on the long-term consequences of maintaining strong IPRs, as well as to assess what actual results would patent reduction or even patent abolition have.

7. References

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