The relative cost structures of steam vs other energy sources in the British economy, 1706-73

The British economy, or any other for that matter, was one that at the dawn of the eighteenth century relied largely on animate sources of energy though the contribution of water and wind were not trivial. But it was about to enter a new era, one that we still go through, in which technologies relying on fossil fuels came to dominate the production of energy. The Newcomen engine initiated this new era and, before the genius of James Watt made its appearance, it became a familiar sight in the island’s landscape. But its adoption was uneven both in spatial and sectoral terms. It achieved a decisive penetration in the northeastern coalfield but not its Scottish counterpart; it aroused the interest of Cornish engineers and mine owners when it made its appearance followed by a retreat in the rate of adoption but an impressive comeback around the middle of the century; it made modest gains in the iron industry but it was hardly present in London; and so on.

This unevenness in the rate of diffusion was conditioned by both economic and non-economic factors, playing out both on the demand and supply sides; they all converged in creating a set of determining factors marked by complexity and feedback mechanisms. The present paper will focus on only one, but a critical one, of these factors relevant to the diffusion of the Newcomen engine: the cost of its adoption in relation to other energy sources. In scouring the literature of the period one does come across simple comparative statements regarding the cost of energy sources. But in an era in which notions such as the cost of capital in the form of interest or the depreciation rate of machinery were imperfectly understood and erratically applied, it was natural to lack precise figures. However, one is struck by the fact that modern economic historians have continued making impressionistic statements in this regard but did not bother to producing such precise figures despite the fact that the evidence is robust enough to allow such an exercise.

The paper is divided into two main sections. The first one looks into the components of the annual fixed and operating cost of Newcomen engines whereas the second one engages in the same discussion in regard to other energy sources (horses, water- and wind-power, and adits). The literature on technological diffusion often utilizes the concept of the threshold when comparing two alternative technologies. It often happens that the new one scores such technical advances over time that its cost declines to the point of piercing the cost line of the old one in which case its adoption is suppose to gain speed. The present exercise will show that, by and large, the concept of the threshold was not terribly relevant in comparing different energy sources; their costs remained fairly apart, in most cases, thus facilitating the decision making process of adopting agents.
Fixed cost of Newcomen engines

There is a considerable amount of observations regarding the purchase price of steam engines but the deduction of capital cost per hp is not straightforward because of the ambiguity as to whether prices include ancillary costs, such as the engine house and the sinking of shafts, not to mention there is scarcity of data on the hp of particular engines. Nevertheless, the evolution of such cost can be traced when this information is combined with general estimates by various authors.

The typical size of a steam engine through the 1730s was 10hp (roughly corresponding to a cylinder diameter of c. 30 inches, or somewhat above); this was a mean figure of a wider range from as low as 5-6 hp during the first decade of diffusion to as high as 15 hp around the time of the expiration of the patent.¹ Purchase prices would range, according to testimony given before Parliament, from as low as £800 for poor quality engines to as high as £1,200. To the mean of £1,000, which matches Rolt’s estimate, we have to add another £100 or so for the cost of “contingent works” which could refer to the sinking of a new shaft and/or the cost of the engine house.² The mean value of the total cost of steam engines for the period up to 1740, based on the first 16 observations of the Appendix Table, was £1,086, rounded up to £1,100 to match the general estimates. The cost per hp of such an engine, henceforward Engine I, comes to £110.³

Beginning in the 1740s, and through the end of the period, the increase in the power of engines is more pronounced but the range of deviation of the mean decadal values more narrow, the typical engine at the time being c. 25 hp, having a 40-45 inch cylinder diameter. General estimates deviate on how much an engine of that size would cost.⁴ According to Dickinson, the cost reached £1,700 by the mid-1740s, a figure that probably refers to a typical size engine and is all inclusive. But Raistrick provides a much lower figure (£1,200) for an engine of 40-45 inch, drawing his evidence from colliery engines in Tyneside, and a range of £1,000-1,500 for the 1750s and 60s. He is in line with Kanefsky’s estimates referring to c. 1760: £1,200 for a 45 inch engine and £1,700-1,800 for a very large one of 70 inches corresponding to 50-55 hp. Finally, there is an account by an expert (Robert Mylne) given in 1775 before a parliamentary

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¹ XYZ
³ The standard deviation cannot be calculated since the hp of most engines in the table is not known.
committee based on his experience over the previous 3-4 years; according to him, an engine of 18 inch diameter would cost in London £1,400 inclusive of all the pump work but not the cost of the engine house. The above figures are wildly different.

There are a couple of samples that seem to support the more modest figures. Raistrick refers to four unidentified engines built in the 1750s or 1760s, three of them by Brown, whose costs average c. £967. Flinn uses a sample of eight engines, most of them built since the 1740s, with a mean cost of £1,140. However, the more robust sample (17 observations) of engines for the post-1740 period in the Appendix Table gives a mean value of £1,751.38, rounded to £1,750 and corresponding to £70 per hp for these larger engines (henceforward Engine II).

It would be stating the obvious to note that the cost of larger engines did not have to increase proportionally to their power. But another reason of the slower increase of purchase prices was the cost reduction in two key components of the engine, the boiler and the cylinder. The engine had wooden parts, e.g., the beam that was made out of a continuous oak log and the pumps for the pit that were originally made of elm (but later by cast iron). But metal parts dominated the cost structure. The skills to make boilers were transferred by craftsmen who made them for breweries or sugar refineries but brass was also used occasionally. The top would be covered by a sheet of lead under the presumption that plates of iron riveted together could not be made tight enough to withstand the pressure of steam. Typical examples of such boilers were a copper one made in Wales in 1717 costing £150 and another one made of brass for the Ketley company in 1760 which cost £402. As early as 1717 wrought iron plates were used to make them; by the 1760s they were common. Prices of iron boilers recorded by the author were in the £43.5–£126 range, broader to the estimates provided by Kanefsky (£80–100) referring to 1760. The amount spent could easily reach a few hundred pounds in the case of powerful engines which used a number of them such as the 98 hp Walker colliery engine (1763) which had three of them in service and one standby.

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7 Boilers were known as haystack or balloon from their shape; they kept evolving with different designs by John Payne, James Blakey, and others. For sources, see Catalogue of the collections in the Science Museum ... Stationary
The construction of cylinders also witnessed a significant reduction in price. The very first ones were made of brass by using the expertise of bell founders or, in the south of England, mostly of gun founders and, according to one account, they “were faulty in workmanship, and of great expense.” Indeed, at 1s 4d per lb, brass was very expensive although it could be sold for scrap at 8d per lb. As a result, it would fetch prices as high as £250 in the south where the syndicate experienced problems finding foundries; but the greater presence of brass founders and the increased competition on the Tyneside, which stuck to the material the longest, meant that they could be purchased locally for as low as £150. Desaguliers recommended them as late as 1744 based on sound theoretical principles, i.e., that they could be cast with walls thinner than iron and thus heat and cool more rapidly, speeding up the engine’s working cycle by 1-2 strokes/minute; their higher efficiency would counterbalance their higher cost. In practice, however, brass cylinders cast 1/3 inch thick could not withstand the mechanical stresses and the ones constructed were nearly one inch thick. In addition, brass cylinders had limitations in terms of increasing their size (no more than 28-29 inches diameter) and thus the engine’s power, evident by the multiple small engines erected in several collieries (e.g., Jesmond, Heaton, Tynemouth Moor, Long Benton, Byker). As the need for achieving greater depths in collieries became keen, they demanded bigger cylinders; brass would not only have increased the cost substantially but also would necessitate thicker walls thus giving up its presumed thermal efficiency. Iron offered a much cheaper alternative at 36s per cwt though it was more corrosive and prone to breaking in which case such cylinders would have zero value. Iron cylinders came to the market as early as 1718 from an unknown source but the most likely culprit was Coalbrookdale given its business with Parrott. The company certainly made them by 1722, constructing 22-27 of them by the expiration of the patent (there are discrepancies regarding the figures found in the literature) but in larger numbers once it bought better boring equipment in 1734 and came

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9 Stuart, *Historical and descriptive anecdotes*, p. 303.
to dominate the market; the company made at least 108 such cylinders by 1760 accounting for over half of those made by that year. Tyneside stuck to its ways until Isaac Thompson, the company’s agent in Newcastle, sold an iron cylinder to Brown in 1752 and, in light of the latter’s prestige, others followed. A number of iron cylinder prices found by the author were in the range of £20-122, although there were higher ones but the material was not specified by the primary sources. The price reduction compared to brass cylinders was obviously quite considerable.

There were two main capital cost charges, the first one being interest on invested capital. No series of interest rates is available for the period, the nearest proxy being the yield on Consols which was lower compared to interest rates prevailing in industry; their yield stood at 3.5% in the period 1756-70. The author has decided to follow Allen who assumed a five percent rate translating, on an annual basis, to £55 for Engine I and £87.5 for Engine II. Calculations of depreciation rates are not straightforward because it was a notion that was “imperfectly understood and inconsistently applied”; even when the latter was the case, the adopted rates varied quite widely. Some steam engines were abandoned or discontinued within a short time following their installation such as the one at Wheal Vor (1710-4), Trelogan (1732-5), and another one at Trelogan which operated continuously during the period 1752-60, and intermittently until 1762 at which point it was dismantled and parts of it were sold for c. £88. There was also a good number of engines that were in operation for many years and eventually sold second hand fetching good prices. The Bagilt Marsh engine, whose size was fairly typical for the pre-1740 period was erected in 1719 and sold in 1733 for £700 recovering a good portion of its original value. Six other engines sold several years after their installation during the post-1740 period fetched a mean price of £585.6. And in some cases their lives extended up to 1 ½ centuries; after all, colliery owners had every incentive to keep them in good

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10 An illustration of such machinery can be found in Chaloner and Musson, *Industry and technology*, n. p., illustration # 59.
12 Kanefsky, *Diffusion of power technology*, pp. 149-50,167 (quote from the latter page).
condition since selling a used engine would fetch a small portion of the original total cost. For some of these engines the depreciation rate can be deducted based on estimates of their values in years following their installation while still working, in other cases from information referring to their entire operating lives. The mean depreciation rate of eleven such engines was 7.5% indicating a useful life slightly exceeding 13 years. The annual depreciation for Engine I would be £82.5, and £131.25 for Engine II.

The last component of fixed cost was the patent premium. It is well-known that Newcomen came to an agreement with Savery, probably in 1705, which included the former as part of the latter’s patent. It was the most rational choice since attempting to secure his own patent would probably have solicited Savery’s opposition and would not have lasted for more than 14 years. Newcomen enjoyed the benefits of the patent until his death in 1718, though from 1715 on he was a mere member of the syndicate which took over the patent through its expiration in 1733. Newcomen was personally involved in the erection of some engines but its marketing became more aggressive once the syndicate took over, in the process using the expertise of key figures such as Calley, Potter and Beighton. Of particular interest was the agreement struck between Newcomen and Stonier Parrott, his father Richard, and George Sparrow, all three involved in a number of collieries, reaching a more ambitious scope under the syndicate. It was to last 99 years and allow the three partners to build as many engines as they wished in the various collieries they were involved, in exchange having to pay £150 the first six months and £420 for each engine erected. If a colliery became very profitable and raised above 20,000 stacks of coal per year, an extra payment of £100 for every 5,000 stacks had to be paid. The three partners aspired, through this

14 Costs relating to erection and that of the engine house were not recoverable. Kanefsky believes that engines tended to have substantial longevity; see Diffusion of power technology, pp. 273-4; Flinn, History of the British coal industry, p. 122.

15 The range of depreciation rates was 0.66-33.33%. The mean adopted here is virtually identical to the one used by Allen (7.1%); see Allen, British industrial revolution, p. 174. The engines in my sample, along with the years of erection and of the year the estimate on their value was made or the year they stopped operating, were: Howgill (1717/1726), Griff (1718/1729), Dudley Wood (1737/1752), Park colliery, Dudley (1725/1748), Tanfield Moor (1750-1876 or 1891), Bedminster colliery (1750-1900), Fairbottom valley, re-erected at Bardsley (1750-1827), South Liberty colliery (1760-1900). To these engines the three aforementioned ones with short lives (Wheal Vor and the two at Trelogan) were added. Sources: Allen, “The 1715 and other Newcomen engines at Whitehaven,” pp. 254, 266-7; White, “Early Newcomen engines,” pp. 209, 211-2; Allen, “The 1712 and other Newcomen engines, pp. 59, 70, 76; Catalogue of the mechanical engineering collection, p. 30; Catalogue of Watt centenary exhibition, p. 11; Stowers, “The development of the atmospheric steam engine,” p. 88.

agreement, to become powerful middlemen between the syndicate and colliery owners. But the relationship soured and by 1725 Parrott took the initiative to petition the House of Commons to annul the patent by making the argument that the Newcomen engine should not have been included under Savery’s patent to begin with given their very different working principles. Parrott wished to bring this action on behalf of numerous colliery owners who, he claimed, gave him their full support frustrated by the seemingly erratic policies of the syndicate when it comes to the premiums: extreme variability, in some cases charging no fees, and arbitrary refusal to do business with some mine owners or to allow the erection of the engine in certain places such as London with the exception of the York Building. In the end, Parrott’s efforts failed to gain much support and the syndicate went on to secure enormous profits given the number of engines installed during the monopoly period at often exorbitant premiums.  

Setting the premium does seem to have been arbitrary as it becomes apparent from Figure 1. There was no discernible pattern, for instance, in relation to the power of engines. The 1714 Griff engine and the one at Broseley (1715) were of the same power (3 hp) but the annual premium per hp in the former was £121.33 through 1720 (reduced to £50 thereafter) but only £6.66 for the latter; the figure stood at £36.4 for the Howgill engine (1717), and just £2.62 for the one at Trelogan (1732). The same inconsistencies apply when we take into account the cylinder diameter. For instance, the total annual premiums for the Bilston engine (1714, 13 inches) were in the range of £150-208 during different periods of the patent but only £20 for the engine at Pelsall (1717, 16 inches). The engines at Byker, Stevenston, Fidoe’s, and Heaton had comparable cylinder sizes (24-33 inches) but the annual premiums ranged from £65 to £420. There was one, fairly weak, correlation between premium levels and location, with engines in Wales and, especially, Scotland being charged lower amounts, though such instances also occur in English

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17 Parrott’s initiative built on the frustration of numerous mine owners, particularly those who resented the premium if they happened to be in the midst of financial difficulties. A good case in point is Griff colliery in which Parrott and his partners had a stake. Two engines were installed (1714, 1718) proving successful from a technical point of view but the colliery did not meet the expectations of high profits and thus the partners decided to surrender the remainder of their 29-year lease to Richard Newdigate in 1720. The latter erected two more engines in 1725 but the colliery closed down two years later and the engines were dismantled and sold in 1731. The main reason for the demise of the colliery was that the more accessible seams were getting exhausted, making it impossible to compete effectively with the neighboring colliery at Hawkesbury. But the premium payments was another factor, in fact, re-opening the colliery was contemplated in 1728 once the patent expired three years later. See, Jenkins, “Savery, Newcomen, and the early history of the steam engine,” pp. 122, 131; Rolt, Thomas Newcomen, p. 84.

18 The engine at Austhorpe (8 hp) carried an annual payment of £250 “for working and keeping the engine in order.” If that refers to the premium payment then the charge per hp comes to £31.25; see Smiles, Lives of the engineers, vol. 4, p. 62.
counties. There is also a fairly clear trend in terms of charging either lower premiums as the expiration of the patent approached or a lump sum, beginning in 1726 or so, which translated to lower annual amounts for the remaining years (e.g., Howgill, Edmonston, Houghton-le-Spring, Trelogan, Saltom pit). Smith believes that the premium policy of the syndicate was not arbitrary but geared towards installations in locations and performing duties that would give the best results.19 But it appears that the main criteria were the power of the syndicate vs. potential adopters which weakened as the patent came close to expiration; and the willingness to charge lower amounts in regions where the presence of other high cost elements (to be discussed below) rendered adoption more difficult (e.g., Scotland). In the end, the mean value of 20 premium observations was £138 (of a range spanning £20-420) adding the biggest component to the annual fixed cost of Engine I through 1733.

Operating cost of Newcomen engines

The cost of repairs and replacement parts would add a small amount to the operating cost of an engine but, unfortunately, it is difficult to assign figures due to the scarcity of data.20 Stevenston colliery spent £26 on repairs in 1723 but it is not clear whether this figure includes the cost of parts. Major replacement costs would refer to items such as boilers. Howgill colliery spent £18.78 in 1719 on “mending” its copper boiler with the expectation that it will last for a good many years, in contrast to iron boilers that would need replacement once every 1-2 years depending on whether “day” or “coal” water was used.

Labor cost was also, by and large, not exorbitant. The annual salary of the engineer at Trelogan (1732) was £39 but excluding an unknown amount for five assistants. Economies of scale were realized in this colliery when, by 1762, one engineer was responsible for two engines adding £19.5 to the labor cost of each engine but excluding an unknown amount for seven assistants. Savings were probably more substantial in the case of the six engines at Heaton which employed eight men in 1741 for an annual

labor cost per engine at £24.7. But in Scotland labor cost was often far more exorbitant in lieu of the scarcity of local engineering skills necessitating the use of “imported” English expertise. At Edmonstone and Whitehill, in 1726 and 1727 respectively, the chief engineers were getting paid £200 plus half of the net profits of the collieries.  

Despite the spotty data on these two types of cost, we are fortunate to have combined figures on both of them for a number of collieries which are consistent with the aforementioned evidence. The annual cost of repairs, parts, and labor for both Engines I and II would be taken as £126.7. However, labor cost in Scotland continued to be exorbitant throughout the period and thus the combined operating labor and capital cost would be defined at £231 for Scottish engines during both periods.  

The fuel consumption bill scored the widest variability and, depending on location, had the potential of imposing the heaviest financial burden. The evidence is somewhat fragmentary but the different elements are consistent enough to provide fairly robust estimates. Beginning with the first phase of diffusion, through the 1730s, the fuel consumption of six engines having disparate hp but averaging c. 10hp was 38.25 lbs/hp/hour. Making the assumption that engines would operate for 12.26 hours/day, this rate translates to an annual consumption of 20,376.7 bushels (764.1 tons). The financial burden would be fairly small in collieries. Several pithead prices from northern and Scottish collieries (1710-25) indicate that sleck would be valued at c. 0.05s/bushel, ordinary coal for 0.08-0.14s, whereas “sea” coal would fetch c. 0.18-0.20s (see Figure 2 for all coal prices cited). Collieries would use mainly sleck but some “good coal, the market article” would have to be thrown in to get the sleck going. At the

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21 This sort of arrangement, however, was not universal. The keeper’s wage at Stevenston in 1723 was £52. For sources on the labor cost see: Whatley, “The introduction of the Newcomen engine to Ayrshire”, p. 72; Bald, General view of the coal trade of Scotland, pp. 22-3; Allen, “The introduction of the Newcomen engine,” p. 189; Rhodes, “Early steam engines in Flintshire”, pp. 219, 223; Rolt and Allen, The steam engine of Thomas Newcomen, p. 153; Raistrick, “The steam engine on Tyneside,” p. 139.

22 The engines whose data are taken as representative are: regarding Engine I, I take a weighted average of the labor and capital operating cost for the Howgill engine which was £301 for the period 1718-23, i.e., c. £60 annually, on average; and for four engines at Heaton colliery during the period 1734-39 at £143.3/engine. For Engine II I rely on data for six Heaton engines during two weeks in July 1741, the respective cost on an annual basis being c. £69. The latter figure is certainly an underestimate in light of economies of scale realized at Heaton when it comes to labor cost but not in collieries with a single engine. Kanefsky cites a figure of £1/week or more just for the wage of the engineman. Hence it was decided to assign the same value to Engine II for capital and labor operating cost borrowing the figure from Engine I. For Scotland, I rely on data of the weekly operating cost, minus fuel, of the engine at the Earl of Dunmore’s coalworks in 1769; the respective figure comes to c. £231. For other sources, see: Allen, “The 1715 and other Newcomen engines at Whitehaven,” p. 254; Raistrick, “The steam engine on Tyneside,” p. 139; Hamilton, Economic history of Scotland, p. 208; Tann, “The steam engine on Tyneside,” p. 55; Kanefsky, Diffusion of power technology, pp. 172-3.

23 All references to the fuel consumption of individual engines and the operating time are taken from XYZ,
The aforementioned figures the annual fuel bill for Engine I in collieries would be £51. However, coal prices elsewhere were much higher. The mean price of coal in London during the period 1706-39 was 0.86s/bushel translating, at the aforementioned annual rate of consumption, to £876. Fuel cost in Cornwall would not be far lower. A ton of coal would cost 15s to land in Cornwall in 1760 and land carriage would add another 5s. Cornish prices are hard to get for earlier years but if the London price ratio for 1760 vs 1706-39 applied to Cornwall (c. 20 percent lower in the latter period) then the Cornish price would be 16s/ton. The infamous duty imposed by the government, abolished in 1741, added 3.25s/ton resulting in an annual fuel bill of £735.4.

Similar regional variations emerged regarding Engine II. Utilizing 54 observations from 47 engines (those with known hp have a mean of 21.3hp, hence similar to Engine II), the fuel rate was 29.5lbs/hp/hour. The annual consumption would be 39,288.5 bushels (or 1,473 tons); at 0.177s/bushel in collieries, the annual bill would reach £347.7. The fact that the Jarrow colliery engine, which was probably somewhat less powerful (40 inch diameter), had an annual bill of c. £250 in 1743 and that two engines at Elswick and the Earl of Dunmore’s collieries (of unknown hp) had bills of £281 and £266 respectively in c. 1740 and 1769 indicate that the adopted figure is of the right order of magnitude. The London version of Engine II, at a mean price of 0.97s/bushel during the period 1740-73, would have an annual bill of £1,905.5. And the Cornish version, at a price of £1/ton (in 1760), would have a bill of £1,473. Indicative

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24 An indication that the estimated annual fuel bill is of the right order of magnitude is the evidence from Stevenston colliery where the respective figure was £39 in 1723; and the engine at Bagillt colliery also had a fairly low fuel bill in 1735 because it used sleck. See Whatley, “The introduction of the Newcomen engine to Ayrshire”, p. 72; Rhodes, “Early steam engines in Flintshire”, p. 221. The quote is from Stuart, Historical and descriptive anecdotes, p. 19.

25 The annual bill for the first York Buildings engine (1714) was £1,000. See Rolt and Allen, The steam engine of Thomas Newcomen, p. 84 Larger engines could have been more efficient such as the 2nd engine at York Buildings of 20hp (12.41 lbs/hp/hour in 1726) but not necessarily cheaper in terms of their total consumption bill.

26 Flinn stated that there were probably some similarities in the movement of prices overtime between coalfields though the absolute levels may have differed substantially; see his History of the British coal industry, vol. 2, p. 306.

27 According to Pole, the duty added £350/annum to the annual fuel bill, though he does not specify the power of the engine he has in mind. Barton believed it added £600 in the case of larger engines. Barton, Cornish beam engine, pp. 17-8, 20; Kanefsky, Diffusion of power technology, p. 172; Pole, Treatise on the Cornish pumping engine, p. 13.

28 Replying to an inquiry in 1752, Brown pointed out that an engine with a 42-inch diameter would burn 20 bolls in 24 hours. Assuming 28 bolls=1 Newcastle chaldron then this engine would burn 176.6 lbs per hour. Such cylinder diameter was supposed to correspond to a 25hp engine but that would translate to a rate of 7lbs/hp/hour, an unrealistically low figure. The only explanation is that Brown had in mind engines of much lower hp at this cylinder diameter. See, Raistrick, “The steam engine on Tyneside,” p. 162; Raistrick, Dynasty of ironfounders, p. 145.

of the fairness of the latter figure is that Barton's estimates for the annual bill of a somewhat larger Cornish engine (47 inch diameter) revolved around £1,500-2,000.\(^\text{30}\)

The above figures regarding operating cost are in broad agreement with general estimates and comparable figures referring to specific engines. For instance, Desaguliers argued that the operating cost of the Griff engine installed in 1714 never exceeded £150 and data from Oct. 1728-Oct. 1729, a “wet year”, show that this and another engine at Griff installed in 1718 had a combined operating cost (but excluding the cost of new parts) which came to £94.6 per engine.\(^\text{31}\) In contrast, the operating cost of *Engine I/collieries* is estimated at £177.7. The difference is accounted by the fact that one of the Griff engines was very small at 3hp (the power of the second being unknown). We are on firmer ground when it comes to the estimates regarding operating cost for *Engine II/collieries* (£474.4). Raistrick cited £400 as a general estimate referring to the 1750s-60s, and so did Stowers referring to a specific (but unnamed) engine; moreover, the respective figure for the Wallbottle colliery engine was also £400 in 1744, whereas that of Tanfield Lea stood at £416 in 1755.\(^\text{32}\)

The overall estimates are summarized in Table 1. It is interesting to contrast my total cost estimates to those of other authors. Crafts calculated the annual cost per steam hp of a “typical” Newcomen engine in “mining” in 1760, without specifying these terms, at £33.5. This figure is somewhat above my figures of *Engine II* referring to Scottish and English collieries (£31.9 and £27.7 respectively) but well below the figure for the Cornish version (£72.7).\(^\text{33}\) There are also some estimates by Allen on the evolution of costs

\(^{30}\) During trials in 1768-1770 one of the two Trasevean engines consumed 1,294 tons/year, i.e., similar to the figure adopted here. There are references by Wilson to a number of other Cornish engines with considerably higher daily rates of fuel consumption compared to *Engine II*: two engines at Wheal Rose and Wheal Busy (c. 13 tons each), two engines at Chasewater (16.8 tons in winter, 12 in the summer), and one at Godolphin (6 tons). But it is not clear which specific engines he refers to (there were several in these mines) and the hp is often not known; but, given such figures, these engines were probably very large ones. See Wilson, *A comparative statement*, pp. 3-4; also Barton, *Cornish beam engine*, p. 20; Smiles, *Lives of the engineers*, p. 66.


\(^{32}\) Raistrick, “The steam engine on Tyneside,” pp. 146, 153; Stowers, “The development of the atmospheric steam engine,” p. 88; Dickinson, *Short history of the steam engine*, p. 61. The only figure which is out of sync with my estimates is the one cited for the engine at Griff colliery at £208 (1770); see White, “Early Newcomen engines,” p. 209.

\(^{33}\) Crafts, “Steam as a general purpose technology,” pp. 342-3. My estimates on earlier engines also seem to be on firm ground. Dickinson cited the water-lifting performance of a colliery engine in 1752 based on a detailed contemporary account; its effective hp can be calculated as 11hp, raised to 12.5hp to get its nominal hp, i.e., to allow for friction. In other words, the power of this engine was very similar to that of *Engine I*. The author of this account estimated its annual cost at £365 but there was no mention of depreciation. If we add to his figure the rates I have adopted for *Engine I* regarding depreciation and the premium then its cost per hp is virtually identical to my figure for *Engine I/collieries*. See Dickinson, *Short history of the steam engine*, pp. 56-7.
Table 1: Total annual cost and annual cost per hp (in £) of steam power, 1706-73

<table>
<thead>
<tr>
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<th>Engine IA, 1706-33</th>
<th>Engine IB, 1733-39</th>
<th>Engine II, 1740-73</th>
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**Operating cost**

|                      |                    |                    |                    |
| Labor+parts+repairs  | 126.7              | 126.7              | 126.7              |
| (but in Scotland)    | 231                | 231                | 231                |
| Coal/colleries       | 51                 | 51                 | 347.7              |
| Coal/London          | 876                | 876                | 1,905.5            |
| Coal/Cornwall        | 735.4              | 735.4              | 1,473              |

**Total annual cost**

|                      |                    |                    |                    |
| and annual cost/hp   |                    |                    |                    |
| English collieries   | 453.2/45.32        | 315.2/31.5         | 693.1/27.7         |
| Scottish collieries  | 557.5/55.75        | 419.5/42           | 797.4/31.9         |
| London               | 1,278.2/127.82     | 1,140.2/114        | 2,251/90           |
| Cornwall             | 1,137.6/113.7      | 1,000/100          | 1,818.4/72.7       |

Sources: see text.

per hp showing a decline of the overall cost driven by a modest reduction in capital cost and a far more drastic one in fuel cost. My exercise clearly justifies this pattern. However, there are two major issues with his statements. First, his overall cost lines are drawn depicting a smooth gradual decline. The elimination of the premium with the expiration of the patent in 1733 and the fairly sudden growth in the size of engines beginning in the 1740s meant that the decline of cost per hp was more abrupt at these two points resembling more of a step-like pattern (see Figure 3 below). Second, his statement (relying on von Tunzelmann) that fuel and capital costs accounted for 45 per cent each, with labor filling the residual 10 per cent, is borne by my data, more or less, only for the collieries version of Engine II. The principal components of costs in collieries for Engine I were the cost of labor, raw materials, and replacement parts as well as the premium payments through the expiration of the patent. In contrast,
by far the most dominant component of cost in locations such as London and Cornwall was the cost of fuel (c. 65-85%), its weight increasing as time went by. An attempt was made to duplicate these estimates for the Savery model. At least 11 such engines were installed during this period, seven of which were experimental, three in mines, and one in waterworks. The power of only three experimental engines is known, all of them being 1hp. The purchase price of such engines would be c.£80; assuming the same interest and depreciation rates, the combined cost would be £10. The premium, assuming a charge proportional to the 10hp Newcomen engine, would add another £13.8 to the annual fixed cost. In terms of operating cost, fuel consumption had the potential of being a dominant component. Savery himself was evasive and underplayed the amount of coal necessary to operate his model. There are few data in this regard. In 1774 Smeaton run a trial of two engines erected in Manchester by Wrigley to work water-wheels. The first engine was of 2 2/3hp and consumed 31.5 lbs/hp/hour; the second engine was nearly 5hp and consumed 29.4 lbs/hp/hour. These rates are not much higher compared to Newcomen engines at the time. Though they may have been higher earlier, before Wrigley’s improvements, their mean value was used to calculate the fuel

34 My comments on Allen’s figures are based on a more refined analysis of the data which is not reproduced here due to space limitations, though easily deduced from the figures of Table 1. See Allen, British industrial revolution, pp. 172-5.
35 Desaguliers installed an engine in his garden in 1728 which cost him £80 and, despite the fact that the figure does not include the cost of piping that would have added several pounds, it was adopted because the purchase cost could have been lower; the 1712 engine installed at Kensington cost £50. See Switzer Introduction to a general system of hydrostatics and hydraulicks, p. 328; von Tunzelmann, Steam power, pp. 47-8; Hills, Power from steam, p. 35; Thurston, History of the growth of the steam engine, p. 44.
36 Wrigley modified the design of the original model by relying on only one cylinder, as opposed to two in Savery’s design. Steam was condensed in the cylinder having atmospheric pressure forcing up water from below; and then instead of expelling the water by steam, as in Savery’s design, the water flowed out by gravity onto a cistern which stood above a water wheel. This modification reduced the necessary amount of steam to a bit higher than atmospheric pressure thereby reducing substantially the risk of boiler explosions as well as fuel consumption. He also incorporated some changes brought by Blakey who focused on introducing self-acting valve gear and using oil on the surface of the water in the cylinder to reduce steam condensation. These modifications, however, did not prove satisfactory. See Musson and Robinson, Science and technology, pp. 397-8; Thurston, History of the growth of the steam engine, pp. 44-5. On Savery comments on this issue see his The miner’s friend, p. 28.
37 Farey, Treatise on the steam engine, p. 125; Goodeve, Text-book on the steam engine, p. 9; Thurston, Manual of the steam-engine, pp. 11-2. There are also two accounts, on the Kensington engine of 1712 and one erected by Wrigley at the works of Mr. Kiers at St. Pancras, London towards the end of my period, or a bit beyond, regarding their fuel consumption but the references are not precise enough to allow the calculation of the rate. See Switzer, Introduction to a general system of hydrostatics and hydraulicks, p. 328; Farey, Treatise on the steam engine, p. 125; Stuart, Historical and descriptive anecdotes pp. 158-9; Stuart, Descriptive history of the steam engine, pp. 42-3; Thurston, History of the growth of the steam engine, p. 45. The recorded rates of the two Manchester engines are virtually identical to the estimates provided by Hills (31lbs/hp/hour) and Thurston (33.26 lbs/hp/hour). See Hills, Power from steam, p. 242 and Thurston, “On the maximum contemporary economy of the high-pressure multiple-expansion steam-engine”, pp. 313, 315.
consumption at the beginning of the century for a 1hp engine at 1,622.15 bushels which translates to an annual cost of c. £4 in collieries, £69.75 in London and £58.5 in Cornwall. Unfortunately no information was found on the labor and capital cost of maintaining these engines. Without it, the total annual cost would be in the range of £27.8-93.5 per hp. In the end, the cost of Savery engines was similar to that of the Newcomen model.

It would be interesting, in closing, to compare the thermodynamic output of these two models. For the Newcomen engine, I have estimated from a sample of firms covering the time periods for both Engines I and II that the quantity of water being capable of lifted was c. 21mil ft lbs per hp per day. When it comes to Savery engines, the very early ones had a much lower capacity. Two engines, both of 1 hp installed at Kensington (1712) and Desaguliers’ house (1728), had a capacity of slightly over 14 mil ft lbs. But by 1774 two engines installed in Manchester by Wrigley, of 2.66 and c. 5 hp, delivered a mean of almost 24 mil ft lbs per hp per day, that is exceeding the performance of Newcomen engines.39

Horses

Horses, attached to gins, was the traditional method of lifting water. A large number of them were needed since they could work for only a few hours a day. The engine that was erected at Elphingstone, East Lothian, in 1720 came to replace no less than 50 of them. Still, their purchase cost was lower compared to steam engines, their main drawback lying in their high operating cost because they were expensive to feed and called for additional manpower to handle them. The expense of winning Walker colliery in 1711 was £5,011 18s including the use of horses for draining; two horse gins were used, working night and day, the sinking going down to a depth of 30 fathoms. An expert, John Barnes stated in a affidavit in 1722 that if the same process was undertaken with a steam engine the cost would have been “much cheaper”. The same financial burden was in place when it comes to doing the work once new pits were sunk. The operating cost of horse gins at Gregory lead mine was £390 in 1765 but at

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38 Assuming a 12.26 hours work day. For Engine I the sample was comprised of the engines at Dudley Castle, Griff, Park, and Alan Flats; for Engine II from an unnamed colliery, and two engines installed at Warmley Brass. To find these figures one has to take the number of gallons lifted and multiply by 8.33 (translating it to lbs) and by the height in feet. The product should be divided by 60 to find the foot lbs/minute. To find the hp of an engine needed to drain this quantity, the final product should be divided by 33,000. See Michell, Mine drainage, p. 359; Power Catechism, pp. 132-3; Allen, “Introduction”; Rolt and Allen, The steam engine of Thomas Newcomen, pp. 61, 146-7, 149; Rogers, The Newcomen engine, pp. 28-9; Allen, “Some early Newcomen engines,” p. 199.

39 Galloway, The steam engine and its inventors, pp. 67-68; Hills, Power from steam, p. 35; Farey, Treatise on the steam engine, p. 125; Goodeve, Text-book on the steam engine, p. 9. For some additional comments and estimates on their lifting capacity, see Switzer, Introduction to a general system of hydrostatics and hydraulicks, p. 328; Clark, Elementary treatise on steam, p. 33.
Bedworth colliery right before the dawn of the steam era and at Hawkesbury mines later on, the figure reached over £2,000 annually.\(^{40}\)

The other drawback of horses lied in their lifting capacity. A typical steam engine at the time could lift 28,548 ft lbs/minute, given a rate of 21mil/day. Watt defined hp as being equal to 33,000 lbs but this figure is unrealistic. Smeaton and other engineers argued that a good horse can raise 22,000 lbs one foot high per minute if the objective is to have it working for eight hours a day, considerably lower than steam.\(^{41}\) But while experts unanimously agree that the Newcomen engine “was considerably cheaper per gallon of water raised than the old methods of horse-gins,” specific figures are hard to find.\(^{42}\) Precise data on cost and lifting capacity are necessary, and it is often hard to come up with such figures. Nevertheless, the task is feasible.

One of the earliest and most comprehensive accounts refers to Howgill colliery, Cumberland. It is an extremely detailed report prepared in 1713 laying out the cost of horses when it comes to reclaiming three abandoned sections of the mine while weighing also the option of purchasing a steam engine (installed in 1717). The use of horses would take 147 days to lift the specified quantity of water and would cost £233.3 (including the cost of ropes, buckets, and other miscellaneous expenses), a sum that was raised to £247.2 to include the estimated interest and depreciation charges. In contrast, the 5hp steam engine that was installed could have completed the task in 90.85 days and would have cost £56.41, i.e., 22.8% of the cost of horses while draining the same quantity of water.\(^{43}\)

Another comparison can be made for Griff colliery where more than 50 horses were used at the beginning of the century with an annual operating cost of £900. Labor cost was estimated at £300 while


\(^{41}\) Two teams of ponies at West Earth colliery (1752) raised 133,280 ft lbs/minute. The number of horses per team is not specified but if they were a total of six horses, each of them raised 22,213.33 ft lbs. Other experts, however, defined their lifting capacity as a range; according to one account, a horse working a gin on a circular track can exert 16,000-26,000 ft lbs per minute. See Flinn, *History of the British coal industry*, p. 114; Farey, *Treatise on the steam engine*, p. 439; *Catalogue of the collections in the Science Museum*, p. 8; Burn, *The steam-engine*, pp. 39-40.


\(^{43}\) Horses worked 20.4 hours a day while I made the assumption that the steam engine worked 12.26 hours/day. I have taken into account the annual cost of Engine I/collieries. The report of the mining agent refers also to the annual operating cost of horses once the reclaiming of the mine was complete but not enough information is given to engage in the same exercise. See Allen, “The 1715 and other Newcomen engines,” pp. 242, 244, 261-3. Interest and depreciation charges were calculated based on a purchase price of £10/horse. Horses used in mining cost at least £6-7 c. 1700, “and to pay any less was a false economy”, while by 1775 they would cost Lumley colliery £12 per horse. The working life of horses was taken as 12 years. See Flinn, *History of the British coal industry*, p. 113; Hatcher, *History of the British coal industry*, p. 227 (quote from this source).
interest and depreciation charges added an estimated £26 and £43.3 respectively. The total annual cost comes to £1,269.33 or £3.47 daily. We have sufficient information to reconstruct the annual cost of the steam engines that were installed subsequently (1714, 1718, 1725). The first one was of 3hp but the others probably more powerful and thus a purchase price of £1,100 would be a fair estimate translating to £55 interest charges, while depreciation added £75 and the premium was £150. The operating cost per engine (mean of two engines in the late 1720s) was £94.65 (but excluding an unknown amount for the cost of new parts), a figure that conforms to Desaguliers statement that annual operating expenses at Griff never exceeded £150. The total cost of an engine was £374.65 rounded up to £400 to include the cost of new parts. The daily cost was £1.09, i.e., 31.5% of the cost of horses drawing the same quantity of water. The cost ratio of the two methods regarding these two collieries in the early part of the century stands at a mean of c. 27%. 44

The ratio remained remarkably stable in subsequent decades. Another detailed estimate referring to an unnamed colliery in 1752 points out that the cost of drawing 67,200 gallons of water per day would amount to £438 annually, a figure that was raised to £448.66 to include interest and depreciation cost. The cost of a steam engine, of c. 12hp, is also provided but without depreciation. When the latter is included the annual cost comes to £450, virtually identical to that of horses, but drawing 250,560 gallons/day. The annual cost of extracting the latter quantity with horses would have been £1,672.86 or £4.58 daily compared to a daily cost for the engine at £1.23. The cost of steam was 26.8% to that of horses. 45

However, in locations other than collieries the cost gap between the two energy sources was much narrower. Smeaton supplied estimates in 1766 for the comparative cost of horses vs. steam for the New River Head company, London. The engine would draw 1,307.73 tons/day and cost 24.65s. In contrast, horses would draw 490.4 tons/day and cost 12.54s but the cost of drawing the same quantity as the steam engine would be 33.43s. In other words, the cost of steam amounted to 73.7% of that of horses. 46

In the end, a 5hp engine was installed in 1769.

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44 I have assumed that there were 52 horses with three of them in each team, that a driver got paid 12d and that there was a tubman for every two teams getting 12d based on evidence from Gregory lead mine and Howgill colliery. See Stuart, *Historical and descriptive anecdotes*, p. 619; White, “Early Newcomen engines,” pp. 208-9; Band, “The steam engines of Gregory mine,” pp. 269-70.


46 I have assumed a 12.26 hours work day, that four horses used one pump, and the same operating cost for horses as in the unnamed colliery of 1752 to which I added estimates for interest and depreciation charges. See Scott, “Smeaton’s engine of 1767 at New River Head,” pp. 119-20.
**Water power**

Water wheels were one of the most common ways of drainage prior to the steam age. According to Pryce, writing in 1778, the preferred method of draining in Cornwall, was to use pumps driven by small water wheels of 12-15 feet diameter; and if the depth was considerable to use them one on top of the other, in one case seven of them being placed in such a way. Around the year 1700 John Costar, an engineer from Bristol, came to Cornwall and showed them that utilizing water wheels of 30-40 feet diameter was preferable.47

The cost of water wheels was not particularly exorbitant. One such wheel of the bob type, the most efficient of its kind, was erected at Strathore, Fife, in 1738 or 1739. Its size was pretty typical in that it had a 21 ft wheel diameter, operated twin beams and was capable of performing nine strokes a minute raising 185 hogsheads of water per hour from an unspecified depth. The total cost of the engine, mounting, pit and pumps was over £200. But, on average, wheels would cost less than £100 and the inclusion of the transmission mechanism would increase this amount by c. 50%.48 However, “the building of dams, ponds, aqueducts and so on might incur a coal master in great expense even where a suitable stream lay not too far distant from the colliery.” The cost of building water courses for a Lancashire spinning mill in 1786 was £223 3s while Smeaton estimated that a two-mile leat driven through hard rock would cost £400.49

When it comes to annual cost only rough estimates can be provided. The erection cost of a typical size wheel (20-25 ft diameter, c. 14.25 hp) and its related infrastructure was c. £367, conforming to Kanefsky’s assessment that total installation cost was £20-30/hp. Annual interest charges would be £18.35. Depreciation rates would be higher than steam engines evident by the fact that insurance valuations found by Tann placed the value of small wheels at £40-60, for larger ones at c. £100, i.e., at about half the cost of a new wheel. At a 10% rate, depreciation charges would add £36.7. Finally, £10 was added for replacement parts and maintenance work, which could be done cheaply by carpenters and clockmakers, bringing the annual total cost to £65, and the cost per hp to £4.5.50

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50 The lifting capacity of such a “typical” wheel was conditioned by morphological factors, varying widely. The rule used to finding the power provided by a water stream is given in Allen, *Science of mechanics*, pp. 198-9 and Kanefsky, *Diffusion of power technology*, pp. 21-22. But to apply the rule we have to have precise information on water flows and heights for specific sites, something that is rarely the case.
Adits
There is speculation that adits may have been used for drainage in the Middle Ages. They were certainly common by the 16th century, although in Scotland an account written in 1672 speaks of them as being a fairly new invention. Their feasibility hinged on the nature of the terrain, rocky or soft and crumbly strata making the task impossible. But when feasible they could be extended gradually to run over several miles; in Fife the average length of 27 adits was 1.25 miles. Considering this length as typical and given a rate of £1.11/yard based on an estimate for Barnsley Moor (South Yorkshire) in 1716, the total cost would amount to £2,444.4, though lower figures have been found such as the sough erected in Felling Grounds, Worcestershire, by Parrott costing £500 in 1717-8. The annual interest charge would amount to £122.2. In terms of operating cost, ventilation shafts had to be sunk from time to time, in some occasions exceeding the entire cost of the adit. Passages could be blocked by falling roofs and debris following heavy flows and to make them operational again could be fairly expensive. I will assume that £32.5 was spent annually to clean damaged sections as was the case at the Gregory lead mine in Derbyshire in 1766; this section was 130 yards long, i.e., c. 6% of 1.25 miles. The total annual cost would amount to, roughly, £155.51

Windmills
Windmills were mainly erected in Scotland, their effective application to mines dating shortly after 1708 when the town of Montrose sent John Young to Holland to study superior Dutch construction techniques. It is not clear how instrumental was Young’s trip but several windmills were erected subsequently in Scotland, especially close to the windy Firth of Forth. There is a surviving estimate from c. 1738 for the erection of a windmill with pumps going down 20 fathoms in Strathore, Fife citing a figure of £57 7s for the wright’s workmanship. A slightly later estimate raises the cost to £115 5s but this assumed that the pumps would sink to a depth of 30 fathoms. Given such figures, interest charges would be c. £4-5 a year. Depreciation rates, however, could add a more substantial amount since windmills were often blown away by strong winds such as the one erected in 1737 in the property of John Gray, owner of Westmuir colliery near Glasgow who saw his investment blown to pieces in 1740. Such short life span would add another £28-29 for a total of c. £33, a figure that would be taken as the upper limit of the annual total cost of windmills. Given that the typical drainage windmill would

generate 5hp, the annual cost per hp was £6.6.\textsuperscript{52} However, since this is an upper limit, the cost of wind power would be taken as equal to that of water power (£4.5).

Figure 3 pulls together the entire evidence on the cost evolution of various methods of lifting water. It is not an ideal depiction in that it refers only to “typical” steam engines and provides either a rough or less than complete evidence when it comes to other energy sources. However, it is a thorough review of the existing evidence and does allow engaging in a preliminary contrast between the findings of this theoretical exercise and how well they fit the actual patterns of utilization of the various energy sources. The most obvious general conclusion is that the concept of the threshold is largely irrelevant since the cost structures of the various methods was such as to place them in three distinct ranges. A more refined sectoral and regional analysis allow us to draw the following conclusions:

First, horses were decidedly the most expensive energy source in collieries despite their substantial efficiency improvement over time, presumably stemming from the utilization of better equipment and pumping devices; this disadvantage applies also to Scottish collieries despite their higher operating cost of steam. Steam power, however, remained initially less competitive to adits as well as wind and water power. But the elimination of the patent premium and the improved efficiency of larger engines in the post-1740 period meant that engines with very low fuel consumption would operate along the Smin line and thus pose a challenge to the utilization of adits, though water- and wind-power remained unbeatable alternatives. These expectations are met fairly well when contrasted to actual patterns of diffusion. Water was not readily available in collieries and thus its use was largely absent. Adits were constructed when the morphology of the terrain allowed it. But steam had the widest potential applicability and came to dominate this sector.\textsuperscript{53}

Second, the situation in London was considerably different. The cheapest methods either could not be utilized (adits) or were of limited applicability (water and wind). The costs of steam and horses were probably along similar lines through the 1730s but the decline in the cost of the former subsequently meant that horses could compete only if the utilization of steam involved engines whose fuel consumption was well above the mean. These expectations are met since the adoption of engines in London takes place mainly in the post-1740 period although their anemic prior diffusion was also due to restrictions imposed by the syndicate.


\textsuperscript{53} The references to the actual diffusion of the various methods in collieries and elsewhere is drawn from XYZ.
Third, in the metal mines of Cornwall the cost structures of horses and steam were comparable to those in London and thus horses were fairly competitive through the 1730s. On the other hand, adits, water- and wind-power clearly offered the best options throughout the period even if engines achieved the lowest levels of fuel consumption. That is precisely what one observes when looking at actual patterns of diffusion, i.e., widespread use of water-power, which was more readily available in the county, matching (if not exceeding) the hp generated by steam.

Comparing the cost structure of the various energy sources is a vital factor in understanding the temporal and spatial diffusion of steam power during this period. But the author concurs with Nuvolari, von Tunzelmann, and Verspagen (NVT) that models emphasizing the relative profitability of two competing technologies based on current factor prices or the threshold approach are largely simplistic in light of a complex set of (often non-quantifiable) factors. Such factors were, to name just a few: the impact of the patent premium, the spatial diffusion of engineering skills and its concomitant impact on labor costs and fuel efficiency, and the effect of the poor transportation infrastructure on the price of coal as well as information and logistical delays regarding the installation of engines.

Nevertheless, the present exercise was deemed useful because the relative cost structures of competing energy sources had not drawn any precise quantitative formulations. Most importantly, the part of the exercise referring to steam power provides the material needed to measure the effect of the factors driving its diffusion, at least to a considerable extent, from a regional and sectoral perspective. This can be done in the context of a formal model shedding light on what NVT called the “microbiology” of the diffusion process “seen as the emerging outcome of micro-processes of technological learning and market selection among boundedly rational agents” suggested by evolutionary theory. Such analysis should also discuss factors that have been neglected by the literature such as the distribution of firm sizes within potential adopting sectors and how it impacted the ability of firms to finance the purchase of particular techniques; or the extent to which the various energy sources could increase output, whether market expansion was sufficiently robust to justify it, and how the increase in marginal output related to marginal cost and profitability.

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### Appendix Table 1: Purchase price of engines and total cost of erection (in £)

<table>
<thead>
<tr>
<th>Year</th>
<th>Engine</th>
<th>Cylinder diameter (inches) or hp</th>
<th>Stated cost</th>
<th>Total cost</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1715</td>
<td>Woods mine</td>
<td>22 in.</td>
<td>over £1,000</td>
<td>over £1,000</td>
<td>“erection and setting up” cost</td>
</tr>
<tr>
<td>1717</td>
<td>Howgill</td>
<td>5 hp</td>
<td>200</td>
<td>350?</td>
<td>added the estimated labor cost of erection and of the engine house</td>
</tr>
<tr>
<td>1718</td>
<td>Griff</td>
<td>?</td>
<td>2,000</td>
<td>2,000?</td>
<td></td>
</tr>
<tr>
<td>1719</td>
<td>Whiston</td>
<td>?</td>
<td>“at least” 1,500</td>
<td>“at least” 1,500</td>
<td>“permission to erect together with the expense of erection”</td>
</tr>
<tr>
<td>1725</td>
<td>Park colliery</td>
<td>25 in.</td>
<td>500</td>
<td>600?</td>
<td>Added estimated cost of engine house</td>
</tr>
<tr>
<td>1726</td>
<td>Edmonstone</td>
<td>28 in.</td>
<td>1,007.56</td>
<td>c. 1,200</td>
<td></td>
</tr>
<tr>
<td>1727</td>
<td>Whitehill</td>
<td>29 in.</td>
<td>1,200</td>
<td>1,350?</td>
<td>added the estimated labor cost of erection and of the engine house</td>
</tr>
<tr>
<td>1728</td>
<td>Mr. Gun-Jones engine</td>
<td>?</td>
<td>300</td>
<td>300?</td>
<td></td>
</tr>
<tr>
<td>1730</td>
<td>Coneygree</td>
<td>30 in.</td>
<td>700</td>
<td>700?</td>
<td></td>
</tr>
<tr>
<td>1730</td>
<td>Bushblades</td>
<td>?</td>
<td>800</td>
<td>1,827</td>
<td>Extra cost of civil engineering work</td>
</tr>
<tr>
<td>1733</td>
<td>Ridley</td>
<td>33 in.</td>
<td>849.8</td>
<td>849.8</td>
<td></td>
</tr>
<tr>
<td>1733</td>
<td>Heaton</td>
<td>15 hp</td>
<td>700</td>
<td>700?</td>
<td></td>
</tr>
<tr>
<td>1734</td>
<td>Bo’ness</td>
<td>?</td>
<td>1,500</td>
<td>1,600</td>
<td>Pre-erection estimate, added the estimate for the cost of the engine house</td>
</tr>
<tr>
<td>1737</td>
<td>Saltom pit</td>
<td>42 in.</td>
<td>1,201.95</td>
<td>1,300?</td>
<td>added the estimate for the cost of the engine house</td>
</tr>
<tr>
<td>1737</td>
<td>Dudley Wood</td>
<td>36 in.</td>
<td>700</td>
<td>800?</td>
<td>added the estimate for the cost of the engine house</td>
</tr>
<tr>
<td>1738</td>
<td>Long Benton</td>
<td>42 in.</td>
<td>1,200</td>
<td>1,300?</td>
<td>added the estimate for the cost of the engine house</td>
</tr>
<tr>
<td>1743</td>
<td>Jarrow</td>
<td>40 in.</td>
<td>1,200</td>
<td>1,200?</td>
<td></td>
</tr>
<tr>
<td>1744</td>
<td>Walbottle</td>
<td>70 in.</td>
<td>1,691.77</td>
<td>1,691.77</td>
<td></td>
</tr>
<tr>
<td>1745</td>
<td>Coalbrookdale</td>
<td>?</td>
<td>854.17</td>
<td>854.17?</td>
<td></td>
</tr>
<tr>
<td>1749</td>
<td>Warmley Brass</td>
<td>14 hp</td>
<td>2,000</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td>1753</td>
<td>North Wood</td>
<td>?</td>
<td>1,000</td>
<td>1,000?</td>
<td></td>
</tr>
<tr>
<td>1754</td>
<td>Saltwellside</td>
<td>32 in.</td>
<td>410.12</td>
<td>410.12</td>
<td></td>
</tr>
<tr>
<td>1754</td>
<td>Coalbrookdale</td>
<td>48 in.</td>
<td>751.32</td>
<td>751.32?</td>
<td></td>
</tr>
<tr>
<td>1755</td>
<td>Tanfield Lea</td>
<td>?</td>
<td>1,200</td>
<td>1,200?</td>
<td></td>
</tr>
<tr>
<td>1758</td>
<td>?</td>
<td>?</td>
<td>846.32</td>
<td>846.32?</td>
<td></td>
</tr>
<tr>
<td>1761</td>
<td>Dawley</td>
<td>60 in.</td>
<td>710.58</td>
<td>710.58?</td>
<td></td>
</tr>
<tr>
<td>1763</td>
<td>Walker</td>
<td>98 hp</td>
<td>“nearly” £5,000</td>
<td>£5,324?</td>
<td>added the estimate for the cost of the engine house</td>
</tr>
<tr>
<td>1764</td>
<td>Bo’ness</td>
<td>?</td>
<td>1,637</td>
<td>1,961?</td>
<td>added the estimate for the cost of the engine house</td>
</tr>
<tr>
<td>Year</td>
<td>Location</td>
<td>HP</td>
<td>Cost Pre-erection</td>
<td>Cost Post-erection</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------------------</td>
<td>----</td>
<td>-------------------</td>
<td>--------------------</td>
<td></td>
</tr>
<tr>
<td>1764</td>
<td>Placket Winster</td>
<td>?</td>
<td>c. 5,000</td>
<td>c. 5,000?</td>
<td></td>
</tr>
<tr>
<td>1767</td>
<td>New River Head</td>
<td>5 hp</td>
<td>800?</td>
<td>800?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pre-erection estimate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1768</td>
<td>Dolcoath, Bullengarden</td>
<td>17 hp</td>
<td>2,200?</td>
<td>2,200?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pre-erection estimate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1770</td>
<td>Griff</td>
<td>60 in.</td>
<td>2,500</td>
<td>2,500?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pre-1740 mean = £1,086</td>
<td>Post-1740 mean = £1,751.38</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Whenever possible, the hp of an engine is stated or, in the absence of such figures, the diameter of the cylinder. However, contrary to the belief of some authors, the two variables do not show a consistent correlation and thus the diameter figures should be treated with caution as an indicator of power. The stated cost refers to the figures found in the secondary literature. Some guesswork was involved on the part of the author as to whether they included ancillary expenses such as the labor cost of erecting the engine, the sinking of shafts, and the erection cost of the engine house. If these were certainly, or most likely, omitted figures they were added to the stated cost based on general estimates or mean values. The labor cost of erecting the engine in the middle of the eighteenth century was £40-60, the mean value of £50 was added. The cost of an engine house prior to 1740 was c. £100 based on the mean of two figures. Such cost increased after 1740, the figures varying depending on how well was made, whether it was simply functional as opposed to paying attention to aesthetic details, and whether outside labor was hired as opposed to employing one’s workers. According to Kanefsky, the range was £200-500 or more but for the purposes of the present calculations £324 was added based on the mean of two observed values. For sources on these particular costs, see Kanefsky, *Diffusion of power technology*, pp. 150-1; Dickinson, *Short history of the steam engine*, pp. 59-61; Raistrick, “The steam engine on Tyneside,” pp. 146, 156-8; Tann, “The steam engine on Tyneside,” p. 55; Allen, “The 1715 and other Newcomen engines,” p. 246.

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Figure 1: Annual premiums of Newcomen engines

Notes: The continuous lines represent engines for which the premiums are known for a number of years. The single marks represent engines for which the premium is known for just one year, in most cases the year of installation, though there is a good chance the premium figures of these engines remained stable for a number of years. In the case of one engine (Woods mine, Flint) the deal struck with Newcomen in 1715 was to entitle him to 1/3 of the profits, implying the absence of a fixed premium, but this engine was not included in the graph in the absence of profit figures.

Note on sources: London prices were derived as a simple arithmetical mean of several values for each year from various sources gathered by Beveridge in the wider London area: Eton college, Westminster school and abbey, Greenwich hospital, Chelsea hospital, Lord Stewart’s department, and Navy victualling; see his *Prices and wages in England*, pp. 146-7, 194-5, 294, 313, 434-6, 577-8, 684. Pithead prices for Engine I are from Nef, *The rise of the British coal industry*, vol. II, pp. 390,394, and for Engine II from Ashton and Sykes, *The coal industry*, p. 252. The four straight lines represent means for a particular range of years. The 1760 Cornish price is from Barton, *The Cornish beam engine*, p. 20 and Kanefsky, *The diffusion of power technology*, p. 172. All prices are in shillings/bushel, converted from different measures used by the various authors. Some of the prices series (e.g., Beveridge, Nef) reflect coals of different qualities and/or are wholesale or contract prices. They were not flexible in the short run though they were bound to reflect price movements in London tied to prices in the northeastern coalfield (where coal mostly came from) beyond the very short run; Flinn, *The history of the British coal industry*, vol. 2, pp. 306.

Note on transportation costs: There are discrepancies in the literature on the cost of overland transportation ranging from the cost of coal doubling every two miles (but quadrupling in the Lancashire coalfield) to doubling every ten miles. In the case of a Glamorgan estate, it was more expensive to transport coal to the dock from various pitheads of an estate than to produce it. According to a general estimate (without reference to specific goods), the cost was not much less than 1s/ton/mile translating to doubling the price of ordinary coal in the early part of the century every six miles. The same discrepancies exist when it comes to water transportation, one estimate claiming it was four times cheaper, another one 20 times. On this issue as well as lists of freight charges for various places and transportation means, see Levine and Wrightson, *The making of an industrial society*, p. 9; Szostak, *The role of transportation*, pp. 117-9; Baines and Fairbairn, *Lancashire and Cheshire*, vol. 2, p. 300; Burstall, *A history of mechanical engineering*, p. 145; Jackman, *The development of transportation*, pp. 717-9; Turnbull, “Canals, coal and regional growth,” pp 541-2.
Figure 3: Annual cost per hp of various energy sources (in £)