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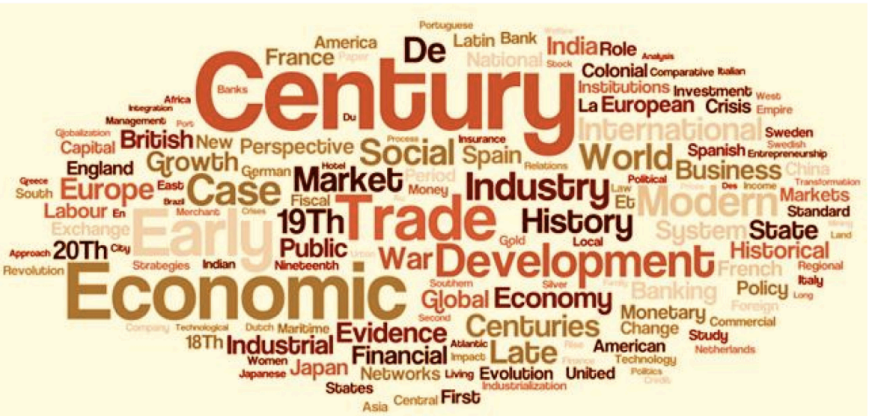

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Power & Profit:
Copper Mines & Steam Engines in Late 18th Century Cornwall[1]

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Abstract

In the inaugural issue of *Past and Present*, Eric Hobsbawm emphasised the complexity of workers' and capitalists' attitudes to new machines. Moreover, noting that: "only rarely were new machines immediate and obvious paying propositions", he suggested the potential of a history of profit to understand the motivations for introducing machines and the consequences of their adoption. This article grapples with Hobsbawm's "profit puzzle" to understand the implications of the adoption and use of the Boulton & Watt steam engine for capitalists and workers in Cornish copper mines between 1777 and 1791. It shows that the engine's economic implications for the people who invested in, and worked, the Cornish copper mines were conditioned by a complex relationship between power and profit. Power is assigned three meanings in this analysis: steam power, which was crucial to the mining of copper and the costs of its production; imperial power, given fluctuating demand for copper from different parts of the British Empire; and market power since control over price setting on the British copper market had decisive implications for Cornish mining profits. The article shows that the evolving relationship between power and profit conditioned both the enthusiasm for the B&W engine in Cornwall and the subsequent hostility that Cornish miners and mining adventurers displayed towards the partners. More generally, it suggests the potential of studying the economic and social history of new machines through the lens of profit to understand the motivations for introducing machines and the consequences of their adoption.

Keywords: profit; mining capitalism ; new technology; British Empire; steam engine

Codes JEL: N00, N73, N83

[1] Previous versions of all or part of this paper were presented in the Historical Capitalisms & Social Theory workshop at the University of Chicago in March 2019, the Eli F. Heckscher Lecture in September 2019, and the Institut Paul Bairoch's Séminaire Avancé de Recherche in October 2020. Both the paper and the author have benefitted enormously from the comments received on these occasions although some excellent suggestions, which require further archival research, will take a bit more time to implement.

Power & Profit:
Copper Mines & Steam Engines in Late 18th Century Cornwall

On October 6th, 1787, Matthew Boulton – James Watt's business partner in the Boulton & Watt (hereafter B&W) steam engine business – wrote to him in a panic from Cornwall to tell him that: "There are 400 Miners already assembled and are calling all they can together and are going to pull down Vivian's House. I am too much distressed to write more".[2] Boulton's vexation was explained by the fact that John Vivian was a close associate of B&W in Cornwall. In a letter the following day, Boulton explained that the miners continued to Truro but the Magistrates had been given the alarm, and "with the inhabitants took every measure in their power to collect arms, some cannons, and every weapons [sic] they could find".[3]

The miners dispersed, perhaps impressed by the opposition they encountered, or mollified by the promise that the "principal Gentlemen of the County" would consider their case at a general meeting that week. Still, as Boulton reported, they "gave notice that unless something was done to mend the Copper Trade they would return to Truro next Saturday and take their Revenge". On their way home, "they intimated their intention of calling upon me and as I thought it would be better to avoid these Drunkards and the making them any promises, I made my escape the back way". Arriving in Truro, Boulton learned that: "[t]he Mayor sent a letter to the Secretary of War to request 2 Companies at Truro for their protection. Lord Falmouth also accompanied with another letter, and likewise he wrote one to Mr. Pitt to inform him of these commotions and distresses". Social unrest in Cornwall, it seems, was of sufficient importance to merit national attention.[4]

Reading this breathless account by Matthew Boulton, one of the heroic figures of Britain's machine age, we seem to hear echoes of Eric Hobsbawm's classic discussion of machine breakers. In the inaugural issue of *Past and Present*, Hobsbawm exhorted historians to move away "from a view of machine-wrecking as synonymous with early 19th century Luddism to study workers' attitudes to machines before the rise of the factory system".[5] From this perspective, Boulton's story of an enraged "mob" of copper miners, riled up against him and his associates, would seem to be important. The copper industry was one of the most rapidly-growing industries in the British economy in the 18th century, overshadowed only by the spectacular expansion of the cotton industry.[6] Moreover, the Cornish copper mines played a decisive role in the early commercialisation of the B&W engine, accounting for most of the partnership's profits in its early decades.[7] Thus, any resistance to the adoption of the steam engine in Cornwall, as well as its repression, would merit our attention. Yet, far from objecting to the use of B&W's steam engines to pump water from Cornish copper mines, the miners were protesting the stoppage of these machines. Paradoxically, it is the contrast between what Cornish miners were about, and classic incidents of machine breaking, that makes this example an excellent illustration of important themes in Hobsbawm's pioneering article.

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[2] Archives of Soho, Boulton & Watt & Successor Firms : Correspondence & Papers (hereafter B&W), MS 3147/3/11, Matthew Boulton (MB) to James Watt (JW), 6 Oct. 1787.

[3] B&W, MS 3147/3/11, MB to JW, 7 Oct. 1787.

[4] ibid.

[5] E. J. Hobsbawm, "The Machine Breakers", *Past and Present*, 1(1) (1952), 57-70.

[6] The copper industry displayed the highest rate of growth in real output of all of Britain's industrial sectors from 1700 to 1770. From 1770 to 1780, and again from 1780 to 1790, it ranked among British's three or four fastest-growing industries, being substantially surpassed only by the cotton industry (N. F. R Crafts, 1985. *British Economic Growth During the Industrial Revolution* (Oxford, 1985), 23).

[7] Jennifer Tann, "Riches from Copper: The Adoption of the Boulton & Watt Engine by Cornish Mine Adventurers", *Transactions of the Newcomen Society*, 57, (1996) 27-51.

Hobsbawm argued that workers' attitudes to the adoption of machines were conditioned not by any general hostility to new machinery but by its expected implications for their standard of living. Since Cornish miners considered idle, not active, steam engines as a threat to their livelihood, they offer an interesting contrast to better-known cases of workers' resistance to new machines.[8] But B&W's turbulent relationship with the Cornish offers scope for an even broader reading of Hobsbawm's article since he emphasised the complexity of capitalists' as well as workers' attitudes to the adoption of new machines. Noting that: "only rarely were new machines immediate and obvious paying propositions",[9] Hobsbawm encouraged us to ask to what extent, and for what reasons, capitalists could generate profits from adopting them. In *Industry and Empire*, he identified this "profit puzzle" as crucial for understanding the path towards Britain's industrial revolution.[10]

Since Hobsbawm's seminal work, there has been a dramatic transformation in our understanding of the history of British industrialisation. For a time, the very notion of an industrial revolution was called into question but it has returned with gusto in recent historical research. With it comes a renewed emphasis on Matthew Boulton and James Watt although now they are portrayed as emblematic of cultural, political and knowledge revolutions as much as technical transformation.[11] The result is a rich impression of James Watt and Matthew Boulton as entrepreneurial archetypes of a British "industrial enlightenment".[12]

If the partners as "savants" and "fabricants"[13] seem a long way away from the well-documented turbulence of their business dealings in Cornwall, that is surely because recent research pays so little attention to their efforts to turn their new machines into "paying propositions".[14] Recent historical research seems to take it for granted that the adoption of the B&W engine reflected "a marriage between business sense and mechanical knowledge", as Margaret Jacob put it, but without offering much explanation of the engine's commercial success.[15] An earlier literature has more details to offer on Boulton and Watt's business, including their Cornish engines, but tends to appeal to the same happy combination of Watt's "great inventive genius" and Boulton's "natural talent for business enterprise" without engaging with Hobsbawm's puzzle.[16]

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[8] See, for example, Adrian Randall, *Before the Luddites: Custom, Community and Machinery in the English Woollen Industry, 1776-1809*, (Cambridge, 2004).

[9] Hobsbawm, 1952, 64.

[10] Eric J. Hobsbawm, "The Industrial Revolution, 1780-1840" in *Industry and Empire: From 1750 to the Present Day*, (London, 1970), 40.

[11] For contributions that pay particular attention to Boulton & Watt, see Sean Bottomley, *The British Patent System during the Industrial Revolution, 1700-1852 : From Privilege to Property* (Cambridge, 2015) ; Margaret Jacob, *The First Knowledge Economy : Human Capital and the European Economy, 1750-1850*, (Cambridge, UK, 2014); Peter Jones, *Industrial Enlightenment : Science, technology and culture in Birmingham and the West Midlands, 1760-1820* (Manchester, 2008) ; Christine McLeod, *Heroes of Invention : Technology, Liberalism & British Industry, 1750-1914* (Cambridge, 2007); Joel Mokyr, *The Enlightened Economy : Britain and the Industrial Revolution, 1700-1850*, (London, 2009) ; Jenny Uglow, *The Lunar Men : The Friends who made the Future* (London, 2002).

[12] The formulation is found in Joel Mokyr, *The Gifts of Athena : Historical Origins of the Knowledge Economy* (Princeton, 2002) and developed in Jones, 2008 ; see also Kenneth Quickenden, Sally Baggott, & Malcolm Dick, *Matthew Boulton : Enterprising Industrialist of the Enlightenment* (Surrey, 2013).

[13] Jones, 2008, 17.

[14] For the most careful and complete analysis of B&W's business in Cornwall, see Jennifer Tann, "Riches from Copper: the Adoption of the Boulton & Watt Engine by Cornish Mine Adventurers", *Transactions of the Newcomen Society*, 67 (1995) 27-51.

[15] Jacob, 2014, 20.

[16] For an early and influential example, see Eric Roll, *An Early Experiment in Industrial Organisation being a History of the Firm of Boulton & Watt, 1775-1805*, (London, 1930), 28, 87.

A notable exception is Robert Allen's influential account of *The British Industrial Revolution in Global Perspective*.[17] The relationship between profit and technological change is the centrepiece of Allen's historical analysis but it is presented in such unambiguous terms that there is no puzzle about it. Allen argues that the economic conditions that prevailed in late 18th century Britain meant that the adoption of the steam engine offered cost savings that allowed capitalists to generate greater profits. Thus, Allen's analysis suggests that Cornish mining capitalists – the mining "adventurers" as they were called in their day -- faced a straightforward economic calculus when it came to the adoption of the steam engine that depended on an assessment of its cost-saving potential.

Strikingly, that is how Boulton and Watt themselves understood the economics of their engine but by drawing on the rich archive of the B&W partnership, held in Birmingham's Central Library, this article suggests that they were mistaken. Specifically, it shows that Boulton and Watt failed to grasp the complexity of the evolving relationship between power and profit that determined the economic implications of their engine for the Cornish copper mines. That relationship, as we shall see, conditioned both the enthusiasm for the B&W engine in Cornwall and the increasing hostility that Cornish miners and mining adventurers displayed towards the partners.

Power has three meanings in my analysis of the historical conditions that influenced the profitability of Cornish mines. First, there is power in the sense of steam power, which was crucial to the mining of copper and the costs of its production. I show that B&W's calculations, notwithstanding their sophistication, substantially overestimated the cost benefits of their engines for Cornish mines. More problematically still, their calculations ignored the challenges of selling increased quantities of copper mined in Britain due to the adoption of their engine as well as the contemporaneous expansion of Anglesey's copper mines. Power in the sense of imperial power is crucial in this regard given fluctuating demand for copper from different parts of the British Empire, which had significant implications for when mines added capacity and how profitably they could work it. Finally, there is power in a third sense, power as market power, since a growing capacity to mine copper, and the promising but uncertain prospects of its sale, meant that control over price setting on the British copper market had decisive implications for Cornish mining profits.

As Boulton and Watt gained experience in Cornwall, they began to grasp some of the complexities of the relationship between power and profits for Cornish copper mines. Ever confident of his own savvy, Boulton came to believe that he knew better how to manage that relationship than the mining adventurers themselves. In 1785, with John Vivian among others, he embarked on a breathtakingly bold scheme to control British copper prices through the creation of the Cornish Metal Company. That cartel's ignominious record, and ensuing efforts to slash the output of Cornish mines, provides the context for understanding why the Cornish miners were so angry with Boulton and Watt and their associates in the late 1780s.

[17] Robert Allen, *The British Industrial Revolution in Global Perspective* (Cambridge, 2009).

BOULTON & WATT IN CORNWALL

James Watt's inventiveness needs little introduction given his well-known success in improving Thomas Newcomen's engine design by adding a separate condenser. When Watt sought recognition for his technical achievement through a patent awarded in 1769, he was clear about the importance of his economic motivations: "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. I was at that time spurred on by the alluring hope of placing myself above want without being obliged to have much dealing with mankind."[18] Before his engine was patented, Watt had struggled to make ends meet, racking up substantial debts in the process, and transferring two-thirds of his patent to a financial partner to survive. When Watt's partner faced his own difficulties, he transferred his share of the patent to Matthew Boulton in 1772, in payment of a debt.[19]

Matthew Boulton was one of Britain's leading manufacturers of buttons and other metal "toys". Based in Birmingham, he was an active figure in intellectual circles, as studies of Birmingham's Lunar Society have emphasised.[20] In seeking wealthy clients for his expanding toy business, Boulton gained political contacts that he cultivated for broader purpose.[21] Crucially, his political lobbying contributed to the passage of an Act of Parliament in May 1775 that extended Watt's patent until 1800; the partnership of Boulton and Watt was established on June 1st 1775 to run for the patent's 25-year duration.[22]

Though an intelligent and creative man, Boulton had earned more financial rewards in the marriage market than the commercial one. He managed to dissipate the fortune of his first wife, Mary Robinson, in his business ventures. When she died in 1759, Boulton set his sights on Ann, her younger sister, marrying her the following year and gaining access to her dowry. His wives' brother objected, fearing more money would be lost, but his death in 1764 left Boulton with an even greater share of the Robinson fortune.[23] By the late 1770s, Boulton had sunk a great deal of it in his toy business, which he conducted in partnership with John Fothergill, but its fortunes "had gone from bad to worse".[24] Mired in debt, Boulton was desperate that the new engine partnership would help him turn a corner, expressing terrible anguish to Watt about his sorry financial state as they struggled to build their business.

From the beginning of their partnership, therefore, Watt and Boulton were men on a mission to make money from steam engines. Their attention to economic concerns pervades their correspondence and is evident in their earliest decisions about commercialising their engines. The principal use of steam engines in the late 1770s was to pump water and the standard engine employed for that purpose -- the Newcomen steam engine or 'common engine' -- burned enormous amounts of coal. As a result, it was initially viable where there was a pressing need to

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[18] JW to William Small, 28 July, 1769, cited in Bottomley, 249.

[19] Roll, 17 ; J. E. Cule, 1935, 'The Financial History of Matthew Boulton, 1759-1800', (University of Birmingham Master's thesis), 54 ; Jennifer Tann, *The Selected Papers of Boulton & Watt, vol. I, The Engine Partnership, 1775-1825*, (Cambridge, MA, 1981), 34-5.

[20] Robert Schofield, *The Lunar Society of Birmingham : A Social History of Provincial Science and Industry in Eighteenth-Century England*, (Oxford, 1963) ; Jenny Uglow, *The Lunar Men : The Friends who Made the Future*, 1730-1810 (London, 2002).

[21] Uglow, 198-205.

[22] H. W. Dickinson, *Matthew Boulton*, (Cambridge, 1937), 83-86.

[23] ibid., 30, 34-36; Cule, 1-2, 8 ; Quickenden, Baggott & Dick, 2013, xvii.

[24] Cule, 291.

pump water, and coal was cheap, so the engine's earliest market was found in the coal mining region of the north of England.[25]

Copper mines in Cornwall had a similar need to pump water since the expanding market for British copper encouraged mining investors to go deeper to access ore. They had to bring in their coal from Swansea, however, and the duty on sea coal added to their burden, so the Newcomen engine was initially not cost effective for Cornish mines. But in 1741, following a petition from the Cornish mines, the government agreed to allow "a Draw-back of the Duties upon Coals used in Fire Engines for draining Tin and Copper Mines in the County of Cornwall".[26] From then, we observe an increase in the number of common engines in Cornwall, with about 60 of them installed by 1775.[27] Even so, the relatively high price of coal paid by Cornish mining adventurers meant that it was often unprofitable for them to work their engines.

It is no surprise, therefore, that the Cornish adventurers took an early interest in Watt's engine and B&W received its first order from Cornwall in 1776.[28] The partners showed an early appreciation of the economic potential of the Cornish copper mines for their fledgling business with Boulton writing to Watt in September 1777 to tell him to "remember there is but one County of Cornwall and dont let us give that away".[29] It was a truth they repeated to each other even as new opportunities arose. When Watt patented the rotative engine in 1783, Boulton was keen for it to power machines in the mills springing up in late 18th century Britain but Watt emphasised that the rotative engines pulled in low profits compared to the powerful pumping engines operating under their licence in Cornwall.[30] Boulton quickly agreed with his partner, characterising Cornwall "as the only spot to anchor our business".[31] A year later, in 1784, Boulton suggested that one of the partners spend six months in Cornwall since they had "much serious business" there "and business of more amount than all our other business many times told".[32]

The money that B&W generated from their engine business came not from manufacturing[33] but from an annual licence fee or "premium" they charged for the operation of an engine built by different "companies" of Cornish mining adventurers to their patented design.[34] As Watt

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[25] Alessandro Nuvolari, Bart Verspagen, Nick von Tunzelmann, "The early diffusion of the steam engine in Britain, 1700–1800: a reappraisal", *Cliometrica* 5 (2011) 297.

[26] William Pole, *A Treatise on the Cornish Pumping Engine* (London, 1844), 15.

[27] William Pryce, *Mineralogie Cornubiensis : A Treatise on Minerals, Mines, and Mining* (London, 1778), xiv.

[28] Roll, 71.

[29] B&W, MS 3147/3/1, MB to JW, 6 Sept. 1777. Indeed, there were even earlier signs of their interest in 1775 and 1776 (see Roll, 70-71).

[30] "There is no doubt that fire engines will drive mills, but I entertain some doubts whether anything is to be got by them, as by any computation I have yet made of the mill for Reynolds I cannot make it come to more than £20 per annum which will do little more than pay the trouble." (B&W, MS 3147/3/6, JW to MB, 28 Nov. 1782).

[31] B&W, MS 3147/3/7, MB to JW, 20 Oct. 1783.

[32] B&W, MS 3147/3/8, MB to JW, 4 Nov. 1784 ; for repeated emphasis, see B&W, MS 3147/3/9, MB to JW, 23 Sept. 1785.

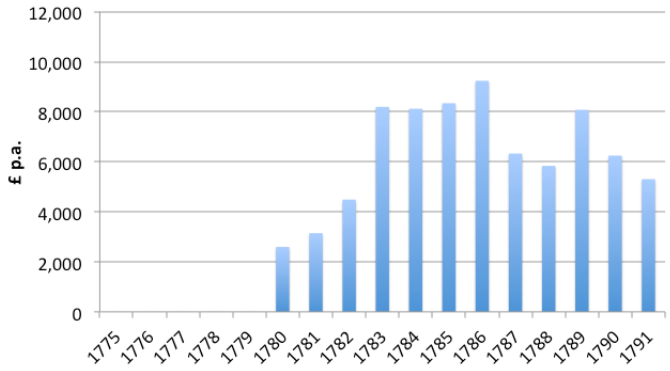
[33] Until the mid-1790s, the partnership's manufacturing activity was limited to strategic parts for its engines such as valves (Tann, 1981, 8-10).

[34] In his account of the development of capitalist organisation in the Cornish copper industry, John Rule explains that a group of adventurers formed a company and agreed a royalty -- usually one-sixteenth of the earnings – with the landlord for a mining lease. The initial capital the adventurers contributed depended on the "share" they had undertaken and the company was run on a system of accounting known as the "cost-book" system. It involved a single set of accounts – the cost book -- in which all expenditures (for investment and operating purposes) were recorded against receipts (from the sale of mined ore). The

explained: "Our profitts arise not from making the engines but from a certain proportion of the savings in fuel which we make over any common engine that raises the same quantity of water to the same height. The proportion of savings we ask is one-third part to be paid to us annually for twenty-five years, or if our employers chuse it, they may purchase up our part at ten years price in ready money."[35]

It was this principle that B&W applied in building their business in Cornwall from 1777 and the "bargins" signed with the Cornish mining adventurers were to prove incredibly lucrative. Writing to Watt from Cornwall in 1784, Boulton predicted annual premiums of £12,000 from that county alone.[36] As Jennifer Tann explains, Cornish engines did provide "a sound financial base" that ensured the survival of the B&W business and its subsequent expansion.[37] Still, as Figure 1 shows, profits from the Cornish mines fell short of what B&W had hoped to generate from their Cornish business. The closest they came to the £12,000 in annual profits that Boulton had anticipated was £9,241 in 1786 but there was a fairly steady decline in premiums thereafter, until they tailed off altogether in the 1790s.[38]

Figure 1 Premiums from Cornish Mines, payments received



Source: estimated premiums are reported in Jennifer Tann, 1995, "Riches from Copper: The Adoption of the Boulton & Watt Engine", *Transactions of the Newcomen Society*, 41.

The partnership faced criticism of its premiums, and demands for abatements from the mining adventurers, almost as soon as its engines were put to work in Cornwall. As early as 1780, Watt told Boulton: "I am at this moment so provoked at the undeserved rancour with which we are persecuted in Cornwall that were it not on account of the deplorable state of debt I find myself in I would live on bread and cheese and suffer the water to run out of their addits before I would relax the smallest circumstance of what I thought my right… and as it is I shall become every day more and more rigid in proportion as they show their hellish disposition".[39] Two years later, Boulton's complaints about the "inveterate, ungenerous and envious miners and mine lords" of

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cost book was balanced at routine intervals and if profits were recorded they could be distributed among adventurers in proportion to their shares but if losses were recorded and/or development capital was needed, "calls" were made on the adventurers in proportion to their shares (John Rule, *The Vital Century: England's Economy 1714-1815* (Abingdon, 1992) 171).

[35] JW to Jonathan Hornblower, 17 Oct. 1776, in Dickinson, *Matthew Boulton*, 1937, 95.

[36] B&W, MS 3147/3/8, MB to JW, 8 Nov. 1784.

[37] Tann, 1995, 43.

[38] The premiums that B&W eventually received for the 1790s came only as a result of legal actions that the partners brought against some of the Cornish adventurers.

[39] B&W, MS 3147/3/4, JW to MB, 17 Oct. 1780.

Cornwall suggested little improvement in relations.[40] And in the mid-1780s, he advised Watt that: "I assure you it is power only which the people we are concerned with, will pay any regard to: for as to honour, honesty, gratitude or any such like principles, they pay no attention to [them]."[41]

The partnership were well aware that the Cornish thought little better of them with Boulton noting: "I don't know a man in Cornwall amongst the Adventurers but what would think it patriotism to free the mines from the tribute they pay us, and thereby divide our rights amongst their own dear selves."[42] He acknowledged that the difficulties of negotiating bargains with the Cornish adventurers increased when the mines were not making profits: "The best times for makeing agreements are when Mines are getting money, which is not y^{e} case at present". And the situation was aggravated by the adventurers' hope of cheaper alternatives to B&W engines, notably from the Hornblower family, which the partners deemed to be in violation of Watt's patent.[43] Informed by an unfriendly "Cornubian" that "our reign was now at an end & every friend to the Country ought to encourage the Horners & treat with that Contempt we deserved", Boulton reported that he "immediately found a strong convulsion in my breast but I calld in y^{e} aid of reason".[44]

What "reason" meant initially was that the partners refused to concede abatements, for fear of setting a precedent, but the mining adventurers persisted in their demands.[45] Boulton insisted "we must defend our Birth rights" but he hesitated about taking legal action: "I pray for peace in Cornwall. Remember from what small beginnings the American War had begun and has now ruined England. The reasonable people must be made content for though we may force them by Law yet compulsion will not be dureable".[46] Under continued pressure, therefore, the partners made concessions in the premiums they charged but their efforts were to prove insufficient to placate the Cornish adventurers. Plunged into a deep crisis from the mid-1780s, the Cornish mines eventually stopped their engines and ceased mining, provoking a wave of fury directed against Boulton and Watt.

How could this have happened, we might well ask, from such promising beginnings? It is possible, as Boulton and Watt came to believe, that the Cornish were the most irrational and diabolical people they had ever encountered. In this article, I suggest a more sober interpretation based on an analysis of the relationship between profits and power for Cornish copper mines, a relationship that was, as Hobsbawm suggested, much more complex than Boulton and Watt allowed. Understanding the vagaries of that relationship offers new insights into the enthusiastic reception of the B&W steam engine in Cornwall as well as the subsequent development of a profound hostility towards Boulton and Watt among the Cornish miners and adventurers alike.

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[40] B&W, MS 3147/3/6, MB to JW, 7 Dec. 1782.

[41] B&W, MS 3147/3/9, MB to JW, 7 Aug. 1785.

[42] B&W, MS 3147/3/6, MB to JW, 2 Nov. 1782.

[43] B&W, MS 3147/3/8, MB to JW, 19 Aug. 1784

[44] B&W, MS 3147/3/6, MB to JW, 10 Oct. 1782

[45] "the Cornish gentlemen are so apt to bring the offsprings of our own generosity as presedents against us that I must own I am fearfull of admitting of any innovations or deviations from the written agreement" (B&W, MS 3147/3/6, MB to JW, 7 Mar. 1782).

[46] B&W, MS 3147/3/6, MB to JW, 13 Apr. 1782 ; Apr. 3, 1782.

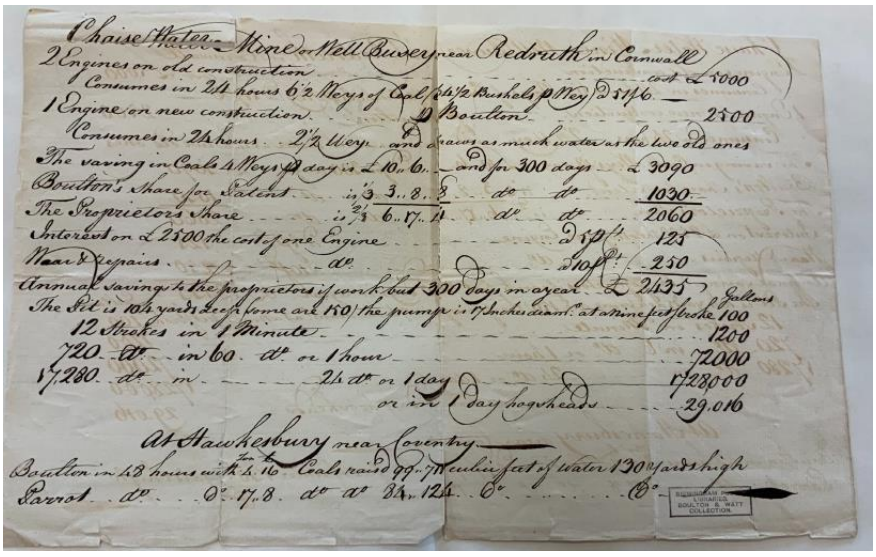
STEAM POWER, COPPER MINING & PRODUCTION COSTS

The B&W partners were convinced that the only way to make "bargins in Cornwall" was to prove "ye rate of goodness" of their engine. To this end, they emphasised the importance of comparison with an old or common engine. "Wheal Union is of such a magnitude", Boulton wrote to Watt, "that I am confident an old Engine of that power would consume in Cornwall 2000£ per annum in Coals more than ours and I dont see how you will convince them lest by comparison".[47] The partners took a sophisticated approach to setting their premiums, based on the seemingly unassailable principle of sharing the cost benefits of the new technology with the mines that adopted it. Yet, if the principle upon which their premiums were based was clear, the practice of applying it depended on complex calculations and considerable effort.

The illustration in Figure 2 of the partnership's analysis for Chasewater (designated as Chaise Water) Engine, one of the first B&W engines that went into operation in Cornwall, gives a sense of some of the challenges involved. In that calculation, a B&W engine is characterised as lifting 100 gallons of water with every engine stroke from a pit that was 104 yards deep. At a running speed of 12 strokes a minute, the engine would raise 1,200 gallons of water a minute, or 1,728,000 gallons over 24 hours. And to run the engine for 24 hours, the partners calculated that 2.5 Weys of coal would be required.

As a basis for comparison, the partners estimated that two old engines would be required to raise an equivalent volume of water in 24 hours. Together they would consume 6.5 Weys of coal so in this case the new technology would save 4 Weys of coal a day, an impressive 62 per cent of the coal used by the old technology. At an estimated coal price of £2.575 per Wey of coal, that meant the mine would save £10.3 (£10.6) a day in coal costs, or £3,090 a year. B&W would take one third of these savings in the form of a premium and the remaining two thirds would accrue to the mining adventurers in coal costs they did not have to incur.

Figure 2 B&W Premium Calculations for Chasewater Mine, 1777



Source: Boulton & Watt (precise reference to be added)

The Chase Water calculations were made prior to the installation of a B&W engine but once one was up and running the partners used measures of actual coal consumption to estimate the

[47] B&W, MS 3147/3/1, MB to JW, 6 Sept. 1777.

premiums owing to them.[48] The amount of water pumped by an engine varied a great deal due to weather, and the condition of the engine being worked, so coal consumption was measured on a daily basis for each engine. It was summarised in monthly "tables", completed with estimates of the coal a common engine would have consumed to raise the same volume of water from the mine, to calculate the quantity of coal saved from working the B&W engine. Coal savings were converted into cost savings at the prevailing coal price, with one third of these cost savings generating the monthly premium owed to B&W by the mining adventurers.

The partners spent a good deal of time working on the structure and layout of their tables to make the economic logic underlying their premiums as clear as possible but, as we have seen, they were contested in Cornwall from the beginning of the partnership's dealings there.[49] Some mining adventurers believed that the complicated calculations were a cover for the partners to advance their interests at the mines' expense. Boulton reported to Watt that he had been told that: "we had cheated, deceived and abused the County, that we had lulld them to sleep, but they were now awakeing by the assistance of Horners that we had tricked them in the leverage, in the length of y^{e} Stroke, & in the whole of our Tables".[50]

The partners worked hard to counter these impressions, painstakingly explaining their logic to anyone who objected to it. When an adventurer complained to Boulton "that it appeared we had overrated the consumption of Coals of the old Engine", Boulton offered to meet him to convince him of the soundness of the calculations.[51] The adventurer welcomed the invitation, since it reinforced his opinion of the partners' "Honour & Candor", which had convinced him "to acquiesce in the Article & to sign the Table without understanding it".[52] Still, Boulton was persuaded "that I shall never make them understand the Tables nor perhaps acquiesce in all the facts from whence they are deduced (for they say no man in the Country understands the Tables except Captain Karkeete". Emphasising that it would extend beyond the bounds of their patience to pay attention to the technical details, Boulton emphasised the importance of "simplifying the Tables": "The fewer Columns & the fewer figures the less will they be puzeled & the less room for caveling".[53]

Faced with the adventurers' continued criticisms and suspicions, however, Boulton began to reach the bounds of his own patience.[54] He complained to Watt that the adventurers turned to business after dinner when too much wine had been consumed, and wondered if the "sixth glass of wine" was a practice they should try to alter.[55] As criticism of their tables persisted, the partners began to see themselves as scapegoats for the mines' mounting economic problems. By the beginning of the 1780s, the mines were complaining about the economics of their business but the partners took the view that the mines' problems in turning a profit were due to the adventurers' not having been "so good oeconomists as they might have been" and asked "[w]hy should they require abatements from us when they are wilfully burning more coals & paying more wages"? They lamented the disorderly state in which the adventurers kept their engines,

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[48] Roll explains that it "was an old practice in Cornwall to measure [the coal consumed], owing to the requirements of the Customs authorities who allowed drawback of the duty on sea-borne coal used in the Cornish mines" (78).

[49] See Roll, chapter 3, 78.

[50] B&W, MS 3147/3/6, MB to JW, 10 Oct. 10, 1782

[51] ibid.

[52] ibid.

[53] B&W, MS 3147/3/4, MB to JW, 2 Oct. 1780.

[54] B&W, MS 3147/3/4, MB to JW, 30 Sept. 1780.

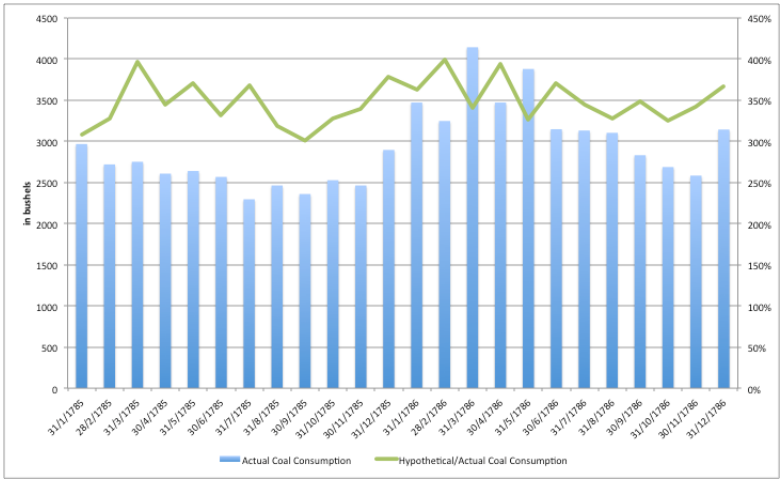
[55] B&W, MS 3147/3/4, MB to JW, 25 Sept. 1780.

their "terrible accounts" which revealed nothing about the business of copper mining, and their poor understanding and management of the dynamics of the copper trade.[56]

There was some improvement in the mines' profits as the 1780s unfolded but it had dissipated by mid-1785, and by 1787 every major mine in Cornwall, except for one, was recording large losses.[57] By mid-1785 Boulton reported: "if something is not done effectually for Cornwall it must give up the Ghost".[58] The increasingly dire situation in Cornwall led the partners to even sharper criticism of the adventurers' way of doing business.[59] From the adventurers' perspective, however, the partners were part of the problem, with their premiums presented as coming at the expense of mining profits.

Some historians have acknowledged that "the method of calculating the premium was not readily grasped", but they tend to suggest, as H. L. Dickinson did, that it "was quite fair because the adventurers only paid so long as the engine was working. If the mine closed down, the payment stopped".[60] If B&W premiums are seen as rational and equitable, then, as Sean Bottomley observed: "the complaints of mine owners about the rapacity of Boulton & Watt's financial demands can be taken with a pinch of salt".[61] However, if we take a closer look at the sophisticated calculations that B&W used to assess the economic benefits of their steam engine for Cornish copper mines, we can see that there was a more reasonable basis for the adventurers' complaints than historians have been wont to allow.

Figure 3 Actual & Hypothetical Coal Costs for Poldice "New" Engine, 1785-1786



Source: author's calculations based on B&W, MS 3147/3/468, Cornish Mines & Engines, Cornish Mines – Engine Calculation, 1783-1791, Poldice new engine.

Representative calculations for one engine, which I have reconstructed from the B&W tables for the Poldice mine, are shown in Figure 3. The bars represent the actual coal consumption of the

[56] B&W, MS 3147/3/6, MB to JW, 7 Mar. 1782.

[57] Tann, 1995, Table 7, 37.

[58] B&W, MS 3147/3/9, MB to JW, 10 June 1785.

[59] In an extraordinary letter that Boulton wrote to Watt, he went through all of the major mines in Cornwall, documenting their management problems and lamenting their sorry state (B&W, MS 3147/3/9, MB to JW, 22 Aug. 1785) ; see also Tann, 1996, 36.

[60] Dickinson, 96. Roll, 78.

[61] Bottomley, 255.

B&W engine and the line shows that a common engine would have consumed somewhere between 300 or 400 per cent more coal than the B&W engine. However, that common engine represented a technical counterfactual since there was no such engine that could have done the kind of work that the "new Poldice" engine did. Worse still is the fact that as an economic counterfactual, the common engines that the partners used in their calculations made no sense at all. Had the Poldice mine run such common engines, their coal costs would have been 3 to 4 times more than those actually recorded. When we look at Poldice's income statement, it is clear that the mine would have made enormous losses and shut down.

By comparing the coal costs of operating their engine with the exorbitant coal consumption of an unaffordable engine, the partners generated unrealistically high estimates of the cost savings their engine offered. To base their premiums on these unrealistic cost savings was like charging a tax on an input that was already expensive for the Cornish adventurers. For the new Poldice engine, the B&W premium would have amounted to somewhere between 80 and 100 per cent of the engine's actual coal costs in 1785 and 1786.

By then, however, the Poldice adventurers were not paying the premiums that B&W's tables suggested for any of their three engines. They had been pressing for abatements since they installed two B&W engines in their mine in the early 1780s.[62] And they convinced the partners to replace their variable monthly premiums with a fixed annuity payment. Thereafter, the amount of the annuity was "brought upon the tapis" on several occasions,[63] not least when the Poldice adventurers expressed an interest in installing a third or "new" engine.[64] The monthly premiums that the tables suggested for 1785 are shown in Table 1 below along with the actual monthly payments that the Poldice mine made to B&W. Abatements represented about 25 per cent of Poldice's monthly premiums in the first part of the year, to cover the teething problems of bringing the new engine into operation, but were reduced to approximately 10 per cent of B&W's "rightful" premiums from May to December.

Table 1 Estimate of B&W's abatements for Poldice Mine, 1785

Premiums based on B&W tables for July 1785	**in £**
Poldice East	£61.18s.3d.
Poldice West	£37.0s.5d.
Poldice New	£68.15s.4d
All Poldice engines	£167.14s.0d.
Monthly payment made, Jan to May (based on annuity agreed of £1,500)	£125
Monthly payment made, June to December (based on annuity agreed of £2,000)	£166 13s 4d

Source: author's calculations based on B&W, MS 3147/3/468, Cornish Mines & Engines, Cornish Mines – Engine Calculation, 1783-1791, Poldice new engine.

What we see in B&W's relationship with the Poldice adventurers reflected a more general pattern for the Cornish mines in the 1780s with partners responding to adventurers' demands on a case-by-case basis. The partners had tried to identify a more systematic alternative for calculating their premiums, "some general proposition" that "would be as free from all objections to either party as possible".[65] Conscious that "loosing adventurers will never pay us pleasantly even though we lowerd our Tables… when they see we are gaining and they loosing", Boulton proposed to tie B&W's premiums to the adventurers' mining profits. Hardly had he

[62] Poldice no. 1 in 1780 and Poldice no. 2 in 1782 (Tann, 1995, 30).

[63] B&W, MS 3147/3/6, MB to JW, 12 Dec. 1782.

[64] B&W, MS 3147/3/8, MB to JW, 21 Oct. 1784.

[65] B&W, MS 3147/3/6, MB to JW, 3 Apr. 1782 ; 6 Apr. 1782.

outlined his scheme, however, that he worried that "we must not State the acc^{t} so as to make our profits = y^{e} adventurers" and sought to counter the impression that premiums came at the expense of profits by beginning "with giving them 1000 P M^{o} profit".[66] He worried too that "unless we guard against them" the mining adventurers would manipulate their accounts to create the impression of losses "even when the mine was in a gaining state".[67]

Boulton's profit-based scheme was never implemented so the partners continued to calculate their premiums based on the monthly tables and use them as the basis from which to negotiate with different companies of adventurers. This approach did little to dissipate the adventurers' resentment of the tables and it served as a constant reminder to the partners that they were making temporary concessions with respect to their 'rightful' premiums. As Boulton put it with regard to United Mines, "I shall give my consent for abating 1/3 of our dues so long as the Mine continues in a loosing State but when ever it returns again into a prosperous state then must our full share of ye savings return".[68]

The partners' reliance on estimated savings in coal costs to negotiate the premiums they charged, even when they offered abatements, would have been bad enough if the Cornish copper mines been competing only with each other. But as the Cornish mines adopted B&W steam engines, they faced growing competition from Thomas Williams in Anglesea, who was responsible for nearly 3,000 tons of copper mined by the mid-1780s, representing about 60 per cent of the output of all the Cornish mines together.[69] Williams made it clear that the costs of mining copper were lower in Anglesey's surface mines than in Cornwall, not least since they did not depend on steam engines to access copper ore.[70] Boulton made much the same point when called about to give evidence to the House of Commons in 1783 in a dispute involving Anglesea and Cornwall about the duty on sea coal.[71] Boulton succeeded in showing "how much the Cornish mines are taxed by their great depths viz: y^{e} expenses of Coal, Cost of interest & repairs of Engines" and, as he noted smugly, "the superiority of our Engines & the services we had rendered the Cornish Mines".[72] What he did not seem to realise, however, was that the B&W premium exacerbated the competitive disadvantage of Cornwall relative to Anglesea by forcing its mines to pay a supplementary charge, based on the coal price, on top of their substantial coal costs.

IMPERIAL POWER & COPPER DEMAND

B&W's sophisticated calculations can be faulted for the misleading estimates they generated of the cost benefits of their engines for Cornish mines but they completely overlooked the challenges of selling increased quantities of copper due to the adoption of their engines in Cornwall and the expansion of Anglesey's copper mines. Power in the sense of imperial power played a crucial role here since expectations about imperial demand for copper, as well as the disappointment or realisation of these expectations, had direct implications for when mines added capacity as well as their prospects for working it profitably.

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[66] B&W, MS 3147/3/6, MB to JW, 3 Apr. 1782

[67] ibid.

[68] B&W, MS 3147/3/6, MB to JW, 7 Mar. 1782.

[69] He took over the operation of the Parys Mine in 1778 and rapidly expanded its output to become a major force on the British copper market. From 1785, he further strengthened his position by taking over Anglesey's other major mine, the Mona Mine (Harris, 1964).

[70] Williams, Commons report.

[71] Harris, 1964, 36-7.

[72] B&W, MS 3147/3/7, MB to JW, 18 May 1783 ; 24 May 1783 ; 31 May 1783.

Prior to the late 1770s, the main source of domestic demand for British copper was the manufacturing copper and brass goods, centred in Birmingham.[73] Although its estimated demand of about 1,000 tons of copper a year played a crucial role in sustaining the British market, it offered limited prospects for spectacular growth. Boulton knew that market as well as anyone so in expressing confidence in the late 1770s that copper demand "at home will be greater and new markets abroad opened", he had something else in mind. And his optimism was widely shared at the time.[74]

Insofar as home demand was concerned, the copper sheathing of ships, a practice endorsed by the British Empire from the late 1770s, looked especially promising. Interest in sheathing ships' hulls with copper stemmed from their vulnerability to shipworms, barnacles and weeds, which reduced ships' speed and shortened their operational lives. Shipworms were a particular problem in the warmer waters of the West and East Indies, where the British Empire exerted considerable naval and mercantile power. Sheathing a ship's hull with copper had been tried for some years as a means to prevent fouling but experiments had been dogged by recurrent technical difficulties. However, the onset of the War of American Independence in the mid-1770s placed a premium on naval speed and encouraged the British Navy to take action.[75] Sheathing was already underway for some ships when an order was issued in 1779 to copper the bottoms of the British Navy's entire fleet.[76] The timing of this order was especially opportune since it coincided with an enormous expansion in the size of the Royal Navy.[77]

And it was not just the naval fleet that promised to be a lucrative new source of demand for copper in Britain. As Peter Solar and Klas Rönnbäck showed in a recent article on copper sheathing and the British empire's slave trade: "[a]mong commercial shippers slave traders were very quick to seize upon the benefits of the innovation. The reason copper sheathing was particularly attractive to slave traders is that they had to spend so much time in shipworm-infested waters". All three British commercial ships with copper bottoms prior to 1778 were built in, and operated out of, Liverpool; from then on, the percentage of copper-sheathed slave ships soared to reach 75 per cent per cent by 1781.[78] Other merchant ships followed, notably the large fleet of vessels that plied the British Empire's trade for the English East India Company.[79]

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[73] The "toy" trade there manufactured buttons, buckles, and other metal trinkets, as well as other light metal goods for decorative and utilitarian purposes. The products manufactured in Britain were not just for domestic use since the rapid expansion of its brass industry, and the improvement of the quality of the brass made, turned Britain from net importer to net exporter (Hamilton [1926] 1967:284-7). Copper was purchased too by British manufacturers of cooking ware and horse accessories but the demand for copper went far beyond the needs of domestic manufacturers (Harris, 1964, 6).

[74] B&W, MS 3147/3/2, MB to JW, 25 July 1778.

[75] Harris, 1964, 45-6.

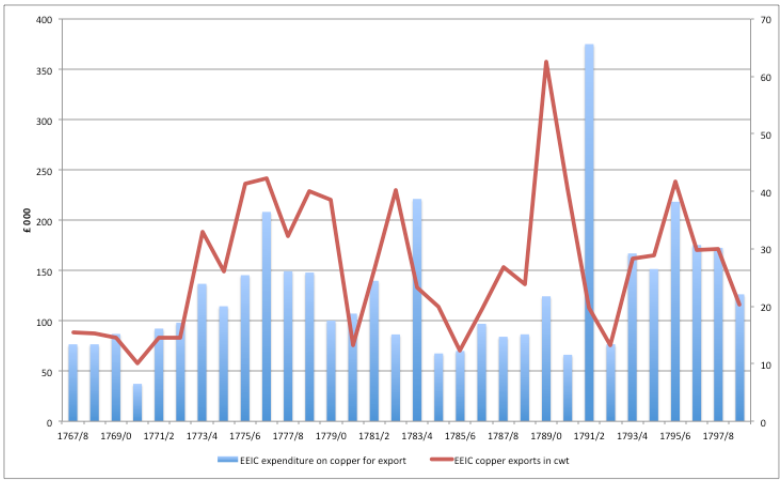
[76] J. W. Harris, 1966, "Copper & Shipping in the eighteenth century", *Economic History Review*, 19, 3, 550-68; John Bingeman, John Bettell, Peter Goodwin and Arthur Mack, Copper and other sheathing in the Royal Navy, *The International Journal of Nautical Archaeology* (2000) 29.2: 222.

[77] Xavier Duran and Patrick O'Brien, "Total Factor Productivity for the Royal Navy from Victory at Texel (1653) to Triumph at Trafalgar (1805)," in Richard Unger (ed.), *Shipping and Economic Growth*. Leiden: Brill, 2011, 279–309.

[78] Peter M. Solar and Klas Rönnbäck, 'Copper Sheathing and the British Slave Trade', 68, 3 (2015) 810-811.

[79] By 1788, 22 of the 26 vessels used by the English East India Company had copper sheathing (Peter M. Solar, 'Opening to the east: shipping between Europe and Asia, 1770–1830', *Journal of Economic History*,73 (2013), 625–61 ; Gareth Rees, 'Copper Sheathing : An Example of Technological Diffusion in the English Merchant Fleet', *Journal of Transport History*, new series, 1 (1971/2), 85-94.

Figure 4 English East India Company's Copper Exports, 1767/8 – 1799/00



Source: H. V. Bowen, 'Sinews of Trade and Empire: The Supply of Commodity Exports to the East India Company during the Late Eighteenth Century', *Economic History Review*, 55, 3 (Aug., 2002), 472.

Clearly, the explosive growth of sheathing held out exciting prospects for copper demand in the late 1770s and early 1780s but there was enthusiasm too about the opening of new markets abroad. Historians including Eric Williams and J.R. Harris, and more recently Joseph Inikori and Nuala Zahediah, have shown the importance of the triangular trade in boosting the demand for British copper in the 18th century.[80] From the 1760s, however, it was the English East India Company's exports that represented the most important overseas market for British copper with substantial growth, as Figure 4 shows, all through the 1770s.[81]

Once we take account of the prevalent optimism about the prospects for copper demand in the late 1770s and early 1780s, it makes sense that the Cornish adventurers would be keen to extract more ore. To do that, however, they needed to pump water from the new depths of their mines. For that reason, as Figure 5 shows, a cluster of B&W engines was built in Cornwall in the late 1770s and early 1780s, facilitating an increase in Cornish mines' output from an annual average of 3,500 tons of copper between 1771 and 1777 to 4,800 tons by 1786.[82] Just as B&W engines were being adopted in Cornwall, moreover, there was a spectacular increase in the output of the Anglesey mines from 950 tons of copper in 1777 to an estimated 2,825 tons of copper by 1786.[83] In the 10 years between 1777 and 1786, therefore, the total output of British copper mines increased by 76 per cent from 4,330 to 7,625 tons.

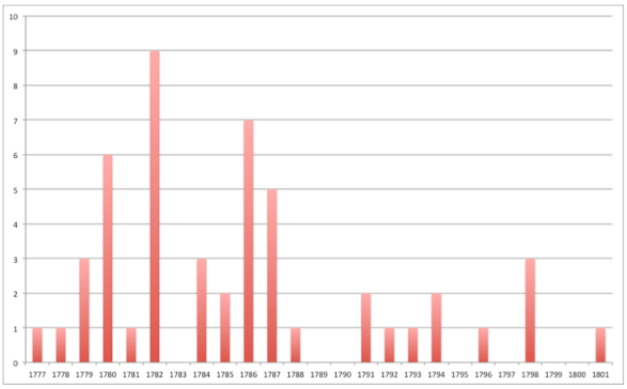
[80] Eric Williams, *Capitalism and Slavery*, London: Andre Deutsch, 1964; Harris, 1964 ; Joseph E. Inikori, *Africans and the Industrial Revolution in England: A Study in International Trade and Economic Development*. Cambridge: Cambridge University Press, 2002; Nuala Zahedieh, 2013, "Colonies, copper, and the market for inventive activity in England and Wales, 1680-1730", *Economic History Review*, 66, 3, 803-825.

[81] Chris Evans, "Welsh Copper: What, When, and Where" in Louise Miskell, 2020, *New Perspectives on Welsh Industrial History*, University of Wales Press, 31.

[82] Representing an increase of 27 per cent.

[83] Symons, Appendix 2, 172.

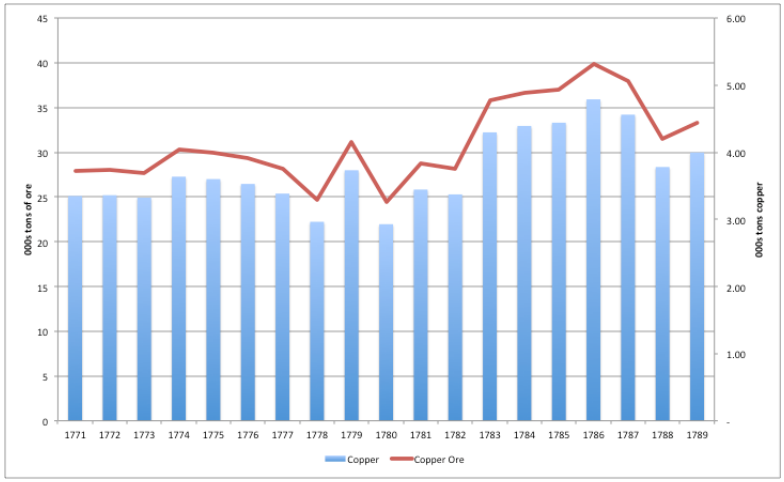
Figure 5 New B&W Engines put into operation, 1777-1801



Source: author's analysis based on Tann, 1996, Table 1, 30.

With output surging, however, the prospects for copper demand began to seem less positive than mining investors had hoped. Copper's strategic importance for the defence of Britain's empire turned out to be a double-edged sword since it induced the British government to place restrictions on exports of sheet copper from 1780.[84] As Thomas Williams explained to a Parliamentary Committee, the prohibition was introduced "under the mistaken and ruinous notion of depriving our enemies, the French, of Copper sheathing for their ships during the American war".[85] But, as Figure 4 suggests, the prohibition also prompted a collapse in copper purchases by the English East India Company to where they had been 10 years earlier. It is litte wonder, therefore, if Boulton argued in early 1782 that the export prohibition was stifling the copper trade's inherent capacity to prosper: "they may as well suppose ye world will be soon at an end as to suppose ye Copper trade will decline if proper measures are taken. The Gentlemen concerned in that trade should apply to the new Ministry who may probably remove the absurdities of the old one and take off the prohibition".[86]

Figure 6 Annual Produce of the Copper Mines of Cornwall, 1771--1789



Source: Charles Lemon, "The Statistics of the Copper Mines of Cornwall", *Journal of the Statistical Society of London*, Vol. 1, No. 2 (Jun., 1838), 70.

[84] 20 Geo. III, cap. 59 (Harris, 46).

[85] Commons Committee Reports, x, 668.

[86] B&W, MS 3147/3/6, MB to JW, 26 Mar. 1782.

If that were not bad enough, the rush to copper the British Empire's naval and merchant fleets from 1779 was followed by a sharp reversal in late 1782 when recurrent technical problems with copper sheathing were revealed. As Williams explained: "a considerable alarm was given both in this country and in France, from the loss of the famous French ships Ville de Paris and the Glorieaux, and His Majesty's ship the Centaur, together with many other vessels at the same time, all which losses were concluded to be occasioned by the ships being Copper sheathed upon iron bolts and other iron fastenings". The "general shock" that the news occasioned led the Admiralty and Navy to suspend copper sheathing "on account of the great number of lives that had been lost".[87].

In the face of dashed expectations for copper demand in the early 1780s, it is little wonder if many of the Cornish adventurers struggled to make profits from their mines. By March 1782, even some of the most successful Cornish mines responded by stopping their engines and shutting down operations. By April 1782, moreover, Cornish orders for new B&W engines had dried up and given its dependence on Cornwall, the partnership found itself without any prospect of new business, with Boulton informing Watt: "We have now no Engine ordered in England, besides Walkers, nor any Applications or Treaties for any so that it seems that our Number are more likely to be diminished than augmented".[88]

The following year brought some brightening of the prospects for the copper market. In late 1783, the development of a new type of copper bolt resolved the technical problems associated with copper sheathing and in 1784 the Admiralty ordered all new and existing ships to be fitted with these bolts. By the mid-1780s, therefore, Boulton reckoned that 1,000 tons of copper was consumed in the 'Sheathing of Shipping' at British shipyards with a further 1,500 tons absorbed by 'Navy Bolts, Nails & Other Naval Uses', representing about one quarter of the copper traded by British merchants at the time. Moreover, restrictions on copper exports were completely removed with the end of the American Revolutionary War in September 1783, allowing exports of copper to France and other European countries to resume. With the removal of restrictions, moreover, purchases of copper by the English East India Company rebounded to levels they had attained in the late 1770s (Figure 4).

Mines were restarted in Cornwall and even by the end of 1783 there had been a major surge in Cornwall's production of copper ore (Figure 6). Orders resumed for B&W engines with three new engines built in Cornwall in 1784 and in November 1784 Boulton expressed optimism about the prospects for the partnership's business there: "I think in 12 or 15 months hence we may make out of this country 12000 per year if ores continue at present price and…"[89] But once again, the reality of copper demand fell short of such optimistic expectations. The end of the American Revolutionary war meant that once the fleet had been fitted with new copper bolts, the ongoing need for copper diminished.[90] Moreover, insofar as export demand was concerned, the surge in the English East India Company's purchases of copper proved temporary; in the second half of the 1780s, these purchases had fallen back to the levels they had reached in the late 1770s. And even though the Birmingham trades continued to buy about 1,000 tons of

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[87] Commons Committee Reports X, p. 667. Williams did not give any specific date for the loss of the three ships he named but George Inman records all three of them as having gone down in September 1782 (George Inman, "Losses of the Military and Naval Forces Engaged in the War of the American Revolution", *The Penn's Magazine of History and Biography*, 27, 2 (1903) 198).

[88] B&W, MS 3147/3/6, MB to JW, 10 Apr. 1782.

[89] B&W, MS 3147/3/8, MB to JW, 8 Nov. 1784.

[90] There are no systematic data available for Navy purchases of copper in the mid-1780s but the experience of the subsequent French wars shows just how much difference hostilities made to the Navy's demand for copper.

copper a year throughout the 1780s, they could not compensate for the relatively disappointing prospects of the newer sources of demand.

MARKET POWER & COPPER PRICES

The combination of a growing capacity to mine copper, and the promising but uncertain prospects for its sale, led to a battle for control of copper prices from the early 1780s. It unsettled the longstanding arrangement that had allowed copper smelters to dictate British copper prices, but without establishing a stable alternative. Power in a third sense is relevant here since efforts to secure and contest market power exerted a major influence on British copper prices and, as a consequence, mining profits.

From 1750, as copper mining became concentrated in Cornwall, Swansea grew into an important centre of copper smelting. It was only a short distance from the north coast of Cornwall, so ores could be shipped at a reasonable cost, and it enjoyed the advantage of rich coal resources for use in the smelting process. The smelters, in contrast to the Cornish mines, were few in number and formed a cohesive group, known as the Associated Smelters or United Companies. They enjoyed considerable market power based on their control of contracts for the purchase of copper ore and the sale of fine copper, and they wielded it, as Harris explained, to dictate "terms to miners on the one hand and consumers of copper on the other".[91]

When Williams of Anglesea entered the copper trade, he posed a major challenge to the smelters' traditional arrangements given his control of a major new source of copper ore. They tried to block Williams' access to the copper market by refusing to buy ore from him at favourable prices but he vowed to break their hold on the copper market by entering the smelting business himself. He appointed a prominent Cornish adventurer, John Vivian, to buy copper ore for him in Cornwall since his own mine did not provide enough for his smelting business, and set his sights on some of the most significant contracts for fine copper.[92] In response, as Harris explained, the Associated Smelters tried "to underbid Williams in the home market but also at the East India Company sales, prices for which were fixed by agreement between the different smelting firms, thus blocking him from the most important foreign market".[93] And as Williams increased his capacity in copper mining and smelting, the Associated Smelters continued to wage their war against him, "passing the costs of the struggle on to the Cornish miners as far as possible".[94]

Williams was well aware of the devastating implications for the Cornish mines. In a letter to Boulton in 1781, Williams told him: "his Co can afford to sell copper at 50£ per ton & not loose by it whereas the Cornish cant afford to work their mines if the Standard is lower than £80 per Ton".[95] That meant the decline in the standard price for copper to £70 in the early 1780s (see Figure 7) was bad news for all British mines but especially dangerous for Cornish mines. Williams wanted Boulton to "try to settle peace" on the copper market and Boulton himself had come to believe that the mining adventurers needed to take some action to drive up the prices the smelters were paying for their ore : "the Cornish gentlemen should remonstrate with the Smeltors when they give for ye Cornish standard less than from 6 to 10£ per Ton under y^{e} selling price of Copper which is now 86 & good ores you say is 65 which is a difference of £21 which is oppressive".[96]

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[91] Harris, 1964, 13.

[92] https://www.gracesguide.co.uk/John_Vivian

[93] Harris, 1964, 40.

[94] Ibid.

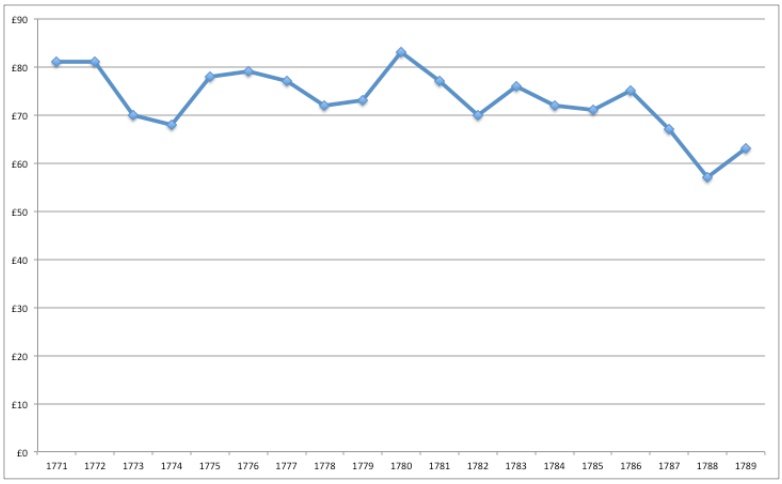
[95] B&W, MS 3147/3/5, MB to JW, 23 June 1781.

[96] B&W, MS 3147/3/6, MB to JW, 26 Mar. 1782.

Tensions between Anglesea and Cornwall seem to have been an obstacle to any kind of mining alliance in the early 1780s but that was to change from early 1785 when Williams approached some prominent Cornishmen and Boulton to discuss a scheme to allow mining interests to benefit from higher prices.[97] Watt was not keen on the partners being involved with the Cornish in any arrangement to influence the price of copper ore but Boulton was adamant they needed to take an active role in pushing forward with the scheme.[98] He believed that if ore could be sold at higher prices, perhaps as high as £90 per ton, everyone could get more profit from the copper trade and "Cornwall is and will be grateful" to the men involved in negotiations "for emancipting them from their slavery and ignorance and now in some way to understand the Copper trade".[99]

Williams, Vivian and Boulton were to play an important role in devising the plan that led to the establishment of the Cornish Metal Company on September 1, 1785. It would act as a syndicate to buy the entire output of Cornish mines at a price determined by its Governor and directors, and then take full responsibility for selling it. In an additional agreement, the Cornish Metal Company and the Anglesea mines agreed to split the market for British copper ore into agreed shares to avoid competition between them. Through these arrangements, the mining interests sought to use their control over the entire supply of British ore to break the smelting companies' hold over the market for copper ore and raise the prices they received.

Figure 7 Standard Price of Copper, 1771-1789



Source: Symons, Appendix 2, Table 2.6, 174.

Sir Francis Bassett, a prominent Cornish gentleman and mining adventurer, was appointed as director of the Cornish Metal Company and John Vivian became the Deputy Governor, with twenty-four of its Directors chosen by the Associated Miners of Cornwall and a further twelve by the subscribers to the Metal Company. The company had an initial subscribed capital of £130,000, making it one of the largest industrial companies in Britain at the time.[100] Boulton and Watt had the right to subscribe to £8,000 on the basis of the shares they held in copper mines. Believing they could not spare even as much as £3,000, Boulton urged Watt to line up friends

[97] Following the fracas over coal duties, Boulton was warned to watch Williams of Anglesea "as he vows revenge on all interested in Cornish Mines" (B&W, MS 3147/3/7, MB to JW, 22 Dec. 1783).
[98] B&W, MS 3147/3/9, JW to MB, 5 June 1785.
[99] B&W, MS 3147/3/9, MB to JW, 10 June 1785 ; MB to JW, 26 July 1785.
[100] Rule, 1992, 135-178.

and associates to help them "to assert their full right" on condition that the partners were given the "powers associated", since "God help any man in this country [Cornwall] who does not have power". Since other directors also asked Boulton to vote their shares, he ended up controlling "the whole directorate".[101]

The mining adventurers of Cornwall agreed to sell all their ores to the Metal Company with the price set at £86 from May 1786 but as soon as the agreement was concluded, the standard price began to rise. Confident they could sell what they produced at a favourable price, the mining adventurers increased output and ordered more B&W engines, with the result that 1786 and 1787 were among B&W's best years for new business in Cornwall (Figure 4). Still, only a few months after the establishment of the Metal Company, Boulton wrote of "doubts and fears" about the company, and "the copper trade in general", and Watt expressed concern that "so many mines setting to work is really a serious consideration, particularly as the sales of copper are not said to be brisk".[102]

The partners were right to worry since the Metal Company turned out to be an unmitigated disaster. Its ignominious story, involving accumulating stocks of unsold copper by the Metal Company, growing suspicions that Anglesea was outselling Cornwall, and rising copper imports as buyers looked for cheaper metal, has been told elsewhere. What matters to my account is that these dynamics prompted the Metal Company to slash the price it was willing to pay the Cornish mines for their copper, bringing it well below the worryingly low level that had stimulated the company's formation. Scrambling for a way to keep their mines open, the adventurers demanded the cessation of the premiums they paid to B&W but the partners refused, even though, as Watt put it, "all seems black and dismal in the copper trade".[103] Confronted with enormous losses, the Cornish adventurers stopped their engines and closed the mines, throwing the miners out of work.

The consequences were devastating for their families and communities and stoked enormous social tensions in Cornwall. It was in this difficult context that four hundred miners marched on Truro in early October 1787. Under the prevailing "tribute system" of payment, copper miners were compensated based on the weight and value of the ore they excavated.[104] Thus, they were keenly aware of the recent decline in the price paid for copper ore and it was hardly surprising if they attributed it to the machinations of the Metal Company and the men they knew who were behind it. That they might try to do something about the problem was predictable and the day before the miners marched on Truro, Boulton had written to tell Watt that: "[t]he miners are forming parties & the spirit of Violence and disturbance" seems to promise "ferment", and that in every direction "distress & destruction stares me in the Face".[105]

Writing the day after the miners' visit to Truro, Boulton reported that "[t]he adventurers say they will not sink money for B&W benefit only, but all parties ought to contribute they say to the employment of the poor". He suspected, moreover, that B&W was being scapegoated, claiming that every Lord and adventurer in Cornwall "would influence & misguide the minds of the Miners provided they could deter us from takeing saveings". Showing the extraordinary

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[101] B&W, MS 3147/3/9, MB to JW, 5 Aug. 1785 ; Harris, 1964, 62.

[102] Harris, 1964, 69.

[103] Harris, 1964, 78.

[104] John Rule, 1971, The Labouring Miner in Cornwall, c. 1740-1870, doctoral thesis, University of Warwick, 35-5 ; see also John Rule, "The Perfect Wage System : The 'Tribute System' in the Cornish Mines" in Rule & Roger Wells, 1997, *Crime, Protest and Popular Politics in Southern England, 1740-1850*, Hambledon Press, 53-66. In contrast, the "tutworkers" broke the ground for mining were paid in terms of the number of cubic fathoms they drove the shaft.

[105] B&W, MS 3147/3/11, MB to JW, 3 Oct. 1787.

resilience of his own self-esteem, Boulton took no responsibility for the disastrous situation, wishing only that he could administer "a little sober advice" to them, since "they are totally ignorant of their own situation".[106] The only solution he had to offer, however, was that "Mr Pitt ought to send either a press-gang [to press the miners into the army] or orders for 3000 Tons of Copper".[107]

The onset of the French wars in 1792 was to bring the kind of support that Boulton sought from the British state but it was nowhere in sight in late 1787 leaving the mining interests to fend for themselves. At a general meeting on October 11th, 1787, the Cornish mining adventurers came to a new agreement with Anglesea that allotted them two-thirds of the market in 1788, and a half of it thereafter, and gave Williams control over marketing Cornish as well as Anglesea copper. A crucial condition of this new agreement, however, was that the Cornish limit their output to 3,000 tons year, and as this policy went into practice, the miners reacted with fury. They turned out in large numbers in April 1788 to protest the closure of the North Downs mine, which had one of the largest mining workforces in the county with more than 1,000 people employed. When Thomas Wilson, B&W's agent in Cornwall, arrived at the mine, he was greeted with great hostility by the miners who, as John Rule explained, were of the opinion that he was responsible for the mine's closure due to his connection with the B&W partnership. More resistance from the miners was expected when another mine in the district announced its closure. "The fact that there was no serious breach of the peace", as John Rule observes, "is perhaps best explained by the fact that there was a party of soldiers in the town and that more were expected".[108]

Nearly a year later, as Wilson reported to Watt, the mining crisis continued to wreak havoc on the labouring poor in Cornwall: "It is really dreadful to think what must come of the poor people to us who must be witness to their distress, there is nothing but starvation or emigration for them".[109] Neither Watt nor Boulton had to confront the prospect of starvation or emigration but the closure of the Cornish mines, one after the other, was certainly not good news for them. As Watt explained to his friend, Gilbert Hamilton, in September 1788: "We are making many small [engines] which do not pay very much but the great ones in Cornwall which were the source of our riches decrease fast… the remedy of stopping some mines [being] fatal to our interests".[110] Even working mines could not be expected to bring in the premiums the partners had hoped to receive. In July 1790, following a meeting with Williams and Vivian and other copper men, Boulton reported that "They are unanimously of opinion that we should insist upon our full dues from all the mines being charged every month, but that we remit (to such of the adventurers who keep their agreements & do not take out their ores) all the abatements we can afford to make".[111] In the late 1780s, therefore, the partners could no longer escape the economic reality that the Cornish mines confronted, a reality that meant it was extraordinarily difficult to turn a profit from pumping water to excavate copper ore.

CONCLUSION

Controversy surrounds the wellsprings of an industrial revolution in Britain but there is no debate about the proliferation of new machines there from the second half of the 18th century. From Boulton and Watt to Robert Allen in our own day, there has been a strong tendency to analyse the economics of machine adoption based on a calculus of cost-saving. No one has proven more articulate in challenging this calculus than Eric Hobsbawm, who cautioned us

[106] B&W, MS 3147/3/11, MB to Wilkinson, 7-8 Oct. 1787.

[107] B&W, MS 3147/3/11, MB to JW, 3 Oct. 1787.

[108] Rule, 1971, 184-5

[109] Thomas Wilson to B&W, August 2, 1788, cited in Rule, 1971, 185.

[110] J. Watt to G. Hamilton, 18 Sept 1788 (cited in Tann, 1995, 40).

[111] B&W, MS 3147/3/14, MB to JW, 9 July 1790.

against the assumption that a capitalist economy has any inherent tendency to cost-saving or technological innovation, emphasising that "[i]t has a bias only towards profit".[112]

In this article, I have grappled with Hobsbawm's "profit puzzle" in the adoption of the B&W steam engine in the Cornish copper mines. The technical improvements that the engine offered were crucial to its adoption but it was not the extent of these improvements relative to a common engine, nor the cost savings they implied, that determined the appeal of Watt's design in Cornwall. Instead, it was expectations about the copper that could be sold, and the price that would be paid for it, which encouraged or stymied the diffusion of the Watt engine. These expectations were influenced not only by the implications of steam power for production costs but also by imperial power, given the importance of the British empire in stimulating demand for copper, as well as market power in light of the repeated price wars that marked the British copper market. Using a history of profit to explore machine adoption by mining capitalists in late 18th century Britain, therefore, opens up our analysis to a much broader range of influences than looking through the lens of cost savings or technical improvement.

Approaching the economics of machine adoption through a history of profit offers insights that go beyond the motivations for introducing and running machines to include the economic and social consequences of their adoption. In this article, I have placed particular emphasis on the consequences of technological change for Cornish miners since these consequences were so much discussed by Boulton and Watt and the mining adventurers who adopted their engines . In contrast to most studies of workers' attitudes to new machines, the B&W engine was a "labour-augmenting" rather than a "labour-displacing" machine in Cornish mines in the 1770s and 1780s. And what we have seen in this case is that far from resenting the adoption of the steam engine, Cornish miners welcomed it as a boon to their livelihoods and protested only when threatened with the withdrawal of its services.

The fact that B&W engines were adopted, then stopped and started and stopped again, hints at the complexity of the economics of machine adoption. In this article, I have suggested there are significant insights to be gleaned from grappling with that complexity by studying the relationship between profit and power for Cornish copper mines. The conditions that encouraged the adoption of steam engines in Cornwall were not necessarily the ones that prevailed when these machines were set to work. And it was these shifting conditions, as I have shown, as much as any contrariness or bloody-mindedness on the part of the Cornish people, that explains the enthusiasm for the B&W engine in Cornwall and the increasing hostility that Cornish miners and mining adventurers displayed towards Matthew Boulton and James Watt.

[112] Eric J. Hobsbawm, "The Industrial Revolution, 1780-1840", *Industry and Empire*, 1968, 40.