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Did James Watt's Patent(s) Really Delay the Industrial Revolution?

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> I have been branded with folly and madness for attempting what the world calls impossibilities, and even from the great engineer, the late James Watt, who said . . . I deserved hanging for bringing into use the high-pressure engine.
>
> —Richard Trevithick to Davies Gilbert, *c*. 1832–1833.

Introduction

A patent constitutes the (temporary) right to exclude others from employing a particular technology or invention, and since the time when the world's first patent law was promulgated in Venice in 1474, they have been awarded in the expectation that offering inventors this right would incentivize their efforts.[1] Later, at the beginning of the Industrial Revolution, political economists were agreed that offering patents was a preferable policy choice compared with alternatives such as offering rewards or prizes. Adam Smith, for example, observed in 1767 that "the inventor of a new machine . . . has the exclusive privilege of making and vending that invention for the space of 14 years by the law of this country, as a reward for his ingenuity, and it is probable that this is as equal a one as could be fallen upon."[2] Abroad, Britain's burgeoning industrial prowess was attributed in

[1] "There are men in this city . . . who have most clever minds, capable of devising and inventing all kinds of ingenious contrivances. And should it be legislated that the works and contrivances invented by them could not be copied and made by others so that they are deprived of their honour, men of such kind would exert their minds, invent and make things that would be of no small utility and benefit to our State." (L. Bently and M. Kretschmer, Venetian Statute on Industrial Brevets, http://copy.law.cam.ac.uk/cam/tools/request/showRepresentation?id=representation_i_1474).

[2] Continuing: "For if the legislature should appoint pecuniary rewards for the inventors of new machines, etc., they would hardly ever be so precisely proportioned to the merit of the invention as this is. For here, if the invention be good and such as is profitable to mankind, he will probably make a fortune by it; but if it be of no value he also will reap no benefit" (Meek and Stein 1982, p. 116). Later, in 1795, Jeremy Bentham expressed himself in similar terms: "[A] patent considered as a recompense

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part to its development of the world's first recognizably modern patent system. In 1823, Goethe observed "that [the] clever Englishman transforms [invention] by a patent into real possession . . . one may well ask why they are in every respect in advance of us" (quoted in Klemm, 1964, 173).

Over the course of the nineteenth century, though, with the growing ascendancy of the free trade movement, attention came to fall less on the rewards that accrued to the inventor and more on the exclusion that patents supposedly foisted on other parties. The classical liberal publication *The Economist*, for example, decried patents: "On all inventors it is especially a prohibition to exercise their faculties; and in proportion as they are more numerous than one, it is an impediment to the general advancement" (*The Economist* 1851, p. 113).

In essence, the debate concerning the utility of patents has changed little over the intervening period, although criticisms of patenting have become more variegated and sophisticated. Broadly speaking, there are four main lines of attack deployed by critics of patenting:

(i) That the exclusion operated by patents prevents or "blocks" follow-on innovations that could have been developed if the patented technology was freely available. Of course, a patentee can choose to forgo this right in return for payment (licensing) but they are not usually compelled to do so. This problem is exacerbated if patents are vaguely worded, allowing a patentee to subsequently expand the scope of their patent beyond what they have invented.

(ii) This exclusion might be justifiable if patents incentivized the development of inventions that would not have appeared otherwise within a reasonable timeframe. However, inventions are less the product of an individual inventive mind and more the inevitable outcome of collaborative, socially embedded processes—that inventors are really "conduits filled by an invention that just had to happen" (Kelly 2011, p. 133). This is evidenced by the alleged ubiquity of Simultaneous Innovation, the phenomenon whereby multiple inventors hit upon precisely the same idea at virtually the same moment—most famously Alexander Graham Bell and Elisha Gray both patenting the telephone on the same day. As such, patents are needless and represent an "extraordinary" and monopolistic imposition on the natural order of things (Boldrin and Levine 2008, p. 128).

for the increase given to the general stock of wealth by an invention, as a recompense for industry and genius and ingenuity, is proportionate and essentially just. No other mode of recompense can merit either the one or the other epithet."

(iii) That inventors themselves rarely use patents. Notoriously, for example, very few of the exhibits displayed at the world's first great fair in 1851 (the Great Exhibition in London) had been patented, and it has been inferred that inventors must have preferred alternative means of protection such as trade secrecy (Moser 2013). This inference, though, relies on the flawed assumption that each exhibit represented a patentable invention.

(iv) Patents embroil inventors in legal disputes and commercial engagements, distracting them from what they are best at—inventing.

Many apparent examples of these processes have been adduced from recent technological and economic history,[3] and this chapter is concerned with examining the plausibility of each of these four arguments in the context of one of the most frequently invoked examples of a monopolistic, innovation blocking patent—James Watt's patent for the sperate condenser, obtained in 1769 at the outset of the British industrial revolution. The industrial revolution was an event of undoubted first-order importance, marking the beginning of modern economic growth. Previously, all global economies had been fundamentally constrained by their reliance on the annual cycle of plant growth as virtually their sole energy input. This ostensibly immutable constraint on production could only be overcome with the adoption of inorganic sources of energy—fossil fuels, in particular coal. By 1700, the transition from organic to inorganic energy sources was already underway in England where coal was being used as a source of heat in a wide variety of industries such as brewing, glassmaking, metal works, and brick making. However, "without a parallel breakthrough in the provision of mechanical energy to solve the problem associated with dependence on human or animal muscle to supply motive power in industry and transport, energy problems would have continued to frustrate efforts to raise manpower productivity." (Wrigley 2010, p. 45). This problem was only solved by the development of the steam engine, which transformed the heat energy produced by burning coal into mechanical energy. Consequently, Tony Wrigley posits that "the steam engine was arguably the single most important technical advance of the whole industrial revolution period."[4]

[3] To give but one other example, it is commonly supposed that by 1917—just as the United States was entering the First World War—endemic patent litigation "had brought the US production of planes to a halt." The impasse was only resolved by the forcible intervention of the government, imposing a patent pool whereby the major US plane companies could share one another's technology (Moser 2013, p. 33). The myth of patent hold-up has now been debunked in Katznelson and Howells (2014).

[4] Wrigley (2010, p. 44). Quantitative contributions to the literature usually suggest that the impact of steam engines was in fact very limited. Von Tunzelmann (1978, p. 157), notably, estimated that the cost savings involved with using steam-power as opposed to alternative power sources such as water was, in 1800, equivalent to only 0.2 percent of National Income. This social savings methodology, though, has been much criticized. See, for example, Leunig (2010).

Watt's condenser, described later in this chapter, represented a sudden and dramatic improvement in the fuel efficiency of steam engines, enabling their application to a plethora of industrial activities such as cotton spinning, iron smelting, and pumping water out of mines. As such, the condenser can certainly be regarded as one of the single most important inventions of the industrial revolution. However, Watt's acquisition and enforcement of his patent is supposed to be illustrative of each of the anti-patent arguments outlined earlier. In brief:

(i) Watt and his business partner Matthew Boulton are alleged to have enforced a much broader interpretation of their patent than they were fairly entitled to and used this to obstruct new developments in steam engineering which might have threatened their monopoly—especially high-pressure steam engines, to which Watt was inveterately opposed. However, high-pressure engines would predominate during the nineteenth century and their delayed appearance prompts Michele Boldrin and David Levine to suggest that Watt's patent "most likely delayed the industrial revolution by a couple of decades" (2013, 38).

(ii) Mark Lemley (2012, p. 716) asserts that Watt has been lionized as the inventor of the steam engine when really, he was just one of many engineers engaged in an unconsciously collaborative effort. This is a strawman. No one has seriously suggested that Watt invented the steam engine. Another version of this argument is that he was one of many steam engineers working during this period and that he was lucky to get just "one step ahead of the pack" when patenting his condenser (Boldrin and Levine 2008, 2). This is distortionary. It is true that there were many steam engineers working in England in the 1760s (around 500 engines had been erected by this point; Kanefsky and Robey 1980, p. 169) but there is no credible evidence of anyone else developing a working condenser. This was Watt's invention.

(iii) Scherer (1965) speculates that Watt may have been relatively unconcerned with obtaining patent protection while developing his condenser. Watt's personal correspondence, though, makes clear that his development of the condenser was motivated by the allure of a patent—or rather the profits he hoped that would ensue therefrom. The same goes for his business partner Matthew Boulton, who went to the trouble of petitioning Parliament for an extension to the patent term in 1775. Similarly, many of the most important developments in steam engineering during this period were patented.

(iv) It has been suggested that once Watt finished developing his condenser, he refrained from further developments, instead concentrating on profiting from the condenser and enforcing his patent.[5] This ignores his

[5] For example, Merges and Nelson (1990, p. 872, n. 141); Lemley (2012, pp. 740–41).

enormous inventive and scientific output during the last quarter of the eighteenth century, detailed later. Watt was the pre-eminent steam engineer of the time.

(v) A slight variation of this argument is that as an enterprise, Boulton & Watt only cared about "extracting hefty monopolistic royalties through licensing" (Boldrin and Levine, 2008, p. 2). We will see instead how the firm endeavored to manufacture as many of the components for its engines as possible; they were the world's first firm to offer entire steam engines for sale.

The rest of this chapter is divided into two halves. The first provides an analytical narrative of the development of the condenser and the foundation of the business partnership that commercialized it, Boulton & Watt (hereafter, the firm is shortened to "B&W," the two individuals as Boulton and Watt). It deals with the last three of the four points discussed earlier. In brief, it will argue that patents were an essential motivating factor in the development and commercialization of the separate condenser. It will also serve as an introduction to the second half of the paper, which is concerned with the first of the four points. It will demonstrate that B&W's patent(s) did not act as an insuperable obstacle to the development of high-pressure steam engines, or indeed other potential developments in steam engines.

The Newcomen and Watt Engines

The world's first commercially viable steam engine had been developed by Thomas Newcomen at the beginning of the eighteenth century. Used mainly to pump water at coal mines, Newcomen's engine was worked by pumping steam into a cylinder which was open at the top and where a piston was positioned. When the cylinder was filled with steam, a spout of cold water was discharged inside the cylinder, reducing its temperature and condensing the steam into water. The condensation of the steam created a partial vacuum underneath the piston, which was now driven down by the (higher) pressure of the atmosphere acting on it from above. The piston was attached via a rocking beam to the pumping gear, so that as the piston was driven downward, the pumping gear moved upward. Steam would then be readmitted to the cylinder, forcing the condensed water out, while equalizing the pressure inside the cylinder with that of the atmosphere outside, whereon the piston would revert to its starting position at the top of the cylinder (Bottomley, 2014, p. 236–37).

Newcomen's engine, though, was extremely inefficient and attention focused on reducing its coal consumption. Especially noteworthy was the work of John

Smeaton, commonly regarded as "the father of English civil engineering," who over the course of two years of experiments was able to determine the optimal configuration and dimensions of the Newcomen engine according to the desired power output.[6] The essential design, however, was unchanged and even after half a century, its use was still largely confined to pumping water out of coal mines where fuel was effectively free.[7] It was during the course of his work as an instrument maker, repairing a model of Newcomen's engine for Glasgow university, that Watt realized that the alternate cooling and heating of the cylinder in each operating cycle of the Newcomen engine was inefficient. His solution was to introduce a second vessel where steam condensation could occur outside the cylinder (hence "separate condenser"), allowing the cylinder to retain its temperature. In addition, whereas previously condensation had occurred in the cylinder, which could never be cooled quickly enough to create anything but a partial vacuum underneath the piston, a more complete vacuum could be achieved by condensing in the much colder separate condenser. Watt's insight formed quickly, and he would later recall that during the spring of 1765 "all . . . improvements followed as corollaries in quick succession, so that in the course of one or two days the invention was thus far complete in my mind, and I immediately set about an experiment to verify it practically." (Muirhead 1854, p. lxxvi).

As elegant as Watt's new design was, it is worth emphasizing that in the previous sixty years since the Newcomen engine had been first introduced, there is no solid evidence that the same idea had occurred to any other engineer. In particular, over the course of nearly ten years of legal battles concerning the validity of Watt's patent for the condenser (patent no. 913), his opponents were unable to adduce any convincing evidence that his invention was not new. If they had, Watt's patent would have been annulled. It can also be asked, if Watt's idea had been the inevitable outcome of his contemporary social/scientific milieu, why it had not occurred to as eminent an engineer as John Smeaton, who had also started experimenting with steam engines in 1765 (Hills 1989, p. 29).

There remained, however, a significant amount of work required to transform Watt's idea into a working engine, and from there into a viable commercial proposition. For example, for the engine to work, the fit between the piston and cylinder had to be as air tight as possible (to maintain the vacuum), but without causing too much friction in the movement of the piston. The solution Newcomen had adopted was to place a flexible leather disk on top of the piston

[6] It was the historian of industrial technology and engineering, B. F. Duckham (1965), who first described Smeaton as "the father of English civil engineering."

[7] Of the 453 steam engines erected to 1769 where a commercial usage is recorded, 338 were used for pumping water out of coal mines, 75 percent of the total; derived from Kanefsky (1979, pp. 448–55). Coal mines could use the cheapest grades of coal for their engines, which often could not be sold commercially and would otherwise have had to be disposed of (von Tunzelmann, 1978, p. 62).

and then a quantity of water above the disk to act as a seal. This method, though, was less suitable for Watt's engine, as he wanted to keep the cylinder as hot as possible, and he knew that water seeping into the cylinder would absorb heat from the working steam. It was only in 1774, after countless experiments, that Watt was able to report cylinders that were being adequately machined.[8] Soon thereafter, an even better solution presented itself, when John Wilkinson patented his new technique for boring iron cannon (partly achieved by the simple expedient of rotating the gun barrel, rather than the boring-bar). It also proved eminently suitable for boring Watt's cylinders and Wilkinson would supply the cylinders for all but a handful of B&W's engines until 1796.

Problems such as these occurred repeatedly in manufacturing a working engine and in total, from when Watt first conceived his idea in April 1765, it took ten years until the first engines constructed according to his design were erected for paying customers. Sums expended on experimentation and development are more difficult to gauge, partly because it occurred under three separate business arrangements. Initially, Watt attempted to finance this himself (spending £1,200), but to do so required he undertake surveying work which inevitably consumed time he wanted to spend on his condenser (Scherer 1965, p. 168). Consequently, in 1768, he entered into a partnership with John Roebuck, an English ironmaster working in Scotland. Roebuck took on Watt's debts and agreed to pay the costs of developing and patenting the condenser, in return for a two-thirds share of the patent. Roebuck, though, was unable to sustain the expenses (his other business ventures were failing and would bankrupt him in 1770), and Watt was forced into undertaking more surveying jobs. Roebuck estimated that the costs of experiments at this stage were £3,000, although some were borne by Matthew Boulton, who would step in to replace Roebuck (albeit, only when he was able to acquire Roebuck's share of the patent from his trustees in 1773; Tann 2013). Finally, once Boulton had become Watt's long-term business partner, J. E. Cule (1940, p. 320) suggests that it took a further £3,370 to render the condenser a marketable proposition, not including set-up costs for manufacturing components and erecting engines.

This was a long-term research and development project, costing at the very least £7,500 and taking ten years to finish. Watt and his partners did not invest so much time and money out of their own beneficence. In 1769, for example, a few months after he had obtained his patent for the condenser Watt wrote to his friend William Small: "It was four years ago when I invented the fire engine and foresaw even before I made a model every circumstance that has since occurred.

[8] An experimental process described in Scherer (1965, pp. 177–78). Watt tinkered with different shaped cylinders, different materials for the piston, and mercury, oil, graphite, tallow, horse dung, and vegetable oil as potential sealants.

I was at that time spurred on by the alluring hope of placing myself above want."[9] Writing to Watt in February 1769, Boulton was similarly forthright:

> I was excited by two motives to offer you my assistance, which were, love of you, and *love of a money-getting, ingenious project* . . . [To] produce the most profit, my idea was to settle a manufactory near to my own, by the side of our canal, where I would erect all the conveniences necessary for the completion of engines, and from which manufactory we would serve all the world with engines of all sizes . . . It would not be worth my while to make for three counties only; but I find it very well worth my while to make for all the world.[10]

Two other important points emerge from the letter besides Boulton's monetary imperative. First, the envisaged scale of the enterprise. Boulton had no interest in a small localized business venture ("three counties only"), as was the case with previous engine builders.[11] This would not have enabled them to recoup the costs of developing the condenser. Instead, he understood that it would be necessary "to make for all the world." This scale of enterprise, though, would never have been possible without patent protection: it would have been nigh-on impossible for B&W to control access to the condenser once their engines had been sold to customers and the workings of the condenser would have been deducible to any reasonably competent engineer.[12] Trade secrecy was never an option and any advantage from "lead-time" fleeting.

Consequently, at around the time when Watt's condenser was becoming a patentable proposition, friends started to press him to acquire his patent. One correspondent, the scientist John Robison, was particularly insistent, writing to Watt in July 1768: "you see my dear Sir how many reasons in a manner force you to bestir yourself in getting your property secured. I have fulfilled my promise to Mr Boulton and Dr Small by pressing the thing upon you in the strongest manner."[13] Watt's apparent reluctance to obtain the patent in mid-1768 may be because he was uncertain whether the invention was yet ready to be adequately specified, but he yielded, and worked incessantly to finish the specification in time (which was eventually quite a short document, as we will see in the following section). Watt,

[9] James Watt to William Small, 28 July 1769, (*The Industrial Revolution* 1993, Reel 1, Item 8).

[10] The letter appears in Rolt (1962, pp. 47–48).

[11] At this moment, the largest engineer by engines erected was probably William Brown, who between 1752 and 1778 was responsible for 32 engines. Similarly, Smeaton was responsible for erecting 26 engines between 1755 and 1786. By contrast, B&W would erect 478 between 1774 and 1800 (Kanefsky and Robey 1980, p. 175). Moreover, previous steam engine erectors did not manufacture the components of the engine themselves, but usually sub-contracted this task to local tradesmen.

[12] The legal mechanisms by which B&W could have prevented customers from reverse-engineering the condenser almost certainly did not exist. For a general discussion of the history of British trade secrecy law, see Bottomley (2017).

[13] John Robison to James Watt, 8 July 1768 (Robinson and McKie 1970, p. 14).

though, was probably right to worry about obtaining the patent prematurely, which was awarded to him in January 1769. The standard patent term was fourteen years and so Watt's patent was due to expire in January 1783. With the time lost in further development, B&W would only have enjoyed an effective ten-year patent term. Consequently, once he had acquired Roebuck's share of the patent in 1773, Boulton used his extensive political contacts to petition Parliament for a 17-year extension to the patent term, so that it would end in 1800. It is revealing of the importance of the patent, that the business partnership between Boulton and Watt was only formalized once this extension was granted in 1775, and arranged to formally end with the patent term on 5 January 1800: the existence of B&W had been entirely contingent on not only the patent but also the extension to its term. It is also worth stressing that without the financial capital and manufacturing plant Boulton provided, it is extremely doubtful that Watt would have been able to turn the condenser into a marketable proposition with his own resources; as he himself acknowledged "without [Boulton] the invention could never have been carried by me to the length it has been."[14]

Returning to Boulton's 1769 letter, the second point to emerge is his determination, years before the partnership had been formalized, to manufacture the components for the steam engines themselves. Previously, it had been usual to obtain engine components from local tradesmen and for the engineer to "only" erect the engine. B&W, though, faced a novel situation. They needed to convince potential customers that their new engine design offered a superior fuel efficiency to the old-style Newcomen engines. The solution they arrived at was to supply the engine parts at or near cost, but to charge a royalty for their engines, calculated as a third of the value of the coal saved. They would thereby incur the risk involved with fuel savings, not the customer. Boldrin and Levine criticize this royalty structure as monopolistic and price discriminatory, although once the principle was established, B&W's customers *asked* to be charged in this manner.[15] Subsequent steam engineers attempting to introduce their own engines designs such as Jonathan Hornblower and Arthur Woolf also adopted this pricing strategy (Hills 1989, p. 107).

Calculating the license fee in this manner, though, tied the financial fortunes of the partnership directly to the performance of their engines. A poorly erected or maintained engine would consume more coal, reducing the fuel differential between Watt's engine and a Newcomen engine. Consequently, there was a pressing

[14] Quoted in Dickinson (1936, p. 200). Dickinson adds his own opinion that without Boulton, Watt "would never have brought his engine into general use, nor derived any reward for his invention, nor followed it up by those equally brilliant inventions connected with the rotative engine."

[15] One customer sought "leave to recommend you to settle the premium per savings [of coal] it appearing to me the most equitable," (Robert Wild to Boulton and Watt, 28 November 1789 [Tann 1981, p. 294]). Later, the partnership offered customers a fixed license fee, although this was ultimately based on the estimated fuel savings as well (Bottomley 2014, p. 255).

commercial reason for the partnership to ensure that engine components were durable and of the highest possible quality. Of course, as Boulton appreciated in his 1769 letter, the best guarantor of quality was to manufacture all the engine components himself at his Soho manufactory near Birmingham, although the logistical and organizational challenges inherent to establishing their new type of business meant that initially the partnership only made the smaller precision parts themselves, relying on subcontractors for the rest. This, though, brought its own set of problems, especially guaranteeing that the parts would arrive on time to where an engine was being erected. Also, at least one major subcontractor, John Wilkinson, exploited their dependence on him as the only provider of cylinders for their steam engines to infringe the patent on a massive scale. In a 1795 letter written to the partnership's lawyer, Watt listed 35 engines (!) erected by Wilkinson without their permission.[16] The matter was only resolved to the partnership's satisfaction once they were able to establish their own iron foundry in 1795, freeing them from their reliance on Wilkinson and enabling them to apply much greater legal pressure on him. Wilkinson eventually relented, and agreed to pay license fees (Bottomley 2014, p. 254).

Consequently, there were pressing reasons for B&W to expand their own manufacturing base and to end their reliance on subcontractors—they could never have been content to simply let the royalty payments come in, as alleged by Boldrin and Levine. This can be clearly seen in their manufacturing accounts (see Table 3.1). Table 3.1 covers the period from 1779 (from when the manufacturing accounts survive) to the end of the patent in 1800. The first column provides the number of engine sales recorded for that year. The second column shows the value of goods manufactured at Soho. The third column divides the value of the goods manufactured by engine sales, to give an indication of how B&W sought to increase the proportion of engine components they were supplying. This though, is only a very rough indication, as some of these components would have been made to replace worn out ones on older engines. For example, by 1797, the account of manufactured goods distinguishes between "whole engines" (£12,770 for 1796–1797) and "extra and other articles" (£2,394).

The accounts clearly demonstrate that B&W grew rapidly to become a major manufacturing concern long before their patent expired in 1800. By 1791, they were making goods valued at almost £10,000 p.a. By 1800, this figure stood at £28,617 (for comparison, nominal GDP per capita in 1801 was around £25). Also, the partnership were contributing a significant proportion of the components for their engines by the late 1780s. For comparison with the figures in the third column, B&W's price list for new engines from 1798 shows that a 4 hp engine cost £262 to construct (and sold at £350, with manufacturing profit of 5 percent

[16] James Watt to Ambrose Weston, 10 September 1795 (Tann 1981, p. 131–36).

Table 3.1 Boulton & Watt, manufactured goods, 1779–1800.

Year	Engines sales[a]	Goods manufactured[b]	Goods manufactured per engine
1779	10	£923	£92
1780	10	£480	£48
1781	4	£92	£23
1782	2	£582	£291
1783	10	£344	£34
1784	15	£806	£54
1785	19	£1,515	£80
1786	21	£2,348	£112
1787	11	£3,639	£331
1788	14	£4,200	£300
1789	20	£3,594	£180
1790	21	£3,800	£181
1791	25	£9,858	£394
1792	18	£9,866	£548
1793	17	£11,831	£696
1794	13	£9,879	£760
1795	26	£5,821	£224
1796	31	£15,295	£493
1797	21	£15,168	£722
1798	23	£17,847	£776
1799	47	£23,139	£492
1800	47	£28,617	£609

a Tann (1977) produces a slightly reduced number of B&W engines manufactured for the period from Kanefsky and Robey (1980), although her figures have been used here as they are annualized.

b Accounts and balance sheets 1783 to 1797 (*The Industrial Revolution* 1993, Reel 75). Value of goods manufactured was not recorded over a calendar year, but from October to September. So the first figure in this column actually relates to the period October 1778 to September 1779.

and royalty charge). A 32 hp engine would have cost around £850 to manufacture and sold for £1156.[17]

[17] J. Watt junior to Boulton junior, 11 September 1798 (*The Industrial Revolution* 1993, Reel 6, Item 61).

The partnership's determination to ensure that engines built to their design were of the highest quality, also meant that they were loath to license the use of their technology to other engineers. They were conscious that a poorly erected engine would damage their reputation as well as limit their royalty payments. This had important repercussions for their relations with other engineers, as we will explore in the following section. In the interim, what this signifies is that the portrayal of B&W as idle parasites, succored by their patents and uninterested in manufacturing could not be a grosser misrepresentation. As we have seen, they had pressing commercial reasons for manufacturing their own engines. Indeed, together, they created an enterprise the likes of which had never been seen before, a factory that could manufacture steam engines in their entirety and then erect them for a customer. They even introduced a rudimentary form of after-sales service. They could not have achieved this scale of production without their patent for the condenser.

Finally, it has been claimed that once Watt finished developing his condenser and the partnership's legal position was secured by an extension to their patent term, he was uninterested in pursuing further developments in steam engineering: he "simply decide[d] to make money from [his] existing invention rather than keep working to improve it" (Lemley 2012, pp. 740–41).[18] This claim is usually attributed to a letter Watt wrote to Boulton:

> On the whole, I find it now full time to cease attempting to invent new things, or to attempt anything which is attended with any risk of not succeeding or creating trouble in the execution. Let us go on executing the things we understand, and leave the rest to younger men, who have neither money nor character to lose. (first quoted in Scherer 1965, p. 174)

The letter, though, reveals more about Watt's personality and his neuroticism than about his inventive output: he was the most innovative steam engineer of the last quarter of the eighteenth century. Among other things, Watt invented sun and planet gearing (patent no. 1306), so that steam engines could produce rotative motion (a competing and ultimately more successful crank may have been stolen from Watt; patent no. 1263; Tann 2013), double acting cylinders (where steam acted on both sides of the piston in a cylinder; no. 1321), parallel motion (allowing a pumping rod to move up and down in a directly straight line; no. 1432), the poppet valve (an improved valve for controlling steam flow into the engine; no. 1432). Watt also developed the concept of "horsepower" (hp) as a means of measuring the power output of engines.

[18] See also Merges and Nelson (1990, p. 872).

Admittedly, Watt wrote his letter at the end of 1785 (it is usually cited as if indicative of the whole patent term), but after this date, he still developed the centrifugal governor for steam engines in 1788 (adopted from windmills and used to regulate the operating speed of the engine). As a firm, also, B&W remained innovative. One employee, John Southern, developed the indicator, used to measure the pressure inside the engine at each stage of the operating cycle (useful for maximizing power output and fuel efficiency). B&W were also probably the first firm to use elliptical cast iron beams in 1797, improving the durability of their engines and their flexural strength.[19] Finally, while it has been suggested that engines capable of producing 100 hp only appeared in the nineteenth century, it appears that the largest B&W engines were capable of this power output before the end of the eighteenth century (Tann 2014).

Boulton & Watt and High-Pressure Steam Engineering

Over the course of the nineteenth century, the greatest gains in fuel economy and power output would be achieved by using steam at ever greater pressures to actively "push" against the piston, rather than using atmospheric pressure to "pull" the piston down. This would also allow for the development of the steam locomotive, which would revolutionize world transport. Watt had conceived of this possibility when working on his separate condenser and included it as the fourth article of his 1769 specification, where he stated his intention "to employ the expansive Force of Steam to press on the pistons."[20] Watt, though, was not the first to have had this idea. In Europe, for example, Jacob Leupold had described a high-pressure engine in *Theatrum Machinarum Generale* in 1720 (Selgin and Turner 2011, p. 848). Similarly, in 1698, Thomas Savery had patented an engine which used steam at high pressures—although it did not use pistons and encountered too many technical problems to ever be considered a success (in particular, the engine's soldered joints could not withstand the high pressures required). At this time, British patent law did not recognize the rights of the first inventor per se, but those of the first domestic "publisher." Use abroad, or domestic use that had been in secret and/or fallen into abeyance, would not invalidate a subsequent patent, at least, not for want of novelty (Bottomley 2014, pp. 165–67).

[19] Nuvolari (2004, pp. 30–31). Cardwell (1994, p. 208) suggests that the company Aydon & Elwell were the first to use these beams in 1795.

[20] In full: "Fourthly, I intend in many cases to employ the expansive Force of Steam to press on the Pistons, or whatever may be used instead of them, in the same Manner as the Pressure of the Atmosphere is now employed in common Fire Engines: In Cases where cold Water cannot be had in Plenty, the Engines may be wrought by this Force of Steam only, by discharging the Steam into the open Air after it has done it's Office." Watt, James. 1769. "Method of lessening the consumption of steam and fuel in fire-engines." England Patent 913, awarded Jan. 5, 1769.

Consequently, although the idea had been previously expressed, if Watt had invented an engine worked by high-pressure steam, then it probably would have been patentable. It is doubtful, however, that at the time when Watt submitted his specification, he had indeed accomplished a finished machine and/or model using the expansive force of steam; the fourth article refers only to an intention and in its 78 words, offers no specific indication of how Watt intended to use the expansive force in practice. It was this vague and elusive article that would be the major source of Watt's legal difficulties over the coming years: specifications were adjudged by stringent criteria at this time. Watt well knew this, but he seems to have believed that concision was the best strategy when preparing his 1769 specification.[21] He was also poorly advised to omit technical drawings from his specification.

This vulnerability in Watt's patent gradually became apparent as others sought to pursue the same technological opportunities; the first British engineer after Watt to experiment with the expansive power of steam was Jonathan Hornblower who patented a compound engine design in 1781. In Hornblower's compound engine, higher pressure steam was used to drive a piston in a smaller, closed top cylinder. The steam then passed to a second cylinder where it expanded further, driving a second piston. High pressure compound engines of this type became the predominant design during the course of the nineteenth century, due to their fuel economy and the smoothness of action that could be achieved by using two working cylinders instead of one. Hornblower, though, never came close to realizing the full potential of his design. Firstly, Hornblower never used the engine at pressures high enough to realize anything like the fuel economy that might have been achieved, and this despite the urging of friends such as Davies Gilbert (later elected as president of the Royal Society, 1827–1830), to do so. Criticism on this point, though, ought to be tempered by acknowledging that metal working techniques at the end of the eighteenth century were not yet reliable enough to ensure that boilers could always contain the steam at the requisite pressures.[22] Secondly, there were technical faults with his engines (as shown in drawings of his ten Cornish engines erected from 1791 to 1794), which also undermined their efficacy. For example, Hornblower's engines used a separate condenser to improve their fuel efficiency, although this had to be limited in size "probably to try and avoid Watt's patent" (Hills 1989, p. 147).[23] Thirdly, Hornblower was

[21] Boulton and Watt (1993, Part I, 1:4).

[22] Matters improved in the nineteenth century, although between 1800 and 1866, 4,067 people were killed in more than 1,000 recorded boiler explosions (Selgin and Turner p. 855).

[23] Hornblower referred obliquely to his use of the condenser in his 1781 patent specification: "Sixthly, that the condensed vapour shall not remain in *the steam-vessel in which the steam is condensed*, I collect it into another vessel." Hornblower, Jonathan. 1781. "Machine or engine for raising water and other liquids by means of fire and steam, and for other purposes." England Patent 1298, awarded July 13. 1781.

determined to pursue an unworkable scheme to develop his engine so that it could pump water out of mines *and* grind corn simultaneously, requiring that the engine work in both horizontal and vertical directions (Todd 1959, pp. 4–6). One wonders what might have been possible if Hornblower had had Watt's good fortune and entered into partnership with a more acute business mind.

Not only was Hornblower infringing the sperate condenser, but also, B&W believed, their sole right to use steam expansively. In 1792, for example, in their published opposition to Jonathan Hornblower's application to Parliament for an extension to his own 1781 patent, they asserted that one of their principle contributions had been to develop "the piston [which] is pressed down by the expansive power of steam; *and not* (as in Newcomen's) *by the weight of the atmosphere*" (original italics).[24] Such, likewise, was the view of informed contemporaries as well. In an undated note, John Smeaton observed that one of the "prohibitions concerning the structure of fire engines injoined by the specification in Mr Watt's Act of Parliament" was "not to employ the expansive force of steam to press on pistons or whatever else may be used instead of them in the same manner as the pressure of the atmosphere is now employed in common fire engines."[25] There can be no doubt that the partnership believed that Hornblower was working in contravention of their patent rights. Interestingly, it appears from a letter Hornblower wrote to his uncle in 1789 that he acknowledged that in his engine "the mechanism is similar to Watt's in most respects," one of which was that "steam is convey'd thither in a state stronger than the atmosphere and acts upwards with a force" (Torrens 1982, pp.191–92). However, despite these infringements, Boulton and Watt failed to take legal action against Hornblower until the very end of their patent term in 1799. This obviously begs the question why they waited for so long. In roughly chronological order, there were three reasons.

(1) In the 1780s, Hornblower's engines performed poorly. In 1782, for example, John Southern, one of B&W's most accomplished agents, inspected Hornblower's engine erected at Radstock. Although he confirmed it was an infringement of the partnership's patents, it made "so wretched a performance as not to equal an Old Usual Engine" (Tann 1981, p. 96). Indeed, it ran so badly that by 1785, Hornblower's engine man at Radstock had started to pass information on to James Watt in the hope of gaining employment with him instead, warning in particular about visitors arriving to inspect the engine from Cornwall.[26]

[24] Boulton and Watt Collection, Library of Birmingham (LB), MS 3147.2.51, Item 22.

[25] LB, MS 3147.2.23, undated.

[26] LB, MS 3147.2.35, Item 5, letter from Shore, dated 12 June 1787. Hornblower's engine man (Thomas Shore) also discussed the failure of his recently erected engine at a coal mine in Timsbury. Here, there were three six-inch pumps working at the mine, but only one pump could be worked "with his engine, he have not got power enough that do work the other 2 pumps with horses" (sic) (LB, MS 3147.2.35, Item 3, letter from Shore, dated 21 February 1785).

Although initially alarmed by the threat posed by Hornblower, the partnership decided against intervening until his engines posed a direct commercial threat: as Watt wrote to Boulton in 1786, "to the trumpeting [Hornblower] if anybody is wicked enough to erect one of their Engines let them, and when we can do no better lett [sic] us try the law."[27] Moreover, Hornblower's first engines ran at coal mines (Radstock and Timsbury), where, of course, fuel prices were extremely low. As such, because the royalty payments to B&W were calculated according to fuel savings, engines at these mines would have paid little to them in any case. Consequently, while Hornblower's engine was in its developmental stage during the 1780s, the partnership refrained from legal action to enjoin his activities: so long as he remained uncompetitive, there was, from a financial perspective, no pressing reason to do so. It also means that Boldrin and Levine's casual "decade or two" can be narrowed down to a certain decade.

Beginning in the 1790s, however, Hornblower started to reach parity with Watt's engines in terms of fuel efficiency, as measured by duty (incidentally, a measurement introduced by Watt). Appropriately, as most engines were used to pump water out of mines, duty was expressed in terms of how many pounds of weight could be raised one foot, by consuming one bushel of coals (standard weight being 86lbs).[28] The Newcomen engines averaged around 4–5 million lbs of duty, although the best could achieve 10 million (Hills 1989, p. 37). The best Watt engine, by contrast, had attained 27.5 million by 1798, although they tended to work at around 18–20 million (Hills 1989, p. 103). Trials of Hornblower's engines indicate that he was only ever able to achieve parity with B&W's engines, at least in respect of duty. Richard Trevithick, for example, measured the duty of one Hornblower engine at Tin Croft mine at 16.6 million lbs; another trial reached 19.8 million lbs. One trial by Hornblower himself (presumably under ideal conditions and with a view to maximizing the result) yielded a figure of 28.5 million lbs.[29]

Hornblower had also started to erect steam engines at mines in Cornwall—by far the most lucrative area of B&W's operation—where he offered terms which were also far more advantageous to mine owners. As has already been discussed, B&W charged their license premium at one-third of the value of the coal savings

[27] James Watt to Matthew Boulton, 23 September 1786 (*The Industrial Revolution*, Reel 4, Item 71).

[28] The weight of a bushel of coals did vary from place to place, though. The standard bushel was 86lbs, but in London, it was 82½lbs and in Cornwall, 94lbs. Jim Andrew, "Old weights and measures," mimeo, 2008, see http://www.museumsassociation.org/download?id=77607. Moreover, it varies from source to source—Hills (1989, p. 36) gives the weight of a London bushel as 88lbs (!).

[29] LB, MS 3147.2.52, Item 4 "History of Jonathan Hornblower's Engine. Thomas Wilson, 22 July 1799." This was a document prepared by Thomas Wilson, B&W's agent in Cornwall, so it might be expected that he would be tempted to underreport the figures for Hornblower's engine. However, the document was prepared with a view to calculating the license payments to be demanded of those using Hornblower engines. This was premised on the work achieved by the engines, and so here, if anything, the temptation would have been to overstate the work achieved by Hornblower's engines.

achieved by using their steam engine, compared with an old Newcomen engine; this saving was considerable. Hornblower offered the identical terms—charging one-third of the coal savings incurred by using his steam engine, but in comparison with a Watt engine.[30] Even though this saving was modest, if indeed there was a saving at all, there was now a considerable incentive for the Cornish mine owners to use Hornblower engines instead of Boulton &Watt's, especially if they discounted the enforceability of the latter's patent. For an illustration using roughly representative figures, let us say a Newcomen engine at a mine consumed £4,000 in coal p.a. If the coal usage was halved by replacing it with a B&W engine, then the mine owner was now only spending £2,666 p.a.—£2,000 on fuel and a royalty of £666 to B&W, as a third of their fuel savings. Now let us say they then replace their B&W engine with a Hornblower engine, which yields an additional £300 p.a. fuel saving. The owner is now only spending £1,800 p.a.—£1,700 in fuel and a £100 royalty to Hornblower.[31] After the first Hornblower engine was erected in Cornwall, at Tincroft in 1791, nine more were erected to 1794, as well as eight other pirate engines by Edward Bull (Tann 1979, pp. 104–05). Unlike his earlier engines at coal mines, this posed a serious threat to the finances of B&W. Worse still, mines with Watt's engines started to withhold royalty payments, in the hope that the separate condenser patent would prove to be unenforceable.

(2) Still, however, Boulton and Watt refrained from enjoining the use of the Hornblower engine. The second reason why they waited so long before prosecuting Hornblower was because they appreciated that their patent was poorly specified and "weak." In 1791, for example, when they were beginning to prepare for legal action, they sought the private opinion of Sir John Scott, then the solicitor-general, and Thomas Plumer, another prominent lawyer, on the sufficiency of their specification. Both were of the decided opinion that the specification was inadequate, Plumer observing that "in what manner the [invention] is to be performed," the specification "seems to be entirely silent."[32] By the terms of English patent law at this time, this should have been sufficient to invalidate their entire patent.

[30] Inevitably, some of the Cornish mine owners who erected Hornblower engines, decided to challenge their license payments on the basis that the savings achieved were not what Hornblower claimed. See, for example, the correspondence between Hornblower and Wheal Wherry mine. LB, MS 3147.2.51, Item 36.

[31] These figures are intended to be representative. Firstly, the fuel savings are broadly in line with the gains in duty seen between different types of engine discussed in the main text. Indeed, it probably understates the savings involved with using a B&W engine compared with a Newcomen engine, and overstates the savings involved with using a Hornblower engine compared with a B&W engine. On the monetary savings involved with adopting a B&W engine (see Matthew Boulton to James Watt, 6 September 1777 [Tann 1981, 173]).

[32] He therefore sought to "impress Messrs Boulton and Watt with such a degree of hesitation and doubt on this subject, as to prevent their hazarding a litigation, which in one event might be so injurious to them, without consulting the advice of their other counsel." (LB, MS 3147.2.34, Item 1, copy of Mr Plumer's opinion, 20 September 1791, covering note).

The partnership also feared that the patent might be revoked by writ of *scire facias*. This was a writ obtainable by third parties who could represent to the attorney-general that the patent in question was invalid and request that a case be brought in the name of the Crown to have the validity of the patent properly tried at common law. The writ was not demandable as a matter of right, and the burden of evidence concerning the (in)validity of the patent sought by the law officer prior to issuing the writ was probably high: while it was not so great that issuance of the writ was unusual, once it was issued and pursued to trial, patentees very seldom won (the first reported instance of success occurring in 1850).[33] Whatever the threshold, B&W's patent certainly flirted with it. In June 1795, for example, their lawyer Ambrose Weston wrote to the pair, "I shall continue to use every exertion in my power to ward off the *scire facias*, which I dread as much as you" and intriguingly, a draft of a writ to annul their patent survives in the National Archives in London.[34]

For whatever reason, though, the writ was never issued and in the final analysis, no attorney-general at the time thought B&W's patent so demonstrably invalid that a writ of *scire facias* ought to issue. Still, vulnerabilities in their patent persuaded the partnership to proceed cautiously, moving in successive steps. First, of all they moved to prosecute only the most blatant infringers, especially Edward Bull who was also working in Cornwall. Bull's engine was in almost every respect the same as Watt's, although he had ingeniously inverted the cylinder directly over the mine shaft, removing the need for the rocking beam that usually connected the pumping rod with the steam engine. His use of the separate condenser, though, was certainly an infringement. Initially, Bull had sought a license from the partnership for the use of their technology when erecting his engines, although this had been refused for the reasons mentioned earlier.[35] Bull, however, chose to press on without their license, and between 1791 and 1794, erected at least eight engines according to his design in Cornwall (Tann 1979, p. 104).

[33] The first reported *scire facias* case relating to patents of invention occurred in 1782 (K.B.: 1 Oldham 1992, p. 767), and there were six more reported cases before the end of the century: *Rex* v. *Else* (1785, K.B.): Bull. N.P. (6th ed.) 76; Davies 144; 1 Carp. P.C. 103; 1 Web. P.C. 64; 11 East 109 n.(*c*); *Times*, Dec. 24, 1785, p. 3; *Rex* v. *Arkwright* (1785, K.B.): 1 Web. P.C. 64; 1 Carp. P.C. 53; Davies 61; *The Trial of a Cause Instituted by Richard Pepper Arden* &c (1785) *Rex* v. *Argand* (1786, K.B.): *Times*, Dec. 6, 1786, p. 3; *Manchester Mercury*, Dec. 12, 1786, p. 2; *Rex* v. *Eley* (1790, K.B.): *Times*, Dec. 9, 1790, p. 3; *World*, Dec. 9, 1790, p. 3; *Rex* v. *Miles* (1797, K.B.): 7 T.R. 367; *Times*, Feb. 21, 1797, p. 3; *Oracle*, Feb. 21; *Rex* v. *Boileau* (1799, K.B.): Farey Report, p. 191.

[34] Ambrose Weston to Boulton & Watt 4 June 1795, (*The Industrial Revolution* 1993, Reel 108, Item 11). National Archives (NA), C217/152.

[35] In October 1791, James Watt wrote to Thomas Wilson, his agent in Cornwall, on the matter of Bull's application: "In respect to Bull, the less we have to do with him the better, if he applies to you on our terms & brings respectable persons as principles you will fix the premium with him & take his order for the size of the Engine but we will not be directed how to make it. Had we agreed to have let him made one of our Engines in such a manner he pleased, he would have made a bad thing & we should have had our share of the disgrace as it now stands" (quoted in Stewart [2017, pp. 137–38]; original at Cornwall Record Office (CRO), AD 1583/4/91).

Once B&W obtained a favorable verdict at common law against Edward Bull in 1795, and then again against Jethro Hornblower (brother of Jonathan) and Stephen Maberley in 1799, they were in a much stronger position to enforce their patent against other engineers who were infringing their rights to the separate condenser. However, two of the judges who had supported the validity of the patent in *Boulton & Watt* v *Bull* (1795) expressed doubts concerning the enforceability of the fourth article of Watt's specification regarding the use of the expansive force of steam. Justice Rooke, for example, noted that Watt "could [not] maintain an action for breach of these articles."[36] This raises a second important point—it is doubtful, at the conclusion of the B&W cases, that they could have enforced this specific clause of the specification. The corollary of this is that Boulton and Watt would not have been able to enjoin the development and use of single cylinder, high pressure engines that did not use a separate condenser—a type of engine that would subsequently be developed by Richard Trevithick in the early part of the nineteenth century (the "puffer")—had such an engine appeared during their patent term. Put another way, their patent would have done nothing to prevent the development and commercialization of this type of engine at the end of the eighteenth century.

Nonetheless, the partnership's overall legal position had been strengthened by their success at common law, and over the course of the 1790s, they obtained *at least* fifteen separate injunctions. There is no record of a single injunction beforehand. But in another important respect, they adopted a more accommodating attitude to their rivals than had previously been the case. It will be remembered that in 1791, the partnership had been unwilling to license Edward Bull, a dispute that ultimately led them to try their right at law. Later, though, they were willing to license Bull's engines, "provided our dues are paid," which admittedly was not always the case and injunctions had to be obtained to prevent Bull from erecting more engines (quoted in Stewart 2017, p.142). Thus, once they strengthened their legal position, by virtue of favorable verdicts at common law supporting the validity of their patent, they moved to collect royalty payments from less egregious infringers, especially those using Jonathan Hornblower's engines (whose efforts to avoid infringing B&W's patent by minimizing the size of his condenser have already been mentioned), alleging that they made use of the technology that they had patented.

(3) Herein lies the third reason why the partnership refrained from legal action against Hornblower for much of the 1790s. Ultimately, they had always

[36] Hayward (1987, 1:383–84). Similarly, Chief Justice Eyre noted that "some weighty observations have been made upon parts of this specification, but those parts appear to me not properly to relate to the method described in the patent; they are rather intimations of new projects of improvement in fire-engines, and some of them, I am very ready to confess either very loosely described or not very accurately conceived . . . they are the fourth and fifth articles" (Hayward 1987, 1:393).

hoped that their financial losses would be minimized by claiming royalties from those mines that used Hornblower engines. The partnership had monitored the use of the Hornblower engines very closely with a view to handing in demands for license fees owed when the time was opportune. The partnership had also made periodic requests for such royalties throughout the 1790s, but they were not backed up with the credible threat of legal action—as contemporaries were well aware. In 1795, for example, after legal action had already commenced against him, Edward Bull observed that B&W had "never attempted to interrupt the working of [Hornblower's engines] except by threats only."[37] Although Bull's engine may have offered certain advantages over Boulton and Watt's engine, it was a clear infringement of their patent. Interestingly, Hornblower seems to have been pleased that Bull lost his case: "I must say I rejoice at it . . . Bull's was a palpable infringement without any improvement whatever' (Torrens 1982, p. 196). Speculatively, Hornblower may have hoped that with this avenue of evading B&W's patent closed off, mine owners would now be minded to adopt his own engine instead.

After the final contest at common law against Jonathan's brother Jethro and his business partner Stephen Maberley had been resolved to the partnership's satisfaction in 1799, they moved quickly, presenting royalty demands to every mine using a Hornblower engine. These were calculated precisely, according to the length of time the engine had been working and the size of the engine's cylinders, as a proxy measure for the coal savings which formed the usual basis of B&W's royalties. For example, Trescavean mine was assessed at £1435 11s. 6d. for a Hornblower engine with 30 and 36-inch cylinders, which had been at work for 80 months and 6 days.[38] In total, B&W calculated that they were due £10,560 from mines working Hornblower engines.[39]

Subsequent events can be traced in the voluminous legal bill B&W accrued over the entire period from 1794 to 1801. Initially, the mines refused to pay, and injunctions were obtained to prevent the working of Hornblower engines. Hornblower himself was served on 21 October 1799.[40] Initially, it did not appear that Hornblower would back down (it was reported to B&W that when served, Hornblower "only said that he thought it was foolish in you to give him any trouble") and Boulton and Watt made serious preparations for the case to proceed to common law, meeting with their counsel in London several times in February 1800 to discuss the subject.[41] Matters proceeded all the way to Hornblower being

[37] NA, C12/204/15, fol. 1. The partnership had made periodic requests to users of these mines throughout the 1790s, but with the favorable verdict in Bull, it seems that the threat of legal action became far more menacing.
[38] LB, MS 3147.2.52, Item 1.
[39] LB, MS 3147.2.52, Item 1.
[40] LB, MS 3147.2.52, Item 20, dated 21 October 1799.
[41] LB, MS 3147.2.52, Item 20, dated 21 October 1799.

served with notice of the trial, when presumably, to judge from B&W's bill, Hornblower surrendered. It is not clear what prompted Hornblower to concede at the last minute. It may simply be that he had been bluffing in the hope that B&W would blink first. In any case the first mine to pay up was Wheal Unity, which paid £2,100 in satisfaction of royalties that had originally been assessed at £3011 5s. 0d in September 1800.[42] A few weeks later, Tincroft, the first mine to erect a Hornblower engine and with the largest assessed royalty (initially at £3,684), paid £2,569 in satisfaction thereof.[43]

Thus, although the story is a detailed and complex one, the outcome is relatively straightforward. Use of a Hornblower engine was possible, free from legal interference from Boulton and Watt, so long as royalties were paid to the partnership for their savings. This was not just the case with those using Hornblower engines. In the middle of the legal action against Edward Bull, for example, mines using his engine could obtain an accommodation with B&W. In 1795, for example, B&W obtained an injunction, preventing the working of the engine at Ding Dong mine which, although based on Bull's design, had been erected and altered by Richard Trevithick.[44] In particular, Trevithick was responsible for increasing the pressure at which the engine worked to achieve better fuel economy, the resultant success of which led to his appointment as chief engineer at the mine (Trevithick 1872). The *Life of Richard Trevithick*, written by his son Francis, records Trevithick's apparent intransigence in the face of this legal action, altering the engine to avoid the patent (by opening up the top of cylinder, thus reverting to the use of atmospheric pressure) and by supplementing its power with a windmill. A more prosaic document survives in the B&W archives in Birmingham—a copy of the licensing agreement Trevithick reached with B&W later in 1796, when he agreed to pay £162 18s. 8d. "as the premium for the using of a certain Steam Engine of twenty-eight inches diameter in the cylinder that is now working on a mine called Ding Dong Mine, for so long time as the said engine shall continue to work single, or by steam pressed on one side of the piston only."[45] Similarly, after B&W had successfully obtained an injunction against Bateman & Sherratt in 1796 (their largest competitor in terms of engines erected), they were also licensed and continued to erect engines using B&W's technology during the patent term (Kanefsky 1979, p. 478).[46]

Herein lies the crucial point. B&W's patent(s) did not act as an insuperable obstacle to the development of high-pressure steam engines, or indeed

[42] LB, MS 3147.2.52, Item 26.
[43] LB, MS 3147.2.52, Item 30.
[44] NA, C12/213/16, f. 3.
[45] LB, M3 3147.2.17, Item 6.
[46] Although they were a very distant second. Between 1782 and 1800, Bateman & Sherratt made 45 steam engines, whereas B&W made 451 (Kanefsky and Robey 1980, p. 175).

other potential developments in steam engines. As the experience of Jonathan Hornblower, Richard Trevithick, and Bateman & Sherratt shows, they were eventually able to obtain licenses to use James Watt's patented technology. Neither was the expiration of B&Ws patent term in 1800 marked by any sudden change in behavior: it did not mark the opening of a new opportunity. Hornblower did not suddenly start using higher pressures in his steam engines; not a single engine was erected according to his design after 1800 (Farey 1827, p. 390). Instead, the opportunities of using Hornblower's engine at higher pressures were left to Arthur Woolf, who patented his design in 1810 (Carlyle 2004). Trevithick continued his work on high-pressure engines, but was hampered by safety issues (seized upon in publicity by B&W) and the dissipation of his energy over multiple ventures, which eventually bankrupted him in 1811 (Hills 1989, pp. 102–03). As with Hornblower, one wonders whether Trevithick would have enjoyed greater success if he had had the same good fortune as Watt in finding a business partner with the foresight and nous of Matthew Boulton.

Conclusion

The story of Watt's patent is an almost ideal illustration of patents working to stimulate the development and commercialization of new technology. It incentivized Watt's costly development of the condenser, a project which took ten years and at least £7,500 to complete. Without the prospect of patent protection, it is unclear why he would have made this investment. Neither would he have been able to join in a partnership with Matthew Boulton, one of the largest and most ambitious manufacturers of the day, and commercialize the condenser. Put another way, without patenting, industry would have been waiting for the condenser to appear "organically" for a very long time. The protection afforded by the patent also allowed the partnership to invest in the establishment of a business the likes of which had never been seen before—a manufactory that constructed steam engines in their entirety, provided for the installation, and then also a rudimentary form of after-sales service.

Neither do the supposed downsides of awarding patents appear in the instance of Watt. He continued to develop improvements, and work on the underlying theory of steam engineering, throughout the lifetime of the patent. Finally, the claim that Watt was able to use his patent to stymie the development of high-pressure steam engineering can be discarded. The partnership had refrained from interfering with Hornblower's engine when it was in its developmental phase and only resorted to legal action at the very end of the patent term in an effort to collect royalty payments from mines using his engine.

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