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ANALYSIS

Footprints in the cotton fields: The Industrial Revolution as time–space appropriation and environmental load displacement

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A R T I C L E I N F O

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A B S T R A C T

This paper offers a method for quantifying the global exchange of (natural) space and (labor) time underlying the economic success of the British textile industry in the late 18th and early 19th century. Using historical statistics on inputs of land and labor embodied in cotton and wool production, respectively, estimates are made of the amount of British land and labor that were 'saved' by displacing fibre production to North America. By comparing inputs of land and labor in the textile exports of England with those in some commodities imported from its colonial periphery, and juxtaposing these data with exchange rates, estimates are also made of unequal exchange. Using such methods, it is possible to bring together the Marxist concern with unequal exchanges of labor time, on one hand, with the more recent concern with ecological footprints, on the other.

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1. Introduction: theoretical background

For many years, I have been pursuing an understanding of industrial capitalism as more of a global zero sum game than a national cornucopia (Hornborg, 1992, 1998, 2001). In this work, I have been using the Second Law of Thermodynamics (the so-called Entropy Law) as a point of departure, arguing that the buildup and maintenance of industrial infrastructure necessarily requires a continuous net input of free or available energy (technically referred to as *exergy* and closely related to the concept of *negative entropy*; cf. Schrödinger, 1944; Georgescu-Roegen, 1971). Purely analytically, it is possible to conclude that industrial infrastructure–whether a factory, an industrial city, or the global 'technomass'–must maintain an unequal exchange of free energy with its hinterland in order to survive and grow. It is also possible to analytically conclude that, under market conditions, this unequal exchange will be orchestrated by the terms of trade between industrial and extractive sectors of the national and global economy, i.e., the rate at which industrial manufactures are exchanged for

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fuels and raw materials. The concept of 'unequal exchange' in this sense is objectively specified rather than normative, and can be applied to several other possible metrics of trade, including material flows (Fischer-Kowalski, 1998). Georgescu-Roegen argued that not only energy but materials, too, suffer irreversible dissipation in economic processes, and that the concept of entropy applied to such processes should be understood in terms of the generation of increasing energetic and material 'disorder' as a by-product of the local creation of cultural and technological 'order' or structure. Prigogine's concept of 'dissipative structures' has been applied to the asymmetric flows of entropy and 'negative entropy' between different sectors of global society (Hornborg, 1992; Clark, 1997).

Combined with a world-systems perspective (Frank, 1966; Wallerstein, 1974–1989), such an understanding of industrial capitalism would provide a theoretical framework for interpreting the socio-ecological logic by which environmental problems tend to be unequally distributed between different sectors of the global population (Martinez-Alier, 2002). What Clark (1997, pp. 8–10) calls the 'entropic costs' of industrial metropoles should be clarified as comprising two dimensions: (1) the appropriation of 'negative entropy' (accessible, high-quality energy and materials) from elsewhere and (2) the displacement of entropy (energetic and material disorder) elsewhere. In the present world order, the first could be exemplified by the struggle of industrial powers to control crucial sources of fossil fuels (Klare, 2001), the second by controversies over various kinds of 'ecological distribution conflicts' (Martinez-Alier, 2002, pp. 258–260), recently perhaps best illustrated by the 'disproportionate' use of sinks for carbon dioxide–and 'disproportionate' share of the burden of its climatic consequences–emitted in the unequally distributed consumption of these fuels (ibid., pp. 213–233).

An important justification for this kind of perspective is that it can help explain widening gaps in technological development and economic growth between different sectors of national and international economies, as the continuous net input of natural resources into industrial sectors–in yielding further technological development–will improve their efficiency and economies of scale so as to increase the asymmetries in exchange in a self-reinforcing manner (Bunker, 1985). Seen in this light, the accumulation of capital is recursively connected with unequal exchange. Another important consideration is the extent to which technological development in industrial sectors, while giving the illusory appearance of liberation from material constraints (as expressed in neoclassical economic notions of substitutability of factors of production[1] and recently also in the notion of 'dematerialization'), in fact represents a displacement of environmental loads to extractive sectors (Muradian and Martinez-Alier, 2001). Richard Wilkinson (1973) has shown that the imperative of substituting for dwindling resources was an important incentive for early British industrialization, prompting exploitation not only of, e.g., new, subterranean energy resources within Britain itself, but increasingly also of natural resources on other continents (cf. Pomeranz, 2000). The reliance of the industrialized North on natural resources from its global periphery has become increasingly obvious in recent decades (cf. Klare, 2001).

2. Questions and methods

Owing largely to its foundation in thermodynamics, this analytical work has been difficult to translate into quantitative, empirical research. Actually traded quantities of exergy and negative entropy, as embodied in commodities, are inherently difficult to estimate. It should nevertheless be possible to detect such structural asymmetries in trade by converting statistics on commodity flows into quantities of *embodied land and labor*. Both these factors of production can be sources of exergy for the accumulation of capital, but have the advantage of being quantifiable, e.g., in annual hectare yields and in hours of human labor. Whether or not the traded commodities are actual physical sources of exergy for capital (e.g., fuels, labor, food), it should be illuminating to calculate net transfers of embodied labor and land in relation to exchange values. The simpler a system of trade relations is, the easier it should be to make such calculations. I have thus chosen to investigate, from this perspective, certain aspects of British overseas trade in the mid-19th century. The years around 1850 are particularly interesting in that it is possible to obtain a wide range of fairly reliable data for these years, during what is a comparatively early and expansive period in British industrialization. These data have the advantage not only of being fairly simple and easy to synthesize, in comparison with modern trade, but also of illuminating the very origins of industrial capitalism. It is not unreasonable to propose, as an hypothesis requiring further methodological refinement, that global patterns of asymmetric resource exchange established in the early phases of industrialization have continued to reinforce themselves through the continuing technological superiority (i.e., the accumulation of capital) that they engendered in northwestern Europe. Recent statistics supporting such an interpretation include estimates of so-called ecological footprints of different nations (Wackernagel and Rees, 1996).[2]

In approaching the statistics on 19th century British trade, I initially posed the following questions:

1. How many annual hectare yields and hours of human labor were embodied in the British imports of raw cotton, wheat, and other commodities?
2. How many annual hectare yields and hours of human labor were embodied in the British production of textiles, and at which rates were they exchanged for those embodied in imports?
3. How many domestic (British) annual hectare yields and hours of human labor were liberated for other purposes

[1] In material terms, land, labor, and capital are not mutually convertible into one another. Land can nourish labor, and land and labor can yield capital, but capital can create neither land nor labor.

[2] The genealogy of the notion of 'ecological footprints' goes back to Borgström's (1965) concept of 'ghost acreages' (cf. also Catton, 1980). Pomeranz's (2000, pp. 313–315) calculation of the 'ghost acreages' of some British imports (sugar, timber, cotton) in the late 18th and early 19th century was brought to my attention after this text had been written.

by the displacement of land and labor inputs to other nations?

The answers to these questions are not as readily available in the standard literature on British economic history as I had anticipated, which suggests that such questions have been far from prominent, to say the least, in the voluminous research on the Industrial Revolution. In fact, my impression is that the conventional economic discourse on industrialization conspires to keep such questions–and their answers–out of view.

3. Results

The figures that I have finally arrived at, often through convoluted deductions from statistics assembled to illuminate very different issues, are presented in Fig. 1[3–30]. For each calculation, I have provided a footnote explaining how the figures were calculated. Some of these figures may seem fraught with uncertainty, but in this first approximation I consider the questions posed and methodology used more important than the minute details of mathematical accuracy. I would very much welcome suggestions on how to improve accuracy in these estimates, whether by consulting other sources or applying other methods of calculation. The results arrived at, however, are probably not too far off the mark to

[3] McDonald and McWhiney (1980, p. 1098) provide the figure 0.8 hand-hours to produce a pound of cotton on an Alabama plantation in 1850. 1 ton = 2204 lb = 2755 h.

[4] The average weight of a fleece of wool (presumably an average for ewes and lambs, i.e. sheep under 1 year old) in 1688–1695 was estimated at 4 lb (Deane, 1957, p. 209) or 1.81 kg, while a more conservative estimate in 1741 suggests 3.5 lb (ibid., p. 211) or 1.58 kg. Modern averages from British breeds and two shearings annually suggest a wool harvest of 4.2 kg/ewe (Sjödin, 1974, p. 384). One way of estimating actual wool output is to use data on numbers of sheep and total wool clip from a year (1867) when both figures are available. Mitchell (1962, pp. 82, 84, 190) gives 28,919,000 sheep (ewes and lambs) in Great Britain and 4,836,000 in Ireland in 1867 and a domestic wool clip in the United Kingdom of 163,000,000 lb = 73,936,800 kg. A total of 33,755,000 sheep in the United Kingdom thus yielded 4.8 lb = 2.1 kg wool/sheep. The total clip divided by 20,483,000 ewes gives 3.6 kg wool/ewe and 278 ewes/ton of wool produced. Labor input per ewe has been estimated at 4 h/ewe (Sjödin, 1974, p. 400) or 1112 h for animal care and 864 h for fodder production and fencing. The latter figure builds on Collins' (1969, p. 460) estimate of mowing rate with scythe (albeit for corn rather than hay) at around 1 acre per worker-day, plus an estimated additional day per acre for drying and harvesting = 2 days/acre = approximately 5 worker-days/ha, and a requirement of 1.5 kg hay/ewe for 120 days × 278 ewes = 50 tons of hay. With worker-days estimated at 10 h and average hay yields at 1.4 tons/acre = 3.45 tons/ha in 1885 (Mitchell, 1962, p. 90), this means about 724 h in fodder production per ton wool produced. With an approximated additional 2 weeks (120 h) spent annually on mending fences, this gives 864 h and a total of 1976 h for 278 ewes. Estimating that wool sales accounted for roughly 50% of income from a flock, this figure has been reduced by half to 988 h. This latter estimate is based on commodity prices for 1854–1860 provided by Schlote (1952, p. 116), according to which wool was valued at £7 per 100 lb = £0.154 per kg or £0.55 per ewe and year. The value of meat production per ewe and year has been estimated at around £0.7, based on a yield of 20 kg × £0.035. This estimate is based on a comparison of meat prices as given by Schlote (ibid.): bacon = £2.6/cwt, ham = £3.2/cwt, salt beef = £2/cwt, salt pork = £2.4/cwt. Mutton has been estimated at £1.8/cwt. One hundredweight (cwt) = 50.8 kg.

[5] Mitchell (1962, p. 100) lists the principal sources and quantities (in thousands of hundredweights) of wheat imports to the United Kingdom in 1850: Russia = 2,766,000 cwt, Prussia = 3,609,000 cwt, Canada = 38,000 cwt, USA = 436,000 cwt. If 1 cwt = 50.8 kg, the metric equivalents are: Russia = 140,512 tons, Prussia = 183,337 tons, Canada = 1930 tons, USA = 22,148 tons. Clark (1993, p. 228) estimates the output per worker in bushels of wheat in Germany in 1850 as 113 bushels and in Russia in 1870 as 80 bushels. Using the average conversion factor from bushels to hundredweights of wheat (1.81 bushel = 1 cwt) in the period 1910–1939 (Mitchell, 1962, pp. 90, 102), I have counted 1 bushel of wheat as equivalent to 28 kg. This gives an output per worker in Germany of 3164 kg and in Russia of 2240 kg. Assuming 3000 h/work-year, this would mean 949 h/ton of wheat in Germany and 1339 h/ton in Russia. Considering that British wheat imports from Prussia and Russia are of similar proportions, whereas imports from North America are still marginal in 1850, I have entered the average of Prussian and Russian conditions = 1144 h/ton.

[6] According to McDonald and McWhiney (1980, p. 1096), the average yield per acre for the American South as a whole in 1850 was about 180 lb of ginned lint. 180 lb/acre = 201.67 kg/ha = 4.95 ha/ton.

[7] Modern agricultural handbooks estimate 6.2 ewes/ha pasture and hay (Sjödin, 1974, p. 384). I have reduced this figure to 5 ewes/ha in the mid-19th century. One way to calculate the number of hectares required per ton of wool would be to simply divide 278 ewes by 5, which gives 55.6 ha. If we divide the total number of ewes in the United Kingdom in 1867 (20,483,000) by 5, we get 4,096,600 as an approximate number of hectares (pasture and hay) allocated to sheep. As the total clip in 1867 was 73,936,800 kg, the amount of wool produced per hectare can then be estimated at 18 kg, which again gives 55.6 ha/ton of wool. Estimating the value of wool as about 50% of total output of sheep in monetary terms, the number of hectares should be reduced by half to 27.7.

[8] Clark (1993, p. 228) estimates the output of wheat per acre in Germany in 1850 at 7.1 bushels and in Russia in 1870 at 3.0 bushels. Converted to kilograms and hectares, this means 2.03 ha/ton in Germany and 4.83 ha/ton in Russia. As wheat imports from these two countries dominate the statistics and are of similar proportions in 1850, I have entered their average = 3.43 ha/ton.

[9] Mitchell (1962, p. 180) provides the following figures for imports of raw cotton from USA to the United Kingdom: 1815 = 54,000,000 lb = 24,494 tons; 1850 = 493,000,000 lb = 223,623 tons.

[10] Mitchell (1962, p. 190) estimates the average domestic wool clip of the United Kingdom in 1800–1819 at 100,000,000 lb = 45,360 tons and in 1850–1854 at 135,000,000 lb = 61,236 tons.

[11] Clark (1993, p. 228) estimates the output of wheat in Britain in 1851 at 12.6 bushels/acre. Converted to kilograms and hectares, this gives 1.14 ha/ton.

[12] Schumpeter (1960, p. 59) for 1800 estimates 55,586,341 lb = 25,213 tons. Mitchell (1962, p. 180) gives 1815 = 101,000,000 lb = 45,813 tons; 1850 = 664,000,000 lb = 254,921 tons. Schlote (1952, p. 21) gives 396,131 tons for 1854.

[13] Mitchell (1962, p. 191) provides the following figures for raw wool imports to Great Britain in 1800: 8,418,000 lb = 3818 tons. The remaining figures (ibid., p. 192) are for the United Kingdom, with re-exports subtracted: 1820 = 9,700,000 lb = 4399 tons; 1830 = 31,600,000 lb = 14,333 tons; 1850 = 59,900,000 lb = 27,170 tons. Schlote (1952, p. 21) gives 47,376 tons in 1854.

lack significance for a rethinking of industrialization (capital accumulation) in terms of the appropriation of land and labor from elsewhere.

4. Discussion

From these data, a number of observations can be drawn about the global economies of (natural) space and (human) time that were (and probably continue to be) recursively linked with 'technological development' or capital accumulation. To begin with, we can now provide provisional answers to the three questions raised at the outset.

1. The 1850 import of 223,623 tons of raw cotton from the American South represented over 616 million hours of (mostly slave) labor and the annual yield of over 1.1 million hectares of agricultural land. If projected onto total imports (254,921 tons), the flow of raw cotton to England in 1850 embodied over 702 million hours of labor and 1.26 million hectare yields. If British figures on wool production are generalized to apply also to imported raw wool, wool imports in 1850 (27,170 tons) represented over 26.8 million hours of labor and 0.75 million hectares. In the same year, imports of wheat represented over 985 million hours and the productivity of 2.95 million hectares abroad. Imports of these three commodities alone–cotton, wool, and wheat–in 1850 represented 1714 million hours of labor and a year's harvest from almost 5 million hectares of land.

[14] Mitchell (1962, p. 98) gives net imports of wheat and wheat meal and flour (with exports and re-exports deducted) to the United Kingdom in 1850 as 19,965,000 cwt = 1,014,222 tons. However, the sum of principal imports in the same source (ibid., p. 100) amounts to no more than 6,849,000 cwt = 347,929 tons, which leads me to suspect that the former figure in fact applies to thousands of quarters (19,965,000 quarters = 253,555 tons). Schlote (1952, p. 61) gives the annual average wheat imports of the United Kingdom in 1849–1854 as 861,790 tons. In view of the contradictory nature of Mitchell's figures, I have used Schlote's.

[15] Farnie (1979, p. 199) estimates output of yarn and cloth, respectively, per hand for the following periods: 1819–1821 = 968 lb and 322.5 lb; 1829–1831 = 1546 lb and 520.7 lb; 1849–1851 = 3079 lb and 2437.8 lb. I have summed up the total output and divided by the total number of hands employed in yarn and cloth production, yielding the following figures per employed: 1819–1821 = 1290 lb = 0.58 ton; 1829–1831 = 2066 lb = 0.93 ton; 1849–1851 = 5516 lb = 2.5 tons. I have estimated the number of annual working hours per employed at 3000, based on six 10-h days/week and 50 weeks/year. This would give the following number of hours per ton of cotton manufactures produced: 1819–1821 = 5172, 1829–1831 = 3225, 1849–1851 = 1200.

[16] Mitchell (1962, p. 199) gives the number of employed in the wool industry in the United Kingdom in 1850 as 154,000. Assuming fifty 60-h weeks, the total number of annual working-hours can be approximated as 462,000,000. When this figure is divided by the number of tons of woolen manufactures produced (66,303), the hours of labor required for production of 1 ton of woolen manufactures can be calculated as 6968.

[17] Clark (1993, p. 228) estimates the output of wheat per worker in Britain in 1851 as 272 bushels = 7616 kg. Assuming 3000 h of work per year, this means 394 h/ton.

[18] According to Blaug (1961, p. 377), quantity of cotton yarn produced can be derived by deducting loss of weight in spinning from consumption of raw cotton, reckoned in the years 1828–1861 at 11%. 1 ton × 89% = 890 kg.

[19] Deane (1957, p. 211) quotes an assessment from 1741 that roughly one-fourth of the weight of raw wool is lost in washing and processing.

[20] Schlote (1952, p. 61) estimates the annual average wheat harvest in Great Britain in 1849–1854 at 3,620,000 tons.

[21] I have used the figure for tons of raw cotton imported (254,921 tons) reduced by 11% (cf. Blaug, 1961, p. 377) to estimate yarn production at 226,879 tons. I have then deducted the export of yarn, estimated at 24.9% or 56,946 tons, to approximate the production of cloth at 170,050 tons.

[22] According to Farnie (1979, p. 7), the average annual volume of exports of cotton yarn and cloth in 1839–1841 was 254,100,000 lb = 115,213 tons. The mean annual rate of increase in exports 1840–1872 is given as 3.9% (ibid.), which in 1850 would mean around 168,910 tons. By deducting the proportion of yarn (56,946 tons), I have arrived at the figure 111,964 tons of cotton cloth exported 1850.

[23] For 1741, Deane (1957, p. 211) gives 262,175 packs of 240 lb or 62,922,000 lb = 28,541 tons. For 1799 and 1805, I have calculated 75% of raw wool consumed in England and Wales, including imports. Deane (ibid., p. 220) gives the following figures for wool consumed (including imports): 1799 = 98,000,000 lb = 44,452 tons × 75% = 33,399 tons; 1805 = 102,000,000 lb = 46,267 tons × 75% = 34,700 tons. For 1850, I have added raw wool produced (61,235 tons) and imported (27,170 tons) and multiplied the total (88,405) by 75%, yielding 66,303 tons.

[24] Thompson (1968, p. 75) gives the average annual imports of guano to Britain in 1851–1853 as 165,350 tons.

[25] Mitchell (1962, p. 291) gives the value of raw cotton imported to Great Britain in 1850 as £21,532,000. Divided by the number of tons imported the same year (254,921), this would mean a price of £84.46/ton. Schlote (1952, p. 21) gives the price of raw cotton in 1854 as £50.94/ton.

[26] Mitchell (1962, p. 291) gives the value of imported wool in 1850 as £1,953,000. Divided by the number of tons imported in the same year (27,170), this would mean £71.88/ton. Schlote (1952, p. 21) gives the price of imported wool in 1854 as £137.18/ton and (ibid., p. 116) the average price of wool in 1854–1860 as £7 per 100 lb = £154/ton.

[27] Thompson (1968, p. 76) gives the average annual value of imported guano in 1851–1853 as £2,628,000. Divided by the number of tons imported (165,350), this gives an exchange value of £15.89/ton.

[28] Drawing on Farnie's (1979, p. 10) figures for average annual value of exports of cotton manufactures (£18,733,000 in 1814–1816) and mean annual rate of increase (2.9% between 1819–1821 and 1859–1861), I have calculated the total value of cotton exports in 1840 as £37,202,000 and in 1850 as £49,513,000. By dividing these figures with the number of tons of cotton manufactures exported (115,213 tons in 1840 and 168,910 tons in 1850), I have estimated the exchange value of 1 ton of cotton manufactures exported at £322 in 1840 and £293 in 1850.

[29] For 1805, Deane (1957, p. 219) estimates a total of £18,500,000 for the final sales value of woolen manufactures in England and Wales. Divided by the number of tons produced (34,699), this gives an exchange value of £533/ton. Deane (ibid., pp. 218–219) suggests an over-all multiplier of 2.5 to estimate the value added to raw wool in the woolen and worsted industries of the early 19th century. Applied to Schlote's (1952, p. 21) estimate of the price of imported wool in 1854 (£137/ton), it would give the figure £342/ton of woolen manufactures. Using his figure for the price of domestic wool (£0.154/kg) in 1854–1860 (ibid., p. 116), however, we get £385/ton.

[30] Schlote (1952, p. 61) estimates the average home price of wheat in the United Kingdom in 1849–1854 as 48.2 shillings per quarter. Converting 1 quarter = 12.7 kg, this would mean £222/ton.

Cotton	Years		**Wool**	Years		**Wheat**	Years	
Hours of labor required for production of 1 ton of raw cotton in American South[3]	**1850**	**2755**	Hours of labor required for production of 1 ton of raw wool in England[4]	**1850**	**988**	Hours of labor required for production of 1 ton of wheat imported to England[5]	**1850**	**1144**
Hectares of land required for production of 1 ton of raw cotton in American South[6]	**1850**	**4.95**	Hectares of land required for production of 1 ton of raw wool in England[7]	1867	**27.7**	Hectares of land required for production of 1 ton of wheat imported to England[8]	**1850**	**3.43**
Tons of raw cotton imported from American South to England[9]	1815 **1850**	24,494 **223,623**	Tons of raw wool produced in England[10]	1800–1819 **1850–**1854	45,360 **61,236**	Hectares of land required for production of 1 ton of wheat in England[11]	**1851**	**1.14**
Tons of raw cotton imported to England (total)[12]	1800 1815 **1850** 1854	25,213 45,813 **254,921** 396,131	Tons of raw wool imported to England[13]	1800 1820 1830 **1850** 1854	3818 4399 14,333 **27,170** 47,376	Tons of wheat imported to England[14]	**1850**	**861,790**
Hours of labor required for production of 1 ton of cotton manufactures in England[15]	1819–1821 1829–1831 **1849–1851**	5172 3225 **1200**	Hours of labor required for production of 1 ton of woollen manufactures in England[16]	**1850**	**6968**	Hours of labor required for production of 1 ton of wheat in England[17]	**1851**	**394**
Quantity of cotton yarn produced in England from 1 ton of raw cotton[18]	1828–1861	**890 kg**	Quantity of woollen manufactures produced from 1 ton of wool[19]	1741	**750 kg**	Tons of wheat harvested in Gt. Britain[20]	**1849–**1854	**3,620,000**
Tons of cotton manufactures produced in[21] (and exported from[22]) England	**1850** yarn cloth 1840 **1850** yarn cloth	 **226,879** 170,050 (115,213) (**168,910**) (–56,946 = 111,964)	Tons of woollen manufactures produced in England[23]	1741 1799 1805 **1850**	28,541 33,339 34,700 **66,303**	Tons of guano imported to England[24]	**1851–**1853	**165,350**
Exchange value of 1 ton of raw cotton[25]	**1850** 1854	**£84.46** £50.94	Exchange value of one ton of raw wool[26]	**1850** 1854 1854–1860	**£71.88** £137.18 £154	Exchange value of one ton of guano[27]	**1851–**1853	**£15.89**
Exchange value of 1 ton of cotton manufactures exported from England[28]	1840 **1850**	£322 **£293**	Exchange value of 1 ton of woollen manufactures exported[29]	1805 **1854** 1854–1860	£533 **£342** £385	Exchange value of 1 ton of wheat imported to England[30]	**1849–**1854	**£222**

Fig. 1 – Estimates of inputs of land and labor in some key commodities in British overseas trade around 1850. Measures are in hectares, hours, metric tons, and British currency ca. 1850.

2. The 1850 production of cotton manufactures in Britain (226,879 tons) represented around 272 million hours of British labor. The production of woolen manufactures in the same year (66,303 tons) reflects a total of over 549 million hours of British labor[31] and the productivity of 2.44 million British hectares of pasture and hay.[32] In order to be able to examine relative exchange rates of embodied labor and land in exports and imports, I have calculated the purchasing power of £1000 around 1850 in terms of raw cotton, cotton manufactures, raw wool,

[31] I have added the number of working-hours required for production of 1 ton of woolen manufactures (6968) and the number of hours required for production of 1.33 ton of raw wool (1314), in order to reckon with 25% loss of weight in processing.

[32] I have estimated the number of hectares required for production of 133 ton of raw wool (368), in order to reckon with 25% loss of weight in processing.

Commodity	Volume for £1000	Embodied labor	Embodied land
Raw cotton	11.84 tons	32,619 h	58.6 ha
Cotton manufactures	3.41 tons	4092 domestic h[33] [14,613 h total]	1 domestic ha[34] [18.9 ha total]
Raw wool	13.91 tons	13,743 h	385.3 ha
Woollen manufactures	2.92 tons	24,183 h[35]	107.5 ha[36]
Wheat (domestic)	4.5 tons[37]	1773 h	5.1 ha
Wheat (imported)	4.5 tons	5148 h	15.4 ha
Guano	62.93 tons		

Fig. 2 – Estimates of the purchasing power of £1000 around 1850 in terms of quantities of some key commodities and their embodied inputs of labor and land.

woolen manufactures, domestic wheat, imported wheat, and guano (Fig. 2[33–37]).

These figures would permit a great number of observations on the asymmetric exchanges of embodied labor and land that contributed to the accumulation of industrial capital in nineteenth century Britain. Let us suggest a couple of examples:

(a) In exchanging, on the world market, £1000 worth of cotton manufactures for £1000 worth of raw cotton, Britain in 1850 gained 123% in terms of embodied labor and 210% in terms of embodied land. If only domestic use of time and space are considered, however, the gain in hours is almost 800% and in hectares about 60 times the space utilized. These gains, representing technological superiority (i.e., capital) accumulated over several decades, further increased as profits were invested in continued technological development. (The efficiency of labor 30 years earlier had been 5172 h per produced ton of cotton manufactures, which means a 331% increase in real output per hour between 1820 and 1850.)[38]

(b) In exchanging £1000 worth of woolen manufactures for £1000 worth of imported raw wool, Britain in 1850 lost 76% in terms of embodied labor but gained 258% in terms of embodied land.

3. Let us also exemplify how these figures can be used to illuminate the role of industrial export production as a means of environmental load displacement:

(a) To export £1000 worth of cotton manufactures from Britain implied much less of a drain on domestic resources than to export £1000 worth of woolens, viz. only 17% of the embodied labor and virtually none of the embodied land. To import the raw cotton to generate £1000 of income from textile production rather than rely on domestic wool meant saving 20,091 British work-hours[39] at the expense of 10,521 work-hours in America and saving 107.5 British hectares at the expense of 18.9 ha in America.
(b) To import £1000 worth of wheat from Russia and Prussia rather than growing it at home meant saving 1773 British work-hours at the expense of 5148 foreign work-hours and 5.1 British hectares at the expense of 15.4 ha in Russia and Prussia. This does not take into account, however, the time–space demands of the domestic export industry whose profits paid for wheat imports. In terms of the ratio of embodied land and labor to exchange value, neither cotton nor woolen manufactures could compete with wheat, but here we see how the exigencies of demography inevitably constrain economic rationality. The growing population of Britain had first and foremost to be fed, and British wheat production around 1850 (3,620,000 tons × 1.14 ha) demanded 4,126,800 ha of the best agricultural land in the country. To spend £94 (1.12 × £84.46) on raw material and 4092 work-hours in the cotton industry in order to be able to import 4.5 tons of wheat (the equivalent of only 1773 work-hours but crucially also of 5.1 ha prime farmland in Britain)–or

[33] $(3.41 \times 1200) + (3.41 \times 2755 \times 1.12)$. I have multiplied the hours embodied in raw cotton by 1.12 in order to reckon with 11% loss of weight in processing. If only domestic expenditures of time are reckoned with, the figure is 4092 h.

[34] $3.41 \times 4.95 \times 1.12$. If only domestic use of space is reckoned with, the figure should probably be less than 1 ha.

[35] $(2.92 \times 6968) + (2.92 \times 988 \times 1.33)$. I have multiplied the hours embodied in raw wool by 1.33 in order to reckon with 25% loss of weight in processing.

[36] $2.92 \times 27.7 \times 1.33$.

[37] I am assuming that prices of domestic and imported wheat are similar.

[38] The reason why no attempt is made here to include capital in these calculations is that capital is itself understood as embodied labor and land, i.e. the product of past relations of unequal exchange of time and space. As such, any attempt to justify the rates of exchange discussed here by reference to British capital would merely serve to mystify the unequal process of accumulation that the calculations are intended to reveal.

[39] $24{,}183 - (3.41 \times 1200)$.

63 tons of guano–is economically rational under conditions of land scarcity, as was very obviously the case in early nineteenth century Britain. In exchanging cotton manufactures for foreign wheat, rather than grow the wheat at home, Britain lost over 56% in hours of labor but gained almost the entire land area used to cultivate it.

(c) Most centrally, from the perspective sketched in the introduction to this paper, the displacement of demands on land represented by the appropriation of the productivity of 1.1 million hectares of cotton fields in North America, which in terms of revenue ultimately generated £66,475,547, meant the 'liberation' of the over 6 million hectares[40] in Britain that would have been required to generate the equivalent amount of revenue from woolen manufactures. This land area exceeds by almost 50% the total area of British wheat cultivation (4,126,800 ha) in 1850. If we add to this the imports of wool from overseas, an additional 0.75 million British hectares were set free, e.g., to fuel the labor force.

(d) This kind of analysis certainly deserves to be expanded to cover the other major commodities that provided the global framework for British industrialization. This applies, for instance, to those periods when Britain relied on imports of iron from Scandinavia, the production of which required huge volumes of Scandinavian labor and charcoal. Other important commodities embodying significant amounts of labor and land in the periphery in the mid-19th century include timber, sugar, tea, coffee, wine, silk, flax, vegetable oils, dyes, hemp, and tobacco.

5. Conclusion

In conclusion, I would like to refer back to the 'zero sum game' perspective on industrial capitalism that I briefly presented at the outset. It is obvious that only a few of Britain's imports in the mid-19th century actually in themselves contributed exergy or 'negative entropy' to its emerging industrial infrastructure. In terms of energetics, as Britain was then self-sufficient in (and a net exporter of) fossil fuels, the prime candidates were wheat and sugar, which provided food energy for a significant proportion of the labor force (Pomeranz, 2000, pp. 313–314). In terms of materials, the prime candidates were iron and timber. The thermodynamic perspective that I have advocated, however, has little regard for national boundaries, as long as imports of exergy and exports of entropy have not developed into national interests, as in the current struggles over oil (Klare, 2001) or deliberations about emission permits (Martinez-Alier, 2002). Unequal exchange can be a very local affair. As the world's first industrial districts were emerging in eighteenth century Yorkshire and Lancashire, the most significant 'periphery' may have been no further off than the nearest coal-fields, where the severity of working conditions and environmental degradation undoubtedly surpassed that of the Alabama cotton plantations (Hobsbawm, 1968, pp. 252–256, 281, diagram 5b). During the course of the nineteenth century, this periphery expanded to truly global proportions, but the logic remains the same to this day. Although deeply submerged beneath statistics catering to the concerns of neoclassical economics, this logic remains founded on the imperative–for all kinds of complex systems or structures–to maintain a net input of 'negative entropy'. This can be achieved through a variety of social strategies complementing and succeeding each other over the course of history. From this perspective, we have seen how the import of raw materials for the textile industry, although not in itself representing an energy source, served to make room for the energy provisionment of the British labor force. Factory workers and coal miners alike ran on wheat.

The British textile industry for two centuries played a central role in generating revenue to maintain an expanding technological infrastructure, originally as a means of coping with severe shortage of land (Wilkinson, 1973). As this expansion continued and spread to continental neighbors and former colonies, mainstream discourse has conspired to ignore the unequal exchange of (labor) time and (natural) space on which technological development has been founded from the start. The complex webs of the modern world economy no doubt make analyses such as these extremely difficult, but we can remain quite certain that capital, however much it tries, will never be able to 'delink' itself from labor and land. The rationale of machine technology is to (locally) save or liberate time and space, but (crucially) at the expense of time and space consumed elsewhere in the social system. The general hypothesis offered here is that to save time and space by the application of increasingly 'efficient' technologies may often tend to imply that someone else in the world system is *losing* time or space in the process. The process of 'globalization' that was in full swing in the early days of industrial capitalism then as now relied on what Harvey (e.g., 1996) has called 'time–space compression'. The point that I have wanted to make in this paper is that such analyses of the very essence of technological development need to be founded on a concrete, empirical understanding of what I would call 'time–space *appropriation*'.

[40] To generate an additional £66,475,547 from sales of woolen manufactures in 1850 would have required an additional output of 194,372 tons (×£342), representing 217,696 tons of raw wool demanding 6,030,196 ha of land.

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