The adoption of steam power during the industrial revolution, 1800-1870. An empirical re-assessment

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Abstract: The old consensus view that the Industrial Revolution was premised on the large-scale supply of mechanical power delivered via steam engines has been undermined by econometric work purporting to show that the adoption of steam engines, both sectorally and geographically, was much more limited than previously supposed. This was in part because alternative power sources (water and wind) remained cost-competitive. Using evidence from a newly compiled 'census' of stationary steam-engine installations in Suffolk, this paper makes two key arguments. One, the adoption of inanimate power sources, especially steam, was quantitatively far greater than previously thought. Two, steam engines enabled a far greater concentration of manufacturing activity, along with the agglomeration economies this entailed, than water or wind power. This resurrects the conventional account of the industrial revolution as being premised on the large-scale use of steam-power.

This paper presents preliminary results from a county-wide census of stationary steam-engine installations in Suffolk between 1800 and 1870, the first of its kind for this period in Britain. The first section offers an analytical survey of the current literature and primary source base concerning power supply in the British economy during the nineteenth century. It begins by outlining the traditional view that by providing an inexhaustible supply of mechanical power, steam engines were an indispensable component of the industrial revolution. It then critically appraises cliometric work that has purported to quantify a surprisingly modest contribution steam engines made to productivity and national income before 1860. It argues that this cliometric is conceptually flawed. Steam power could not invariably be replaced by other power sources; there were some critical economic processes that could only be accomplished by using steam. Similarly, whereas water and wind are only available at particular sites – and then power generation must be spatially dispersed – neither condition applies to steam, thereby removing a critical locational constraint on power output and therefore industrial concentration and agglomeration economies. These processes have been largely discounted. It is also empirically flawed – between 1800 and 1907, we have a wholly inadequate picture of power supply in the British economy. Government reports that have been used in the past, the Factory Returns, are internally inconsistent and demonstrably incomplete; they have misled us concerning the extent to which steam engines were used to power British industry.

The second section outlines an initial effort to rectify this shortcoming in the form of a census of stationary steam-engine installations in a particular county, Suffolk, which will be shortly supplemented by similar compilations of water and wind-power installations. Suffolk may appear to be an idiosyncratic choice. It was decidedly not at the forefront of the British industrial revolution; in 1800, it was the largest county (by population) not to have a single steam engine.[1] Briefly, it was chosen because there are extant lists of wind and water mills in the county, the source base for steam engines is unusually good, and it was one of only eight counties that reported a full return to the 1870 Factory Return (thereby enabling a more thorough assessment of whether the Return(s) can be relied upon).

The third section describes results from this census. It shows that power provision from all sources (measured by horsepower, hereafter hp.) was much greater than previously thought and that the greatest upward revision is achieved by steam. For instance, whereas, the 1850 Factory Return reports 17 hp. of steam installed in Suffolk manufactories – equivalent to one medium-

[1] Steam engine count from Kanefsky 1980. County population from Mitchell 1988.

sized engine – the census indicates that there were approximately 120 steam engines operating in Suffolk at this point, producing a total of 960 hp. The implication of these results is that even in a predominantly agricultural county far away from the minefields, manufacturing was increasingly premised on the supply of coal and steam power.

It also describes very preliminary results concerning the location of all types of stationary power installations. While water and wind mills were constrained in the locations they could be situated and in the intensity of power production, in turn obstructing industrial concentration and agglomeration economies, this did not occur with steam engines. In particular, windmills in Suffolk exhibit a uniform spatial distribution across the county, albeit with clustering *near* population centres such as Ipswich and Bury St Edmunds. Watermills exhibit a linear spatial distribution, spaced out over waterways, albeit with limited clustering *near* and *in* population centres. Finally, steam engines exhibit a highly pronounced clustered spatial distribution, centred *in* population centres.

I

Steam-power was conventionally believed to have been indispensable for industrialisation and the development of the factory system. Unlike animate power sources such as human and animal muscle, or other inanimate power sources such as water and wind, power from steam never tired, was not contingent on weather conditions and was essentially inexhaustible. The first historians of the industrial revolution were unanimous on its importance. In 1884, Arnold Toynbee, wrote that the pre-industrial system of domestic manufacture and the social system it underpinned, "was shattered by the power-loom and the steam engine" (p. 148). Sixty years later, T. S. Ashton described the steam engine "as the pivot on which industry swung into the modern age" (p. 58). This account has been persuasively re-stated by Tony Wrigley (2010, 2016) who emphasises the fundamental constraints inherent to any organic economy, wherein virtually all energy inputs are derived from the annual cycle of plant growth, be it firewood to provide heat energy or feed for men and animals to provide mechanical energy. The latter could also be supplemented without drawing on the annual stock of energy generated through photosynthesis by exploiting environmental forces, namely water and wind. While this certainly represented an important increment to the power supply of pre-industrial and industrial Britain, power generation from these sources was strictly limited in both scale and concentration. For instance, by 1700, nearly

every available site for a water mill had been occupied within a five mile radius of Birmingham and no new water mills were erected there after 1760. Water supply problems had to be mitigated by staggering working hours and efforts to run industrial processes with wind power failed (Pelham, 1963). An ultimately immutable limit to the generation of mechanical energy had been reached.

The constraints faced in the generation of heat and mechanical energy could only be overcome with the adoption of inorganic sources of energy – fossil fuels, in particular, coal. By 1600, burning coal was already the primary source of heat energy in a wide variety of industries such as brewing, glassmaking, metal works and brick making, as well as domestic heating. However, "without a parallel breakthrough in the provision of mechanical energy to solve the problem associated with dependence on human or animal muscle to supply motive power in industry and transport, energy problems would have continued to frustrate efforts to raise manpower productivity" (Wrigley 2010, p. 45). This breakthrough was represented by the steam engine, which converted the heat energy produced from burning coal into mechanical energy. The first economically viable engine was developed by Thomas Newcomen in the 1700s (Bottomley 2014, pp. 233-38). A rudimentary design, it produced a simple reciprocal motion with a very poor fuel economy, such that it could be only deployed where fuel was essentially free (coal pitheads) or where the economic value of their work was sufficient to pay for the capital and operating costs (draining tin and copper mines in Cornwall). During the eighteenth and nineteenth-centuries, new steam engine designs were developed yielding improvements on every point of operation such as capital expense, operating expense, fuel economy, form of motion, regularity of action, reliability, ease of maintenance, and so on, meaning that the steam engine could be profitably adopted as a source of mechanical power for an ever-growing plethora of industrial tasks.

As the mechanical energy produced by the steam engine could be generated without drawing on the annual stock of energy generated through photosynthesis, the constraints of the organic economy had finally been broken. The British economy now had access to inexhaustible supplies of mechanical power – an unprecedented achievement and one which enabled the breakthrough to modern economic growth. Wrigley concludes that "the steam engine was arguably the single most important technical advance of the whole industrial revolution period" (2010, p 44).

However, despite the conceptual clarity of this account, it has been contradicted by cliometric work which purports to quantify steam's contribution to economic development. In this respect, the groundbreaking work is Nick von Tunzelmann's *Steam-power and British industrialization to*

1860 (1978). Von Tunzelmann adopted a social savings analysis to measure the direct contribution steam made to the British economy. He estimated that in 1800, if all steam engines had been removed and replaced by the next cheapest power source (water and wind), the total cost to the British economy would have been equivalent to only 0.2 percent of National Income (p. 157).

Tunzelmann speculated that steam's greatest contribution occurred during the nineteenth-century, preventing an upward pressure on energy costs "that would have taken place if resort had had to be made to successively undesirable water sites" (p. 286). Subsequent work by Nick Crafts (2004), applying a similar social savings methodology to the nineteenth-century suggests otherwise. He finds that the social savings attributable to the adoption of steam power *declined* to 0.02 percent of GDP over the period 1800-30, before increasing again to 0.3% 1830-50 and 1.2% 1850-70. Crafts also reports commensurately trivial contributions by steam to Total Factor Productivity growth, peaking at 0.06% p.a. over 1850-70. These results are attributed to the "slow diffusion of steam power" and that "this is in turn explained by its lack of cost effectiveness" relative to other potential power sources (2004a, p. 345).

Using evidence from the census of stationary power installations in Suffolk, this paper presents two counter-points, explaining why these social savings calculations may be misleading. The first is that it is contingent on the assumption of substitutability, i.e., that steam could invariably be replaced with an alternative power source, albeit at a cost. However, we have already seen in the case of early industrial Birmingham that there were limits to the generation of water and wind power that were soon reached and not mutable as a matter of cost.

The second point is that social savings analysis is contingent on the accuracy and completeness of estimates of total steam power adoption. The more modest the power contribution made by steam, the cheaper and easier it would be to replace with alternatives. In the case of von Tunzelmann, he estimated that the combined power output of all steam engines in Britain in 1800 was equivalent to 29,000 horsepower (hp.). This estimate was soon supplanted by John Kanefsky (1979a, p. 277) who compiled a census of all stationary steam engine installations in England during the eighteenth-century (a methodology akin to the one adopted in this paper). On the basis of this census, he estimated that that total hp. of installed stationary steam engines in England in 1800 was *c*.35,000 to *c*.40,000 hp. (1979a, p.277). Further refinements indicate that that the total is nearer the latter figure rather than the former (Kanefsky, 2017), although

in any event, an upward revision from 29,000 hp. to 40,000 hp. is not in itself sufficient to radically alter Tunzelmann's thesis.

The point is more pressing in the case of whose work for the nineteenth-century which relies on the accuracy of the Factory Returns as revised by Kanefsky (1979b), figures that have been widely cited in the literature (for example, McCloskey 2015, pp. 58-9; Ó Gráda 2016, p. 230). The Returns were produced on an intermittent basis between 1838 and 1870 by the Factory Inspectorate. Their primary purpose was to report on labour usage in manufacturing (especially of women and children), although they also reported power usage in those establishments they inspected, specifically recording whether the power source used was steam and/or water and a power rating.

However, the Factory Returns had two significant shortcomings. Firstly, the Returns only covered those manufacturing establishments where the hours of work were regulated by Act of Parliament. In the first Returns, this essentially meant textile manufactories only. By the time of the final 1870 Factory Return the sectoral coverage was much greater and this has been the Return most frequently used. Specifically, the 1870 Factory Return covered:

i) All manufacturing establishments that employed women and children [30 & 31 Vict c. 146 (1867)]

ii) All manufacturing establishments that employed more than 50 men for 100 days a year [30 & 31 Vict c. 146 (1867)]

iii) All textile mills [3 & 4 William IV, c. 103 (1833) and 24 & 25 Vict c. 117 (1861)], bleaching and dyeing works [23 & 24 Vict. c. 78 (1860); 27 & 28 Vict c. 98 (1864)], earthenware manufacture (excluding bricks and tiles), lucifer match-making, percussion cap and cartridge trades, paper-staining and fustian cutting, metal trades (excluding works with less than six men employed in casting and founding metals), rubber- and gutta-percha-making, glassmaking, papermaking, tobacco, letterpress printing, bookbinding [30 & 31 Vict c. 103 (1867)]

The corollary of this was that those manufacturing establishments that were not specifically included in these categories – i.e., do not appear in the list of named trades and had less than 50 employees who were all adult men – were excluded from the Factory Return. Given the distribution of firm size, and the preponderance of males in manufacturing, this means the

Factory Returns excluded up to half of all British manufacturing by employment (Kanefsky 1979b, p. 363), and the scale of omission varied by sector and location. For instance, while the 1870 Factory Return (conducted in November and December of that year) recorded 94 men working in ship and boat building in Suffolk (and using 16 hp. of steam),[2] the 1871 census (conducted 2nd April) records 418 men working in ship-building.

Secondly, it also meant that the Return omits steam engines in economic sectors that were not deemed to constitute manufacturing, specifically mining, milling and public utilities. In the case of Suffolk, the first sector is irrelevant, but the second two certainly are not.

Kanefsky (1979b) was aware of these omissions in the 1870 Factory Return and sought to compensate by compiling estimates of power usage for these omitted sectors. In particular, in addition to the 1,032,560 hp. reported in the Return, Kanefksy estimated that around 167,440 hp. had been omitted which ought to have been included. The census results discussed below will indicate that this was a gross under-estimate. In conjunction with estimates for mining (600,000 hp, of which coal mining contributed 500,000 hp.), grain-mills (90,000 hp.), water and gas works (60,000 hp.) and 'other' (30,000 hp.), Kanefsky arrived at a total estimate of 1,980,000 hp. installed in Britain (p. 373).

However, two additional points indicate that Kanefsky may have understated the scale of omission. In particular, the Return is riven with inconsistencies which are probably unresolvable. For instance, Suffolk was one of only eight counties in England that reportedly made a full return, including all eligible factories and workshops. This recorded a total of 1824 hp. of inanimate power installed in Suffolk manufactories, of which steam contributed 1792 hp. "Extracted" from the county return for Suffolk is the return for Ipswich, recording 505 hp. of steam and 7 hp. of water. However, the return for Suffolk and return for Ipswich are impossible to reconcile. For instance, whereas there were reported to be 15 metal foundries in Suffolk, using 47 hp. of steam and employing 167 (all men), in Ipswich there were 4 foundries, but using 234 hp. of steam and employing 1523 (again, all men). As Ipswich was a subset of Suffolk, it is unclear how it was able to employ more men and more steam horsepower.

Finally, and perhaps most intractably, there were manufacturing establishments which met the criteria for inclusion in the Return, but which were missed and this occurred even in a county

[2] Which given that these 94 men were distributed across four different employers, meaning that at least three came under the 50 man threshold provided in 30 & 31 Vict c. 146 (1867), it is uncertain why they would have been included in the Return.

which claimed a full return such as Suffolk. We can take the example of silk which had been included in the Returns since the original Factory Act of 1833. As such, one might surmise that the Factory Inspectorate would have been familiar with the relevant establishments and include them in the Returns. Moreover, silk mills tended to be large employers (*c.* 100 to 200 employees) and these were predominantly females. As such, given the remit of the Factory Acts, they ought to have been of especial interest. However, while the Factory Return recorded three silk manufacturing establishments in the county, employing a total of 630 hands (of which 554 were women), the 1871 census records 1708 employed in silk manufacture (1159 of which were women). This discrepancy cannot be attributed to an (undocumented) boom in the Suffolk silk industry in the first three months of 1871. The Post Office Directory of 1869 lists ten silk manufacturing and silk throwing establishments in the county (pp. 1071-72), whereas nine are listed in the 1875 Directory, all with the same owners as in 1869 (p. 1065). Instead, these establishments were omitted by a Factory Inspectorate that was over-worked, under-funded, and riven by infighting (Bartrip, 1982); given that the Inspectorate was failing to prevent widespread flouting of Parliamentary safety legislation – its primary function and a critical actuating factor for the nascent labour movement – it is unrealistic to expect it to have accurately and comprehensively recorded power inputs in industry, a secondary function.

II

Given that the 1870 Factory Return is:

i) Internally inconsistent
ii) Omits steam engines that did not enter its legislative remit
iii) Omits steam engines that did enter its legislative remit

It does not form the basis by which we might make broad conjectures about the British economy and especially its adoption of steam power. Instead of relying on the Factory Returns, the rest of this paper will present results from a census of all stationary steam-power installations in Suffolk over the period 1800-1870. In some respects, Suffolk may appear an idiosyncratic choice for this project. It was certainly a laggard in terms of the adoption of steam power; not a single steam engine was erected there during the eighteenth-century (Kanefsky and Robey, 1980, p. 176). It

was also entirely bereft of mining activity and remained a primarily agricultural county long into the nineteenth century.[3] But of course, neither was Suffolk an *exclusively* agricultural county. It was home to some manufacturers of national and international repute, especially in agricultural implement manufacturing, namely Garrett & Sons and Ransome & Co. (the latter being the first manufacturers to market portable steam engines in 1841; Collins, 1999, p. 211) and in food processing (the country's first sugar beet factory was opened in Lavenham in 1869). Neither was it exclusively rural in character. Ipswich in particular, located near the mouth of the River Orwell and with open access to the North Sea, urbanised rapidly, its population growing to 43,000 by 1871, an eightfold increase from 1781.[4]

Suffolk also recommended itself for three more reasons:

1) It was one of only eight counties to report a full return for the 1870 Factory Return (p. 154). If it is shown that the 1870 Return significantly understated the number and size of power installations for Suffolk (which it did), then it is more likely that the Return did so for the rest of the country and that the understatement for counties reporting an incomplete return were proportionately greater than for Suffolk.
2) The source base for Suffolk is especially rich. In particular, both Ransome's and Garrett's manufactured stationary steam engines, and production registers for both survive from 1850 and 1860 onwards respectively. Similarly, steam engines along with other manufacturing plant tended to be insured (Pearson, 2004, p. 367), and policy registers for the largest insurer in the county (the Sun Alliance Assurance Company) survives from 1819 onwards. These have been used to compile the census in conjunction with a variety of other sources – especially local newspapers, trade directories, mapping and the work of Ronald H. Clark on steam engineering in East Anglia.[5]
3) Finally, it became clear at an early stage of the project that there would be a significant upward revision in the utilisation of steam engines compared with what was recorded in the Factory returns. This made the manual compilation of the census more time-consuming than originally planned, but still achievable. In an industrial county such as

[3] In 1817, 56% of adult males were employed in agriculture (compared with a national figure of 37.4%) and in 1851, this figure remained at 47.7% (having fallen to 27.5% nationwide). Kiebek 2016, pp. 152 & 646

[4] For Ipswich's population in 1781 (5,373), see Smith and Satchell, 2018, p. 261. For population in 1871, see B. R. Mitchell, 1988, p. 26.

[5] Clark, 1935-37, 1950.

Lancashire or Yorkshire (which also reported a full return in 1870, recording 187,336 hp. of steam, over 100 times that of Suffolk, pp. 161-62), it would have been prohibitively difficult, involving the collation of details of tens of thousands of steam engines, rather than hundreds.

The compilation of the steam engine component of the census was modelled on prior efforts by John Kanefsky for the eighteenth-century (1979b, 2017). For every engine, the census records when steam engine(s) were first installed at a particular site or the first recorded instance of a steam engine being used at a site. As such, for every engine there is a precise or proximate start date of operation. The census also records the location for every single engine. When a location is not available, the engine has not been included. This has led to the omission of some potential engines from the census, but by making this a requirement for inclusion, it minimises double counting and helps with recording when an operator replaced their engine(s).[6]

The census also records (where available), the engine's horsepower output, its engine type (specifically whether it worked at high pressure), its industrial purpose, its owner/operator, and when the engine ceased working. Unfortunately, this information is not always recorded – indeed, there are very few engines where everything is available – and in order to prepare estimates for total installed hp. in Suffolk we need to at least estimate or infer when the engine was likely to have ceased working and what its horsepower output was.

In the case of an engine's 'end-date', this information was available for only 123 engines in the database. Thankfully, and as one would expect given that they represented large-scale, fixed capital investments, stationary steam engines tended to remain in situ and to be worked for a period of decades - the average working life for these engines was approximately 60 years, although this admittedly conceals a great deal of variability. At one end, some engines operated for over a century, such as the steam engine which ran a flour mill at Barningham from 1826

[6] Which was a concern for a minority of sites. For instance, when Ransome & Co. first moved their manufactory to Orwell Quay in Ipswich in 1840, it was driven by a 20 hp. engine, manufactured by Boulton & Watt. In 1851 it was supplemented by a 12 hp. engine, manufactured by themselves, and which drove a trip hammer. In this instance, because the engine had a specified purpose, it has been assumed that it was used to supplement the power provided by the older 20hp. engine. In 1867, however, it was reported that the manufactory was now driven by a 60 hp. engine. As no mention is made of the two earlier engines, it has been assumed that they were scrapped or sold on although there is no record to confirm this. Finally, in 1870, Ransome & Co. installed four new 50 hp. engines. Again, in the absence of a record stating the contrary, it has been assumed that the older 60 hp. engine had been sold.

until c.1930 (Clark, 1936, p. 390). Others operated for only a few years, their working lives cut short by bankruptcy of the operator and failure to re-sell the engine, or by accident. In the (frequent) absence of other documentary evidence, the working life of a steam engine has been assumed to be equivalent to the 25th percentile of recorded engine longevity (20 years).[7] As such, it is expected that the resultant estimates for horsepower in Suffolk will be under-estimates.

We also need horsepower figures, but this is only recorded for two-thirds of the engines in the database. Again, this problem can be mitigated by estimating the horsepower rating according to how the engine was used (an industrial sector and/or industrial purpose is available for virtually all of the engines in the census). In some instances, this can be fairly precise. For instance, in corn milling, the industry standard was that 8 horsepower was required to drive each pair of stones (Tann, 1989. p. 410) and accordingly, missing horsepower ratings for steam engines at corn mills have been estimated according to the number of pairs of stones they were being used to drive. Where this information is missing, it has been assumed that the engine drove only one pair, i.e., the rating is estimated at 8hp.

Finally, contemporaries usually measured horsepower in relation to the size of the cylinder (termed nominal horsepower). This was accurate enough for engines worked at low pressures and where there was one single-acting cylinder (i.e., the steam worked once, on one side of the piston), but as working pressures increased and cylinders were increasingly compounded (i.e., the steam would be exhausted from one cylinder into another to perform more work) and/or double acting (the steam acted alternately on both sides of the cylinder) so nominal horsepower increasingly understated actual power output. Unfortunately, these new engineering practices spread more quickly than the more accurate indicated horsepower measurement did and the differential between the two measurements of horsepower was both significant and inconsistent across different types of engine. In the 1850s, William Rankine estimated indicated hp. as being anywhere from one and a half times that of nominal hp. (a multiple applicable to older style engines) to five times the nominal hp. (applicable to the latest high-pressure compound engines; von Tunzelmann, 1978, p. 27). This disparity can be illustrated by reference to the steam engine

[7] To give an example of how this was applied in practice. In 1850, there were two 28hp. Easton & Amos steam engines erected for the Lowestoft Gas and Water Company and remained in operation until 1923 (Bowden, et al., p.64). We can safely include them in any estimate for 1870. However, without an equivalent end date for the 5hp. Ransome & Co. engine, erected for the same client at the same date, we cannot be certain whether to include that in our estimates for total installed hp. in Suffolk for 1870. In this instance, given the longevity of water pumping engines in the database, it has been included for the 1870 estimate.

erected at a silk mill in Glemsford in 1849. This was a higher pressure steam engine built by J. T. Beale of Greenwich and operating at 24 pounds per square inch. It was most likely the solitary engine recorded in Suffolk by the 1850 Factory Return, and it was rated at 17 nominal hp (nhp.).[8] The engine remained operational into the period when indicated horsepower became the preferred measure (indeed, the engine worked into the 1950s), where it was rated at 45 indicated hp (ihp.). (Watkins, 2001, p. 115).

This variance in horsepower measures would not be a problem if we had both nominal hp. and indicated hp. available for every engine, although this is not usually the case. To compound matters, when we do have a horsepower measure, it seldom specifies whether the measure was indicated or nominal and the confusion between the two measures is most pressing for the period 1850-80 (von Tunzelmann, 1986, p. 76). For the census prepared here, it has been assumed that the horsepower recorded was nominal, unless this would be incompatible with other recorded technical information relating to the engine (or, of course, unless the horsepower is specified as being indicated). This is mainly because nominal hp. remained the 'industry standard' beyond 1870. Instructive is a newspaper report on the installation of a new engine at a fertiliser plant a Bramford in 1872. The engine was rated at 80 nominal horsepower (probably the largest in Suffolk at this time). The report continues to describe the other (pre-exisiting) engines at the plant, all in nominal horsepower, and amounting to 147 nhp. The firm (Packard & Co.) delpoyed another two engines at their Ipswich plant, amounting to 70 nhp. At the end of the report, it notes that this total of 217 nhp. yielded an "actual power … upwards of 600 horsepower".[9]

It was also only in 1870 that figures in the Factory Returns "definitely referred to indicated horsepower" (Kanefsky 1979b, p. 363), although even then inspectors were reportedly confusing the two measures (von Tunzelmann, 1986, p. 76). In order to prepare horsepower figures which

[8] Factory Return 1850, p. 8. The Factory Return does not provide the number of engines installed in a county only their total (nominal) hp. output. Consequently, the 17hp. reported in Suffolk silk mills might have been for more than one engine and this is plausibly the case here. There is a record of a steam engine working at a silk mill before 1841, most likely located at Hadleigh which was rated at 9 (nominal) hp. (Page, 1911, p. 273). If the engine remained in operation until 1850 (which given that the mill employed 350 in 1854 it has been assumed that it did; Kelly, 1854, p. 363) *and* was included in the 1850 Factory Return, would imply that the engine at Glemsford was rated at only 8 (nominal) hp. This, however, would imply that its indicated hp. (45) was more than 5 and a half times this nominal hp. figure, unlikely given the evidence in the main text and that the working pressure (24 p.s.i.) was not especially high by the standards of the time.

[9] The Suffolk Chronicle; or Weekly General Advertiser & County Express. - Saturday 02 March 1872, p. 9

are comparable with the 1870 Factory Return, it is necessary to render the predominantly nominal horsepower figures available into indicated horsepower. Until 1849, when there were few high pressure steam engines in Suffolk, the multiplier adopted is 1.5 (i.e., Rankine's lower bound). For instance, the steam engine erected at Edward Greene's Bury St Edmunds brewery in 1836 (and which remained in operation until c.1926. Clark, 1936, p. 391) was rated at 8 nominal horsepower. In the absence of other technical information, this engine has been rated as working at 12 indicated horsepower for the purposes of comparison with the 1870 Factory Return figures. For engines erected from 1850, when high pressure engines were more frequently adopted in Suffolk, the multiplier adopted is 2.5. The intended combined effect of these two assumptions (as well as omitting engines without a location) is that the eventual estimate will be as accurate as possible, albeit with a bias towards underestimating installed horsepower rather than overestimating it. There will be instances, especially as working pressures increased in the 1850s and 60s, where a multiplier of more than 2.5 should be adopted in rendering the nominal hp. figure into indicated hp.

It also needs to be emphasised that the census is composed of stationary steam engines only, not all steam engines. It therefore omits locomotive engines. In practical terms, it would not make sense to count an engine which ranges across county boundaries in a county level census: they could only be incorporated into a national census.

Of greatest concern, and the least remediable of the various limitations highlighted so far, is the omission of portable engines. As the name implies, portable engines were small(er) engines that could be easily moved around a work site to provide power as and when required; they could also be hired short-term from contractors. They were commonly used in agriculture where they were first adopted on a large scale in the 1840s to drive threshing machines and quickly adopted to a wider range of heavy farm work (engine boilers could even be used to steaming roots). By the 1860s, it was estimated that there was enough work to justify an engine for every farm of at least 50 acres (Bourne, 1861, p. 371), a criterion which would have applied to the vast majority of farms in the country (Shaw-Taylor, 2012). As with stationary engines, we have vanishingly little quantitative evidence concerning the power contribution portable engines made to the British economy. If we focus on agriculture, the 'best-guess' work is by Collins (1999) who suggests this

contribution must have been modest, totalling only 1000 hp. in 1840 and 175,000 hp. in 1880.[10] Collins recognised that his figures were "largely guesswork" and subsequent evidence indicates that he significantly underestimated how many portable steam engines were manufactured for the agricultural market. For instance, he estimates that there were around 700 steam powered ploughing sets working in 1880 (p. 212). However, subsequent work by McCutchan indicates there were at least 1477 steam ploughing sets manufactured for domestic customers in Britain in the fifteen years to 1879 - which given the length of their working lives and the re-sale market that existed, virtually all of these would have remained in operation in 1880.[11] Conceptually, portable engines are indistinct from the stationary steam engines recorded in the census. They delivered power to agriculture and manufacturing in the same way as stationary engines did, but with the inconsequential difference that they could be moved around a site.

Neither were portable engines used solely in agriculture – they were also commonly used in construction and for ancillary power at water and wind mills. The (admittedly impressionistic) evidence is that portable engines made a significant power contribution to the Suffolk economy, conceivably greater than that from stationary steam engines. For instance, it was estimated that between 1855-59, the combined horsepower of the portable engines manufactured by the five leading East Anglian manufacturers (including Ransome's and Garrett's) equated to 40,000 hp. (Collins 1999, p. 211). Of course, a lot of these engines were built for export from the region, but neither does this figure include smaller Suffolk firms manufacturing portable engines over this period, such as Turners (who employed 140 men and boys in 1861),[12] W. P. Wilkins (131 in 1861),[13] Whitmore & Binyon (60 in 1855)[14] William Bear (27 in 1861),[15] William Syrett (11 in 1861)[16] and Woods & Co. and whom presumably supplied more local markets.

Despite their potential importance, portable engines have been excluded from the census prepared here for two main reasons. The first concerns the accuracy of the census prepared here.

[10] Collins considered these figures to be modest although it means that steam contributed virtually the whole increment of power provision in British agriculture seen over this period, which increased from 687,600 hp. in 1840 to 862,700 hp. in 1880 (1999, pp. 211-12)

[11] McCutchan 2013, p. 323. On the re-sale market, see chapter 7.

[12] 1861 census. Turners manufactured its first engine in 1842, and its first portable engine in 1849 (Clark, 1950, p. 72).

[13] 1861 census.

[14] Clark, 1950, p. 77.

[15] 1861 census.

[16] 1861 census.

Without a specific location to distinguish between engines, the likelihood of 'double' counting increases. Portable engines were also re-sold more often – reliably tracking regular changes of ownership is simply impossible without surviving records. Secondly, portable engines were not included in the Factory Returns (indeed, it is telling that the inspectors made no attempt to include them). With these caveats and limitations in mind, we can now examine what the Suffolk census of (stationary) steam engines tells us about their frequency of use.

III

Figure 1, the growth of steam-power in Suffolk 1800-70

Figure 1 shows the growth in the number of operating steam-engines in Suffolk from 1800-70, as well as their combined indicated horsepower. At the beginning of the period, it shows that there were very few engines installed in Suffolk: there were zero installations in the 1800s, 2 in the 1810s and 11 in the 1820s (with two engines removed). After this, however, there was rapid growth throughout the period (with a brief, unexplained pause at the beginning of the 1860s) so that by 1850 there was 1120 ihp. installed in Suffolk, and 4795.5 ihp. in 1870.

These figures are significantly greater than figures produced in contemporary Factory Returns. If we focus on the 1850 Factory Return, this records 17 (nominal) horsepower in the county, likely from one engine (which yielded 45 indicated horsepower).[17] By contrast, the census, indicates that at the beginning of 1850 there were approximately 75 stationary steam-engines working in Suffolk, yielding a combined 1120 ihp. In this instance, the discrepancy can be largely attributed to the sectoral coverage of the early Returns, which were limited to textile factories. The census includes only one additional engine that ought to have been included in the Factory Return (working at a silk mill in Hadleigh, rated at 9 nhp. or 13. ihp.). The remaining 73 engines worked in sectors that were not covered by the Factory Return. A large minority of these engines (24, yielding 348.5 ihp.) worked at flour mills[18] while the remainder were spread across a wide variety of activities. Most important by ihp. were land drainage (150 ihp. produced by just two engines),

[17] The engine is described in George Watkins, 2003, p.115

[18] Complicating matters, some of these engines provided power for multiple functions besides milling. At Haughley, for instance, two engines driving a mill were also used to power a sash cord factory (and they remained operational until 1930, by which point they only drove the mill). In these instances, the engine has been categorised according to its primary function.

manufacture of machinery (122 ihp., 7 engines), paper-making (116 ihp., 4 engines), manufacture of construction materials (76 ihp., 8 engines) and brewing (47 ihp., 6 engines).

Table 1, steam-power in Suffolk, 1870

The same point applies to the 1870 Factory Return, despite its much broader sectoral coverage. Table 1 provides more information on this point, showing the sectoral distribution of indicated steam-power working in Suffolk in 1870. The first column provides the sectoral categorisation, which for the sake of comparability is the same as the one used in the 1870 Factory Return. In the bottom quarter of the table are those sectors which were not included in the Return. The second column provides the sectoral distribution of indicated hp. in Suffolk, as recorded by the 1870 Return. The third column provides the sectoral distribution of ihp., as recorded in the steam engine census.

The first point to make is that although the 1870 Return had a significantly larger sectoral coverage than its 1850 counterpart (essentially all manufacturing), there were still significant omissions as it did not include flour milling (accounting for 1120 ihp., 81 engines, in the census), agriculture (284.5 ihp., 20 engines), municipal waterworks (241 ihp., 13 engines), land drainage (155 ihp., 3 engines) or port drainage (17 ihp., 2 engines).

Secondly, in those sectors that were covered by the Factory Return, there were significant omissions (a point presaged by the discussion in Section I). For instance, in the case of silk, the census indicates there was the equivalent of 113 ihp. of steam used in silk, rather than the 17 ihp. reported in the Return; given the preceding discussion on silk employment in the 1870 census, this was to be expected. In total, whereas the Factory Return reports a total of 1792 ihp. in Suffolk, the census reports a total of 2931.5 ihp. These engines were distributed among a wide range of activities; especially important sectors were manufacturing of machines (898.5 ihp., 28 engines) and chemicals (759.5 ihp., 20 engines of which artificial manures contributed 612.5 ihp., 16 engines). At the other end of economic significance, was the steam engine installed at George Sparke's croquet factory in Bury St. Edmunds (10 ihp.) and H. Hutchinson's hair saloon that advertised "hair-brushing by steam-power … sensation beautiful, accident impossible".[19]

Thirdly, there are some minor sectors where steam-power installations have been missed by the census but recorded in the Factory Returns. For instance, the latter records that there were 10ihp.

[19] Framlingham Weekly News - Saturday 15 September 1866, p.1

installed in a cotton manufactory in Suffolk, but there is no record of such an engine in the census. In those sectors where the Factory Return records more installed ihp. than the census, and there is no ambiguity over which sector to assign an engine, then the additional ihp. has been added to the information in the census to produce a 'best-guess' for total installed horsepower in Suffolk in 1870, as represented in the fourth column of Table 1. Those sectors where the Factory Return has been used are highlighted by a dark border. This produces a final total of 3007 ihp. in those sectors covered by the Factory Return, and 4835 ihp. in total.

Finally, it ought to be observed that steam engines were concentrated in Ipswich. In the 1871 census, the population of Suffolk was enumerated at 347,210, of which 42,839 lived in Ipswich (12.3%). By contrast, there were 1,585 of ihp. installed in Ipswich, comprising 33.3% of the census total. No other settlement approached this concentration of steam-power. For instance, Suffolk's next three largest towns by population (Lowestoft, 5% of population, Bury St Edmunds, 4.3%, Stowmarket, 2.6%), had comparable proportions of Suffolk's ihp. (respectively: 4%, 4.5%, 1.8%). In time a more detailed analysis on the location of steam power (as well as water and wind-power installations) will be possible, in combination with the population data for Registrar's sub-districts in the 1871 census. For the moment, it can be observed that the distribution of steam-engines (and it ought to be emphasised that if it were possible to incorporate portable steam engines the picture would certainly be modified) stands in contrast to the distribution of water-power sites which were linearly distributed along the rivers Stour, Gipping, Deben and Lark (although given that Suffolk is a relatively flat county, it was poorly endowed with potential water-mill sites, Laxton, 1986, p. 70), and windmill sites, which were distributed fairly uniformly throughout the county (see the map in Flint, 1979, p. 150). The concentration of mechanical power in Ipswich could not have been achieved with water and/or wind power alone.

IV

The census confirms that the Factory Returns offer an inadequate basis from which to estimate total installed power in Britain during the nineteenth-century. This was partly because of its limited sectoral coverage; before 1870 it says virtually nothing about the economy outside of textiles. The suggestion that large parts of the economy "were virtually untouched by steam"

(Crafts, 2004, p. 342) is an artifact of this limited sectoral distribution.[20] Moreover, it should be borne in mind that Suffolk was one of only eight counties in 1870 that reported a full return of factories and workshops. All else being equal, the omission of steam engines would have been proportionately least prevalent there. This also makes it difficult to extrapolate from these county-level results and to prepare new national estimates. Nonetheless, for information, Table 2 presents new national estimates of installed horsepower in Britain for 1870. To deal with the two minor areas of discrepancy first, Kanefsky's estimates for grain-mills and waterworks and gasworks have been altered so that the amount of ihp. for both sectors in Suffolk was proportional to its population. This is disputable. Waterworks and gasworks in particular were concentrated in urban areas. A more sophisticated means of estimation would be to render these figures proportional to urban population, in which case these estimates would be revised upwards, significantly. Concerning the major area of discrepancy, 'estimated as missing', this new figure is based on the assumption that the extent of inadvertent omission seen in Suffolk was identical throughout the country. This assumption is tenuous, especially without other county censuses of the nature outlined here. However, it is contended that this is likely to be an underestimate of how much was missed on a national scale, given that Suffolk was one of the few counties to claim a full return. In sum, the new figure for total installed ihp. in Britain in 1870 (2,478,560 ihp.) is considered a lower-bound estimate.

Table 2, new national estimates

It is also worth emphasising that the steam engine census itself is still in the process of completion, it is anticipated that these result will be revised upwards in time. The contribution of steam to British economic development was both quantitatively (and arguably, qualitatively) greater than prior work has suggested.

But in another sense, the results from the census are confirmatory of the argument that the 'classical' period of the industrial revolution, *c*.1760-1830 did not see the widespread adoption of the steam engine, but that it occurred later. The first recorded engine in Suffolk was installed at a tobacconist in 1810, hardly an essential prerequisite for the breakthrough to modern economic growth. By 1830, there were still only 11 steam engines installed in Suffolk, producing

[20] Compounded by the fact that the Returns (as does the census) omits portable engines which were frequently used in agriculture.

a combined 89 nhp. (or an estimated 145 ihp). At this point, the economic impact of the steam engine outside the industrial 'pioneers' would still have been very limited. Instead, it appears that steam engines were adopted most vigorously in the period immediately after the industrial revolution. As such, they can be seen as playing a sustentative role, rather a causative one.

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Figure 1, the growth of steam-power in Suffolk 1800-70

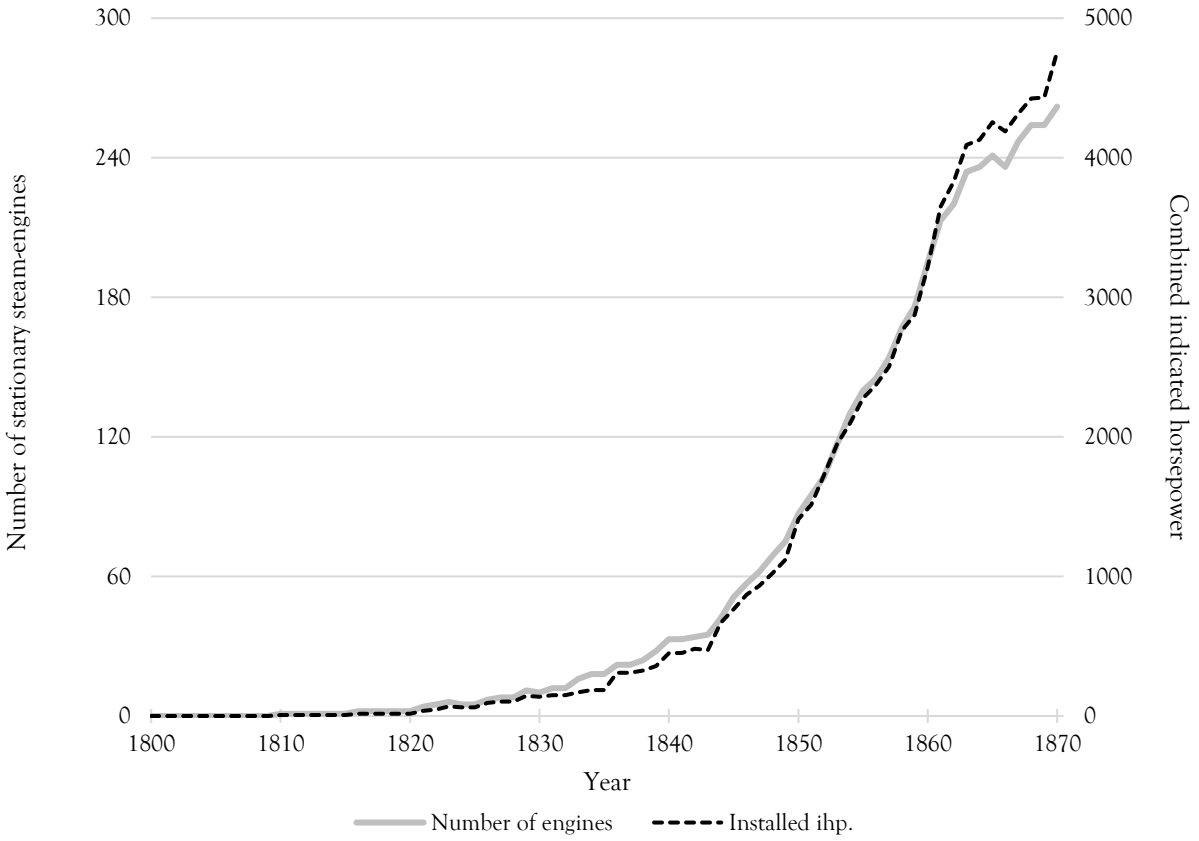

Table 1, steam-power in Suffolk, 1870

Sector	1870 Factory Return (ihp.)	Steam Engine census (ihp.)	Combined
Textiles			
Cotton	10		10
Flax	90	84	84
Silk	17	113	113
Bleaching & Dyes	14	8	8
Handloom weaving	9		9
Boot and shoe making	3		3
Metal Manufactures			
Foundries	47	26.5	26.5
Manufacture of machinery	445	898.5	898.5
Misc. articles of metal	88		
Leather			
Tanners and curriers	21	56.5	56.5
Misc. articles	4		
Chemical works			
Oil and oil cake	113	83	83
Artificial manures	309	612.5	612.5
Misc. chemical works	40	64	64
Manufactures connected with food			
Bakehouses, biscuits, confectionary	6	8	8
Breweries	72	177.5	177.5
Sugar refineries	50	177.5	177.5
Misc.	136	54	54
Manufactures connected with building			
Builders	100	319	319
Carpenters, joiners	51	42.5	42.5
Paper manufacturing			
Papermaking	64	55	55
Misc. manufactures			
Ropemaking	10	11	11
Bricks and tiles	10		
Shipbuilding	16	37	37
Letterpress printing	55	7.5	55
Coachbuilding		25.5	25.5
Tobacco and cigars	6		6
Misc.	6	71	71
Sub-total	1792	2931.5	3007
Milling	N/A	1120	1120
Agriculture	N/A	284.5	284.5
Municipal			
Waterworks	N/A	241	241
Land drainage	N/A	155	155
Port maintenance	N/A	17	17
Services	N/A	8	8
Domestic	N/A	2.5	2.5
Total	1792	4759.5	4835

Table 2, new estimates for total installed horsepower in Britain

Category	Kanefsky (1979b) estimate	New estimates
Factory Return figures	1,032,560	1,032,560
Estimated as missing	167,440	700,900
Coal-mines	500,000	500,000
Other mines	100,000	100,000
Waterworks and Gasworks	60,000	31,000
Grain-mills	90,000	84,100
Others	30,000	30,000
Total	1,980,000	2,478,560