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The ecological footprint of early-modern commodities
Coefficients of land use per unit of product

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Abstract: Land availability and overseas trade have been central topics in economic history. The current paper contributes to this literature by setting the empirical foundations necessary for the calculation of the direct ecological footprints of more than eighty traded commodities throughout the 19th and early 20th century. The main focus is placed upon products which were heavily traded by and within the British Empire during this period. Various secondary sources have been reviewed and are critically discussed while the methodological steps that have been followed for the calculation of an acreage conversion factor for each product are analyzed in detail. The data presented here can be useful for researchers examining the importance of ghost acreages and ecological footprint historically but also the role of natural resources and land use in a long term perspective.

JEL: N01, N50, N70, Q16, Q17

Keywords: ecological footprint, trade, 19th century, ghost acres, Britain, land productivity

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1 Introduction

Land availability and land productivity have been central topics of debate in economic and environmental history. The current study contributes in these debated by providing a broad and solid basis of empirical evidence of actual historical land requirements for the production of various products in various geographical areas In particular, the aim of this paper is to provide quantitative information on the historical land footprint of more than eighty major traded products throughout the late eighteenth, nineteenth and early twentieth centuries. It has been developed in accordance with research that has examined the interplay between trade and natural resources in various contexts and for this reason its scope might be limited.

The main focus in the paper is placed upon products which were heavily traded by and within the British Empire during the aforementioned centuries. In particular the vast majority of the products discussed here reflect imports to the United Kingdom. This is not to say that land productivities of other countries or regions are not reflected in the empirical evidence presented here. Rather the contrary, since conversion factors from regions all over the world are emphasized.

The various sources that have been used are critically discussed and the methodological steps that have been followed are analyzed in detail under each product. It should be stressed that this work does not aim at answering any analytical or explanatory research question. Instead it is exploratory in character trying to establish coefficients on the amount of land that would have been required for these products' production. The main intension is to build a dataset of coefficients that would benefit further research mainly in the fields of environmental history, economic history, agricultural history and history of technological progress. The data can for instance be used by researchers examining the importance of ghost acreages and ecological footprint historically but also the role of natural resources and land use in a long term perspective.

In the construction of this paper, strong emphasis is given on aspects of reliability and validity. The primary intention has been that the reader is able to identify the particular sources that have been used for the construction of the data and that the coefficients built can be reproducible. For this reason when necessary, the methodological choices that are made under each product are systematically discussed while the sources that have been used for the construction of acreage conversion factors are also consistently reported. The wealth of different sources that have been used in this study makes a very detailed source-critical discussion, if not impossible, at least a very exhaustive task. The fact that for many products more than one source has been identified and used means that a very detailed source-critical discussion should actually focus on more than 100 different sources. This does not mean that this paper is not taking a critical stance at the sources used at all. Instead, a detailed source critical discussion follows later in this paper and is applied for the most important sources i.e. the ones used most frequently.

The rest of the paper is divided in five sections. Section two is a methodology section where the general methodology that has been followed is described. Sections three and four take up a critical discussion on the sources and the representativeness of the data. Section five constitutes the largest section and the core of the paper where all the commodities under study and their land-coefficients are discussed. Finally, the last section provides some general conclusions.

Note that this is a working paper and thus the database may be continuously updated. Interested researchers are kindly requested to contact the author to get information on any updated versions.

2 Methodology

2.1 Data identification

The methodological steps that have been used for the construction of acreage conversions factors for each product may differ depending on the type of product, data availability and time period. For this reason, product-specific choices are discussed in more detail under each product rather than in this section. Instead, here, the general methodological strategy which delineates the whole paper is presented along with methodological steps which apply for all products.

To begin with, in order to convert the various traded commodities into their equivalent amount of land embodied in them, various sources have been identified. A first thing that should be stressed is that most sources were identified through web search, using the "*Google*" and "*Google Scholar*" search engines. The vast amount of information needed for such a project would make any other targeted search via for instance library catalogues very time consuming.

In order to account for secondary research published in scientific journals which may have already calculated the bearing of land for different products, a first search strategy was employed. This search was confined to the product categories of grain and flour; other food, drink and spices; and the raw materials included in this paper since for these there is a direct association with land. For each product in these categories, the search term used was; *"product name" + "yield" + "per" + "acre" + "19th century"*. The first one hundred search results were reviewed under each product.

Additionally, in order to account for publications mainly pertaining to the 19th century, a second search strategy was followed which encompassed all product categories. For that, the simple "*Google*" search was employed. A search term such as *"product name"+"per"+"acre"+"country name"* has most commonly been used. Additionally, the search results have in most cases been confined by limiting the search into only a *"Book search"* and also by adjusting for a specific time period in the 19th century or early 20th century. Naturally, the search results were numerous but in the vast majority of cases, the application of filters rendered only the results listed among the first as relevant. The ones selected were identified by the short description provided in Google's search engine before accessing the source. It should be noted that in order for a source to be used, it should have been accessible either online or in a printed form. For this purpose, other online libraries such as the "Internet Archive", "HathiTrust" and "The Making of the Modern World" were extensively use. Another thing to be noted is that the main aim has been that the sources are easily accessible for the reader and thus when possible, the electronic links of the sources are also included in the text so that the reader is re-directed directly to them. Additionally, in all cases, the title and year of the publication are reported along with the specific volume (when applicable) and page from which the information was obtained.

In the vast majority of cases, information has been provided from statistical descriptions found in secondary 19th century sources, scientific journals and magazines or secondary literature and previous research. Anecdotal type of evidence has in general been disregarded. Nevertheless, when information was scarce or no data was available such evidence has been considered, in most cases cross checking through more than one other source for their validity.

2.2 Acreage conversion factors

One thing that should be stressed is that in this paper, only direct land inputs are considered under each product when estimating its acreage conversion factor. This is in contrast with modern ecological footprint methodologies such as these that have been developed by Wackernagel and Rees (1996) where other indirect inputs such as food for workers and land occupied by buildings are also considered. Of course, it is acknowledged that the choice made here constitutes a simplification since for instance in the case of relatively more labor intensive products, the relative importance of land would be downplayed. Nevertheless, it is also a question of where one draws the boundaries in an economic system and of course what is its focal point.

The exclusion of these inputs in this paper is mainly driven by three factors which are listed here in order of importance. The first is simply data availability and time constraints. It would be almost impossible to find such information as the amount of labor per product, per year and per regions for all traded products in the 19th century (especially the earlier part). Secondly, it is a matter of methodological choice on where to place the system's boundaries. The boundary question is actually an intriguing one since one could equally have objections such as what is considered as food for workers and what not? How much of the food for workers should actually be attributed to the production of a particular commodity? Should people or energy not used in the production but rather the transportation process be included in the calculations? For this study, the boundary is drawn at the direct land inputs disregarding any indirect ones that could as well be used. The third factor is rather case specific in the sense that it concerns the motivations behind the construction of this paper. Most of the data here has been constructed in conjunction with ongoing research projects that analyze the importance of overseas land availability for the occurrence of particular historical trade activities. For this reason, direct land requirements were mainly in focus. In particular, these ongoing projects have looked upon the relative role of core and periphery in providing natural resources and people (slaves) through trade and aim at identifying the ecological motives and consequences of these activities in respect with industrialization.

Although direct land requirements have been the main focus, this does not mean that for most products the calculation of its coefficient was a simple task. Relatively simpler cases were agricultural products such as grains, where the yield of for instance wheat per acre is the main coefficient required. However, for more "complicated" products such as wool, flax, hemp, sugar, beer, eggs, hides, various oils and others, more steps needed to be considered. This mainly implied looking backwards at various stages of the production process of the traded product in order to identify modifications that would result in losses/gains from its original (raw material) weight and could thus affect the coefficient constructed. For instance, between hemp and flax fibers and raw hemp and flax, there is a weight loss of a factor of eight and five respectively. Other cases where the demand on land was not a straightforward question were mainly different animal products since one can get multiple products form one animal. For instance, the estimation of the ecological footprint for trades in bacon, ham, lard, tallow and others would again require a first estimate of yield per animal and then the use of a second estimate of land required for the particular animal.

Finally, another overarching methodological choice that needs to be discussed concerns the periodization and accuracy of the coefficients constructed. Although more discussion is provided under each product, it is worth making some general remarks. It is generally the case that for earlier years in the 19th century, statistical information for many commodities is scarce or in many cases non-existent. For this reason, the coefficients are constructed mainly on the basis of ranges of values that could apply throughout the 19th century and for various regions rather than on a yearly basis. In very few cases, due to the inability of finding information, data from later in the 20th century are used.

3 Source Criticism

As already briefly noted, providing a critical discussion for all sources cited in this study would have been a very time consuming task. In order to control for this limitation, in the majority of cases I have used more than one source to obtain a conversion factor. Where issues have arisen I have as far as possible cross checked the data with other available sources. Therefore, where required, the use of corroborative sources within the text proper is noted.

Some sources are used more frequently than others in this paper since they provide a wealth of information for various agricultural products and countries. Since these sources are used more frequently, and thus a big share of the information is based on them, it is worth providing a more extensive discussion just on these.

The most commonly cited source in this paper are the five different volumes produced between 1847 and 1850 by the Scottish merchant, landowner, civil servant, politician, and writer John Macgregor (1797–1857). The full title of this work is *Commercial statistics: A digest of the productive resources, commercial legislation, customs tariffs, of all nations-Including all British commercial treaties with foreign states, Vol. I-V*. It constitutes a major statistical work of international commerce which provides a wealth of information on most economies around the world before the first half of the 19th century.[1] This is also the reason why it is used extensively in the current paper, since for the earlier part of the 19th century, statistical information is extremely scarce for many products and countries. The source has been cited by researchers in economic history but the wealth of statistical information that is provided has not been the subject of any serious scholarly criticism. The only critical discussion that has been found is in Cole (1958) *Trends in Eighteenth-Century Smuggling*. It should be stressed however, that Cole's criticism is very specific and refers to some trade data on tea between England and E. Indies and China. More importantly, the criticism is not targeting the validity of the data but rather their interpretation by Macgregor. One speculation about the origin of the data is that most probably Macgregor has been using data available in the Colonial "Blue Books" which contain a wealth of statistical information on economic and social aspects of the colonies. One control mechanism that has been used in this paper in order to test the reliability of the source was by comparing Macgregor's data with those obtained from other sources. Information from Macgregor was fully corroborated by other sources and no systemic errors have been identified. This was the case for both important goods (such as cotton, wheat, sugar, silk and barley silk) and less important goods (such as pimento and cinnamon).

Other types of sources that are also cited repeatedly in this paper are Statistical reports of official authorities (mainly from the US and Australia) and scientific periodicals and journals such as *The Farmer's Magazine* and *The Queensland Agricultural Journal,* pertaining to the nineteenth and early-twentieth centuries. Information from such sources has been taken at face value- treating their estimates as reliable and valid. This does not mean that the information is necessarily beyond reproach. There may of course be problems mainly due to omissions or wrong entries, but that is something very difficult to control. Again,

[1] A biography on MacGregor, John is provided by (Halpenny 1985)

the main answer to such problems has been the use of more than one source to corroborate the validity of an estimate.

4 Data Representativeness

The data collected and presented in this work is mainly based on estimates for various countries for the majority of the products. One of the main reasons for this has been the close attachment of this work with other research papers, as their basic source of empirical evidence. However, except for the narrower research interests, data availability and time constraint have also been two other deterministic factors in the process of compiling this dataset. Consequently, the geographical and chronological scope of this paper is accordingly limited by these factors.

The underlying geographical coverage, has to a great extend been dictated by the trade patterns of the British Empire. Indisputably, this creates some kind of bias in the estimates and may decrease the external validity of this study as it captures better the ecological circumstances that underpin the production processes and the bearing of land for particular products in particular geographical regions such as the West Indies, North America, South East Asia, parts of the Baltic and Eastern Europe and Australasia. Nevertheless, the centrality of these regions in economic and environmental historiography of trade in the late eighteenth and nineteenth centuries can actually render the dataset a relatively complete source of empirical evidence for future historical research.

Special mention should be made of data representativeness in respect to particular commodities. The overarching question is whether the empirical estimates of ecological footprints presented here are representative of the geographically and chronologically diverse land productivities. Of course an absolute answer is difficult to give to this question. Such an endeavor of estimating the land requirements for all products throughout time and space is impossible in practice, if not in theory. Most of the information is obtained from the main areas of production which it can be assumed were also the most productive ones. So the data actually represent only regions where production took place and may not represent adequately regions where production did not but could have occurred.

For most of the products, and when possible, an acreage conversion factor has been estimated on the basis of more than one geographical areas and for more than one benchmark years. At least for the products which in historiography have been identified as relatively more important this has been the case. Additionally, the methodological choice of presenting a range of minimum and maximum estimates of ecological footprints for the most important commodities ameliorates such problems of selection-bias in these cases and increases the external validity of the estimates. However, in some cases, due to data unavailability or the relatively lower significance of the product, proxy estimates from one country may have been used. In some cases in the estimation process of relatively more "complicated" products such as for instance tallow and lard, the product to animal weight ratio is based on estimates for Britain and the US. Although undoubtedly this creates some kind of bias, since it neglects the relevant product to animal ratios which may pertain to other countries, this is assumed to be relatively small. The reason is that these ratios are not expected to vary invariably but rather within very small ranges. This assertion is supported by the empirical evidence on beef which is presented in this study. In this case, the US and UK's estimates of meat to animal ratios are rather close to the average estimate ratio of various countries.

Consequently, the interested researcher should keep in mind that the data has been compiled under the light of particular research questions, and as a consequence the information under each product should in no way be read as a complete historical study of its production process throughout time and space. Issues of representativeness may arise on the basis of different research questions under investigation. For the purpose of other future research, it might well need to be supplemented with more information from other sources.

5 Historical acreage conversion factors

In what follows, the products under study in this paper are analyzed in an alphabetic order under five broader categories. These are grain and flour; animal and animal products; other food, drinks and spices; raw materials; and manufactured articles. Each product is discussed in a separate section. When needed, cross references to other products are noted.

Some general information is provided here on the weight to mass conversion ratios for grain as well as the conversion from the US unit of measurement to the imperial one (Table 1). These conversion factors have been used in cases where grain productivity in the original sources was reported in units other than bushels. The ratios are based on the

USDA Handbook No. 697 (1992) *Weights, Measures, and Conversion Factors for Agricultural Commodities and Their Products* (here). The conversion to UK bushels is done under the premise that one US bushel equals approximately 0.9689 UK bushels.

TABLE 1 *Grain volume to weight conversion ratios.*

Grain	Pounds per US bushel	Pounds per UK bushel
Wheat	60	62
Barley	48	49.5
Oats	32	33
Peas	60	62
Beans	60	62
Indian Corn/Maize	56	58
Rye, Sorghum, Flaxseed	56	58
Rapeseed	55	57
Rice	45	46
Onion	30	31

Source: USDA Handbook No. 697 (1992)
Note: For rapeseed, an average estimate is used based on the range of 50-60 pounds per US bushel.

5.1 Grain and flour

5.1.1 Barley

The conversion factors for various countries and years are reported in Table 2 along with the relevant sources. Prior to 1870, corn imports to the United Kingdom were mainly from other European countries with Russia and Prussia being the main suppliers. Given the unavailability of data for the early 19th century for many non-Northwestern European countries, a minimum and maximum yields for the whole period until 1870 can be calculated based on information on yields for the mid-19th early 20th century on Australia, US, Canada and France and late 19th century Russia and Poland. Thus an approximate minimum and maximum yield factor prior to 1870 can range between thirteen bushels per acre and twenty one bushels per acre. After 1870 and specifically for the benchmark year 1907 some export countries are reported in more detail while agricultural statistics become more available.

TABLE 2 *Barley yields, in bushels per acre.*

Country	Year	Bushels per acre	Source
Australia, Whales	1835	16.26	Macgregor (1850, V:145)
	1840	20.4	
	1844	18.3	
Austria	1909/13	27.2	Eddie (1968, 213)
Belgium		49.6	
Bulgaria		19.3	
Canada, Prince Edw. Island	1847	12.8	Macgregor (1850, V:322)
Denmark	1909/13	41.6	Eddie (1968, 213)
France	c. 1780	20	Sexauer (1976, 501)
	1815/24	39	Newell (1973, 714–15)
	1840	15.9	Macgregor (1847a, I:348)
	1865/74	53	Newell (1973, 718-19)
	1909/13	25.1	Eddie (1968, 213)
Germany	1909/13	37.3	
Great Britain	1770	32.1	R. C. Allen and Gráda (1988)
	1790s	27.7	
	1812	32	Drescher (1955, 168); R. C. Allen and Gráda (1988)
	1839	32	
	1846	36	
	1850	39-42	
	1909/13	34.2	Eddie (1968, 213)
Hungary	1909/13	24	
India	1870	25	Broadberry, Custodis, and Gupta (2015, 64)
	1891	19.5	Blyn (1966, 274)
	1895	16	
	1900	18	
	1905	15.8	
	1910	19	
Ireland	1770s	34.7	R. C. Allen and Gráda (1988)
	1801/24	34.7	
	1812	39.3	
	1847	39	M. E. Turner (1996, 244-45)
	1850	40	
	1860	34	
	1870	35	
	1880	36	
	1890	38	
	1900	36	
	1970	40	
Italy, European	1909/13	16	Eddie (1968, 213)
Netherlands	1830/40	40	Macgregor (1847a, I:902)
	1909/13	46.5	Eddie (1968, 213)

TABLE 2 *Barley yields, in bushels per acre. (cont.)*

Country	Year	Bushels per acre	Source
Romania	1897-1906	17.9	Whitney (1909, 15) (here)
	1909/13	18.4	Eddie (1968, 213)
Russia	1897-1906	13.8	Whitney (1909, 15) (here)
S. Africa, Cape of Good Hope	1839	13.1	Macgregor (1847b, II:330)
US	c.1791	14	Gallman (1972, 198)
	c. 1800	14	
	1866	22-24	USDA Yearbook (1907, 636)
	1870	22	USDA (1959a); USDA Report (1880, xvii); USDA Yearbook (1907, 636)
	1880	21-22	
	1890	21	
	1900	20	
	1907	23	
	1910	18.9	

Note: The 1815-24 and 1865-74 estimates for France are converted from hectoliters to pounds on the basis of 150 lbs per hectoliter. The estimates from Eddie (1968, 213) are expressed in quintals per hectare. They are converted to pounds on the basis of 220.462 lbs per quintal.

5.1.2 Beans/Peas

Conversion factors for each country and year are reported in Table 3 along with the relevant sources. Due to limited data availability, approximate minimum and maximum acreage conversion factors for beans and peas can be estimated based on yield factors for China, India and the Netherlands in the mid and early 19th century. Thus a minimum and a maximum yield can be calculated at eleven bushels per acre and 20 bushels per acre respectively.

TABLE 3 *Beans/Peas yield, in bushels per acre.*

Country	Year	Bushels per acre	Source
China	1820	17.4	R. C. Allen (2009, 535-6)
Great Britain	1846	30	Drescher (1955, 168)
India	c. 1840	11	Macgregor (1848, IV:706)
Ireland	1847	26	M. E. Turner (1996, 244-45)
	1850	23	
	1860	22	
	1870	27	
	1880	31	
	1890	35	
	1900	29	
	1910	34	
Netherlands	1840/30	19-20	Macgregor (1847a, I:902)

Note: In the original source, the yield for China is given in shi per mu. It is converted to bushels per acre on the basis of 0.151 acres per mu and 157.9 pounds per shi (Chin-keong 1983, xvii). Accordingly, for India, the yield is converted from bushels per bigha to acres on the basis that one bigha was standardized at 0.3306 acres.

TABLE 4 *Buckwheat yield, in bushels per acre.*

Country	Year	Bushels per acre	Source
France	1815/24	23.2	Newell (1973, 714–15,18-19)
	1865/74	37	
Poland	c. 1840	12.5	Macgregor (1847b, II:712)
Russia	1835	21.5	Macgregor (1847b, II:722)
US	c. 1791	17	Gallman (1972, 198)
	c. 1800	17	
	1866	15	USDA (1958b, 18); USDA Report (1880 xvii)
	1870	12	
	1880	13	
	1890	14	
	1900	15	
	1910	17.3	

Note: The estimate for Poland is the average of 10-15 bushels per acre reported in the source. The same applies for Russia with a range between 18-25 bushels per acre. Note: The 1815-24 and 1865-74 estimates for France are converted from hectoliters to pounds on the basis of 150 lbs per hectoliter.

5.1.3 Buckwheat

For the direct ecological footprint of buckwheat, minimum and maximum acreage conversion estimates for all years can be based on those estimates for Poland and Russia and France up to the mid-19th century and the US in the late-19th century. According to these, the yields can range between twelve and a half bushels per acre and twenty one and a half bushels per acre (Table 4).

5.1.4 Maize/Corn and Millet

The direct ecological footprint for corn and millet can be calculated on the basis of common acreage conversion factors for both crops due to the unavailability of many historical sources on millet. It could be expected that at least in the 19th century the relative productivity of a unit of land on millet and maize was rather similar. Charles Fox (1854, 145–46) argued that millet shared similar modes of cultivation with Indian corn while he estimated the usual yield in the US at 20-30 bushels of seed per acre – yields very similar to those for maize. Also, looking at Mulhall (1899, 57,365,765) when reporting the "ordinary yields" of maize for various countries, it is stated that for France and some others millet is included in maize. This does not seem to distort in any significant way the comparative yield figures among the countries. Also, the millet yield per acre in Japan in 1887, at 19 bushels per acre, follows rather closely to the yields per acre on maize reported for other countries (Mulhall 1899, 57).

The conversion factors for maize/corn in each country and year are reported in Table 5 along with the relevant sources. The conversion factors of minimum and maximum yields per acre for maize/Indian corn and millet for the years until 1870 can be based on data from the major producing country, the US as well as Australia and the Gold Coast in the mid-19th century. A minimum and maximum acreage yield can be estimated at twenty five bushels per acre and forty bushels per acre respectively. For the benchmark year of 1907, country-specific data becomes more available but it can be noted that no significant changes in land productivity have occurred.

TABLE 5 *Maize and millet yield, in bushels per acre.*

Country	Year	Bushels per acre	Source
Argentina	1910	22	Knibbs (1913, 378) (here)
Australia, Whales	1835	24.2	Macgregor (1850, V:145)
	1840	31	
	1844	27.6	
	1887	28	Mulhall (1899, 365,765) (here)
	1907	28.5	Knibbs (1908, 311) (here)
	1910	31.4	Knibbs (1913, 378) (here)
Austria	1909/13	18.8	Eddie (1968, 213)
Bulgaria	1909/13	17.4	
Canada	1910	57	Knibbs (1913, 378) (here)
Egypt	1879	19	A. Richards (1978, 734)
France	1815/24	26.1	Newell (1973, 714–15,18-19)
	c.1840	13.4	Macgregor (1847b, I:902)
	1865/74	40.8	Newell (1973, 714–15,18-19)
	1909/13	18.6	Eddie (1968, 213)
Gold Coast	c. 1840	39.2	Macgregor (1850, V:125)
Hungary	1909/13	18.6	Eddie (1968, 213)
India	1891	12.6	Blyn (1966, 277)
	1895	12.4	
	1900	13.5	
	1905	13.5	
	1910	15	
Italy, European	1909/13	24.3	Eddie (1968, 213)
Netherlands	1830/40	25	Macgregor (1847b, I:902)
New Zealand, Auckland	1857	40	Hargreaves (1959, 65)
Romania	1885	14	Whitney (1909, 15) (here)
	1907	13	
	1910	20.5	Knibbs (1913, 378) (here); Eddie (1968, 213)
Russia	1907	13	Whitney (1909, 15) (here)
	1910	19.7	Knibbs (1913, 378) (here)
S. Africa, Cape of Good Hope	1839	11	Macgregor (1847a, II:330)

TABLE 5 *Maize and millet yield, in bushels per acre (cont.)*

Country	Year	Bushels per acre	Source
US	1710	18-30	Nairn (1710, 10) (here)
	c. 1791	24	Gallman (1972, 198)
	c. 1800	24-25	Rasmussen (1962, 583); Gallman (1972, 198)
	1833	20-30	G. R. Porter (1833, 202) (here); Allison (1973, 22)
	1839	25	Parker and Klein (1966, 542)
	1840	25	Rasmussen (1962, 583); Emerson (1878, 42) (here)
	1849	25	
	1850	25	
	1859	25	
	1866	24	USDA (1954); Mulhall (1899, 365,765) (here); USDA Report (1880, xvii); Rasmussen (1962, 583); USDA Yearbook (1907, 609); Rasmussen (1962, 583); Knibbs (1913, 378) (here)
	1870	27.5-29	
	1880	27	
	1890	22	
	1900	28	
	c. 1907	27	
	1910	26-28	

Note: Note: The 1815-24 and 1865-74 estimates for France are converted from hectoliters to pounds on the basis of 150 lbs per hectoliter. The estimates from Eddie (1968, 213) are expressed in quintals per hectare. They are converted to pounds on the basis of 220.462 lbs per quintal.

5.1.5 Oats

The conversion factors for each country and year are reported in Table 6 along with the relevant sources. Given the unavailability of data for the early 19th century for many non-Northwestern European countries, the minimum and maximum acreage yield estimates for oats can be calculated for the whole period until 1870 based on information on yields for the mid-19th and early 20th century Australia, and Canada and late 19th century Russia, Sweden, Romania, Hungary and the US. Thus the minimum and maximum yield factors can vary between twelve bushels per acre and twenty eight bushels per acre. For the benchmark year 1907 country-specific data becomes more available.

TABLE 6 *Oats yield, in bushels per acre.*

Country	Year	Bushels per acre	Source
Australia, Whales	1835	6	Macgregor (1850, V:145)
	1840	12	
	1844	16	
	c. 1907	20.5	Knibbs (1908, 303) (here)
Austria	1909/13	34.6	Eddie (1968, 213)
Belgium	1909/13	64.1	
Bulgaria	1909/13	20.8	
Canada, Prince Edward Island	1847	17	Macgregor (1850, V:322)
Canada, Ontario	c. 1907	38.6	Knibbs (1908, 303) (here)
Denmark	1909/13	51.1	Eddie (1968, 213)
France	1815/24	70	Newell (1973, 714–15,18-19)
	c. 1840	18.1	Macgregor (1847b, I:902)
	1865/74	100	Newell (1973, 714–15,18-19)
	1909/13	35.1	Eddie (1968, 213)
Germany	1909/13	53.3	
Great Britain	1770	37	R. C. Allen and Gráda (1988)
	1790s	27.2	
	1800	34.9	
	1794-1816	36.1	
	1846	40-46	Drescher (1955, 168); R. C. Allen and Gráda (1988)
	1909/13	49.2	Eddie (1968, 213)
Hungary	1909/13	30	
Ireland	1770s	34.6	R. C. Allen and Gráda (1988)
	1801/24	36.6	
	c. 1812	41.4	
	1847	50	M. E. Turner (1996, 244–45)
	1850	46	
	1860	43	
	1870	43	
	1880	48	
	1890	50	
	1900	54	
	1910	59	
Italy, European	1909/13	28.7	Eddie (1968, 213)
Netherlands	1830/40	40	Macgregor (1847b, I:902)
	1909/13	54.3	Eddie (1968, 213)
Romania	1885	17.5	Whitney (1909, 15) (here)
	c. 1907	22	
	1909/13	25.4	Eddie (1968, 213)
Russia	c. 1907	19.3	Whitney (1909, 15) (here)
S. Africa, Cape of Good Hope	1839	5.5	Macgregor (1847a, II:330)
Sweden	c. 1907	27	Whitney (1909, 15) (here)

TABLE 6 *Oats yield, in bushels per acre.*

Country	Year	Bushels per acre	Source
US	c. 1791	24	Gallman (1972, 198)
	c. 1800	24	
	1839	24	USDA Report (1880, xvii); Parker and Klein (1966, 542)
	1849	24	
	1859	24.4	
	1869	25	
	1879	24.6	
	1880	24.4	
	1889	23	
	1899	24.4	
	c. 1907	28.3	USDA Yearbook (1907, 628)

Note: Note: The 1815-24 and 1865-74 estimates for France are converted from hectoliters to pounds on the basis of 150 lbs per hectoliter. The estimates from Eddie (1968, 213) are expressed in quintals per hectare. They are converted to pounds on the basis of 220.462 lbs per quintal.

5.1.6 Rice

The conversion factors for each country and year are reported in Table 7 along with the relevant sources. For rice in the husk a rough average of 2,100 pounds per acre could be estimated while for unhusked rice 1,500 pounds per acre. Note that the rice unhusked, reduces the weight of rice by approximately 20-25% (Malanima 2009, 103).

TABLE 7 *Rice yield, in pounds per acre.*

Country	Year	Pounds per acre	Source
Burma	c. 1900	1590	Mulhall (1899, 514)
Ceylon	1828	1467	Martin (1839, 398)
	1829	1437	
	1830	1372	
	1831	1537	
	1832	4163	
	1833	862	
	1834	954	
	1835	670	
	1836	564	
	c. 1900	1500	Mulhall (1899, 514)
China	1480-1700	1570-3137	Xue (2007, 217)
	c. 1500	1340-2230	Malanima (2009, 103)
	1620	1778	Allen (2009a, 535-6)
	1750-1890	2091-3137	Xue (2007, 217); Goldstone (2003)
	c. 1820	2405	Allen (2009a, 535-6); Goldstone (2003)
India	1600	1064	Broadberry, Custodis, and Gupta (2015, 64)
	1870	1053	
	1891	759	Blyn (1966, 253); Mulhall (1899, 514)
	1895	905	
	1900	930-1660	
	1905	806	
	1910	1053-1250	Blyn (1966, 253); Broadberry, Custodis, and Gupta (2015, 64)
Japan	c. 1900	1630	Mulhall (1899, 514)
Java	1815	1470	Boomgaard and Zanden (1990, 41)
	c. 1830	641	G. R. Porter (1833, 193)
	c. 1900	1340	Mulhall (1899, 514)
Spain	c. 1900	1790	Mulhall (1899, 514)

TABLE 7 *Rice yield, in pounds per acre. (cont.)*

Country	Year	Pounds per acre	Source
US	c. 1710	1350-2700	Nairn (1710, 10)
	c. 1770	1500	Coclanis (1991, 97)
	c. 1790	1500-1800	Gray (1933, 730) (here); Gallman (1972, 198); Wilms (2013, 54)
	c. 1840	1000	A. B. Allen (1843b, 22); A. B. Allen (1843a, 73) (here); P. Coclanis and Komlos (1987, 352)
	c. 1850	1000-1800	Fox (1854, 140); P. Coclanis and Komlos (1987, 352)
	c. 1890	1150-1600	U.S. Bureau of the Census (1960, 299) (here); USDA (1958b, 2)
	c. 1900	1200-1680	Mulhall (1899, 514); USDA (1958b, 2)
	1910	1700	USDA (1958b, 2)

Note: The rice figures for China provided by Allen (2009a, 537) and Xue (2007, 217) are originally reported in shi per mu. They are converted to pounds per acre based on information from Chin-keong (1983, xvii). The figure for Ceylon is an average estimate. The yield of 1840 for the US refers to "upland rice" -meaning rice which is cultivated in uplands and not irrigated lands. This means that this should be considered as a very low estimate given that as is stated in the source the irrigated cultures can give significantly higher yields.

5.1.7 Rye

The conversion factors for each country and year are reported in Table 8 along with the relevant sources. Prior to 1870, corn imports in the United Kingdom were mainly from other European countries with Russia and Prussia being the main suppliers. Given the unavailability of data on rye yields for the early 19th century for non-Northwestern European countries, the minimum and maximum yields for rye for this period can be proxied by yields from the mid-19th century Australia, and Poland, France and the Netherlands and 19th century US. Thus minimum and maximum acreage yield factors can range between twelve bushels per acre and twenty bushels per acre.

TABLE 8 *Rye yield, in bushels per acre.*

Country	Year	Bushels per acre	Source
Australia, Whales	1835	12.5	Macgregor (1850, V:145)
	1840	14.5	
	1844	12.5	
Austria	1909/13	21.2	Eddie (1968, 213)
Belgium	1909/13	34	
Bulgaria	1909/13	15.2	
Denmark	1909/13	25.8	
France	1815/24	24.5	Newell (1973, 714–15,18-19)
	c. 1840	12	Macgregor (1847b, I:902)
	1865/74	34	Newell (1973, 714–15,18-19)
	1909/13	16	Eddie (1968, 213)
Germany	1909/13	28	
Great Britain	1909/13	29.1	
Hungary	1909/13	18	
Ireland	1847	40	M. E. Turner (1996, 244–45)
	1850	38	
	1860	23	
	1870	22	
	1880	20	
	1890	21	
	1900	25	
	1910	29	
Italy, European	1909/13	16.9	Eddie (1968, 213)
Netherlands	1830/40	24	Macgregor (1847b, I:902)
	1909/13	27.8	Eddie (1968, 213)
Poland	1840	12-15	Macgregor (1847a, II:712)
Romania	1909/13	14.2	Eddie (1968, 213)
S. Africa, Cape of Good Hope	1839	5.8	Macgregor (1847a, II:330)
US	c. 1791	12.7	Gallman (1972, 198)
	c. 1800	12.7	
	1880	10.3	USDA Report (1880, xvii)

Note: The 1815-24 and 1865-74 estimates for France are converted from hectoliters to pounds on the basis of 150 lbs per hectoliter. The estimates from Eddie (1968, 213) are expressed in quintals per hectare. They are converted to pounds on the basis of 220.462 lbs per quintal.

5.1.8 Wheat

The conversion factors for each country and year are reported in Table 9 along with the relevant sources. For the years prior to 1870, all imports to the United Kingdom were from other European countries and to a great extend were coming from Russia and Prussia. Based on information from various sources, the yields in this period could actually range between approximately ten bushels per acre and twenty bushels per acre. After 1870 and specifically for the benchmark year 1907 some export countries are reported in more detail while yield statistics are more available.

TABLE 9 *Wheat yield, in bushels per acre.*

Country	Year	Bushels per acre	Source
Argentina	1902/3	12	Bicknell (1904, 31)
Australia	1800	12	Dunsdorfs (1956, 529.534)
	1834	12.6	
	1844/55	15.8	
	1870	10.8	
	1890	8.5	
	c. 1907	9.2	Knibbs (1908, 303)
Austria	1836	18	Clark (1987, 429)
	1909/13	19.6	Eddie (1968, 213)
Belgium	1909/13	36.4	
Bulgaria	1909/13	15.3	
Canada, Prince Edward Island	1847	10.4	Macgregor (1850, V:322)
Canada	c. 1907	20	Knibbs (1908, 303)
China	1620	17	R. C. Allen (2009, 535-6)
	1820	17	
Denmark	1909/13	47.6	Eddie (1968, 213)
France	1750	18-27	Grantham (1993, 486); Sexauer (1976, 501)
	1800	25	
	1815/24	10-26	Newell (1973, 714–15,18-19); R. C. Allen and Gráda (1988)
	1840	33	Grantham (1993, 486)
	1850	16	R. C. Allen and Gráda (1988)
	1862	40	Grantham (1993, 486)
	1865/74	35.3	Newell (1973, 714–15,18-19)
	1892	43	Grantham (1993, 486)
	1909/13	19	Eddie (1968, 213)
Germany, Berlin	1812	16	Clark (1987, 429)
Germany	c. 1907	27-30.8	Whitney (1909, 15) (here); Eddie (1968, 213)
Great Britain	1771	24-25	Drescher (1955, 168); Fairlie (1969, 114–15); R. C. Allen and Gráda (1988); Sexauer (1976, 501); Clark (1987, 429)
	1798	20	
	1801	21.6-24	
	1812	20-24	
	1839	26-31	
	1846	32-41	
	1850	26-41	
	1860	26	Fairlie (1969, 114–15)
	1870	27	
	1876	23	
	1909/13	30.7	Eddie (1968, 213)

TABLE 9 *Wheat yield, in bushels per acre (cont.).*

Country	Year	Bushels per acre	Source
Hungary	c. 1820	10-11	Allen (1992)
	1850	15	Clark (1987, 429)
	1909/13	18.1	Eddie (1968, 213)
India	1870	20.8	Broadberry, Custodis, and Gupta (2015, 64)
	1891	8.7	Blyn (1966, 258)
	1895	8.7	
	1900	10	
	1905	9.5	
	1910	13-20	Blyn (1966, 258); Knibbs (1908, 303); Broadberry, Custodis, and Gupta (2015, 64)
Ireland	1770s	21.2	R. C. Allen and Gráda (1988)
	1801/24	22.1	
	1812	23.3	
	1847	30	M. E. Turner (1996, 244–45)
	1850	20	
	1860	21	
	1870	22	
	1880	27	
	1890	28	
	1900	30	
	1910	35	
Italy	c. 1820	10-11	Allen (1992)
	1909/13	15.1	Eddie (1968, 213)
Netherlands	1830/40	23	Macgregor (1847b, I:902)
	1909/13	33.8	Eddie (1968, 213)
Poland	c. 1840	16-20	Macgregor (1847a, II:712)
Portugal	c. 1820	10-11	Allen (1992)
Romania	c. 1820	10-11	
	c. 1907	17.7	Whitney (1909, 15) (here)
	1909/13	18.6	Eddie (1968, 213)
Russia, Podolia	1826	16.5	Clark (1987, 429)
Russia	c. 1907	9	Whitney (1909, 15) (here)
S. Africa, Cape of Good Hope	1839	5.3	Macgregor (1847a, II:330)
Spain	c. 1820	10-11	Allen (1992)

TABLE 9 *Wheat yield, in bushels per acre (cont.).*

Country	Year	Bushels per acre	Source
US	c. 1791	10	Gallman (1972, 198); Rasmussen (1962, 583)
	c. 1800	10-15	
	1820/37	21.2	Clark (1987, 429)
	1839	12	Parker and Klein (1966, 542); Rasmussen (1962, 583)
	1840	15	
	1849	12	
	1859	12	
	1866	11	USDA (1955); Whitney (1909, 15) (here); Rasmussen (1962, 583)
	1870	12	
	1880	13-15	
	1890	12	
	1900	12-14	
	c. 1907	13-14	
	1910	14	

Note: The 1815-24 and 1865-74 estimates for France are converted from hectoliters to pounds on the basis of 150 lbs per hectoliter. The estimates from Eddie (1968, 213) are expressed in quintals per hectare. They are converted to pounds on the basis of 220.462 lbs per quintal.

5.1.9 Wheat meal or flour

The conversion of wheat meal or wheat flour into acres can be calculated on the basis of wheat to flour ratio and the yield for wheat as reported here under section 5.1.8 *"Wheat"*. According to Sharp and Weisdorf (2013, 94) there can be 392 pounds of flour per quarter of wheat (1 quarter equals 8 bushels).

5.1.10 Other types of flour - barley meal, oatmeal, indian meal

Due to the unavailability of sources, these types of flours can also be converted to land on the basis of wheat flour to grain ratio and subsequently on the basis of each products grain yield per unit of land. See discussion under section 5.1.9 "*Wheat meal or flour*" and under ach product.

5.2 Animals and animal products

5.2.1 Bacon

The ecological footprint of bacon can be calculated on the basis of its weight share in the animal and the animal's bearing on land. In other words, based on the land requirements for pork.

According to the literature, in the mid-nineteenth century United States, bacon cuts made up approximately 25% of the animal's carcass weight while the average carcass weight of an animal was estimated at approximately 208 pounds (USDA Report of the Commissioner of Agriculture 1867, 390 (here); Cuff 1992, 61-6). Consequently, the share of bacon can be calculated at approximately 50 pounds per animal.

As regards the ratio of land per animal, that can be assumed to be approximately equal to one acre per pork in the 19th century. For a detailed discussion on that ratio see discussion under section 5.2.10 on "*Swine/Hog/Pork*".

5.2.2 Beef

The ecological footprint of beef can be calculated on the basis of meat output per animal and the land requirements per animal.

As regards the meat's share in the animal's weight, according to Stephenson (1837, 168) for the United Kingdom, in the early 19th century it is stated that the share of beef in an animals live weight was 57.1% while the live weight of the animal was reported at approximately 1400 to 1500 pounds. Consequently, the meat share was approximately 830 pounds per animal. Another estimate for the late 19th century UK reports the carcass weight at approximately 600 pounds per animal (Drescher 1955, 168). Holmes (1916, 109:276) (here) also reports the average live and dressed weight of beeves for various countries and specifically for the US, Argentina, France, Uruguay and Germany in the late 19th and early 20th centuries. The average meat weight per animal for all countries is 775 pounds. Finally, according to the USDA Report of the Commissioner of Agriculture (1867, 300) (here) in the mid-19th century US, the meat yield per animal is reported at 750 pounds. Consequently, a rough average estimate of 800 pounds of beef per animal can be concluded for the whole nineteenth century.

As regards the amount of land devoted per animal, that is taken to be two acres. As discussed in section 5.2.4 on "*Cattle*", this estimate is actually a little lower than the average common estimate for Europe, US, Brazil and Argentina. Nevertheless, it is consistent with the assertion found in the literature that the land needed for cattle is approximately five times higher than the amount needed for sheep and two times higher than that devoted to hogs. A more detailed discussion on the amount of land per animal follows in section 5.2.4.

5.2.3 Butter

In order to calculate the ecological footprint of butter a first estimate of yield per animal needs to be identified as well as an estimate of land devoted per animal.

As regards the butter yield per animal, in the mid-19th century US an average annual produce would range between 160 to 180 pounds (The American Farmer 1854, 319) (here). A similar range estimate is found for the mid-19th century England in (Horsfall 1855, 539). Kennedy (1864, cxix) (here) reports a somewhat lower estimates for the US in the 1850s and 60s at approximately 50 pounds per cow. Nevertheless, as it is stressed in the source, this can be considered a very low yield since a properly fed cow can produce approximately 500 pounds of both butter and cheese per year. Consequently, an average figure of 175 pounds of butter per animal per year could be a viable estimate.

As regards the amount of land devoted per animal, that is taken to be two acres. A more detailed discussion of how this estimate is obtained can be found under the following section 5.2.4 on "*Cattle*".

5.2.4 Cattle

Before concluding what is the exact amount of pasture land that is required for the raising of cattle and thus provide an estimate of its ecological footprint, it should be noted that this is a rather complicated issue. The main reason is that the amount of land can vary invariably, especially so in this particular historical time period when frontier expansion was a central economic activity. In the literature it is stressed that the carrying capacity of land will vary significantly and is dependent on various factors such as the type of vegetation, the soil's fertility and the rainfall (Hitchcock 1914, 25) (here). Characteristic of this is Hitchcock's (1914:25) claim that "*the carrying capacity (of the pasture) can be told only by experience*".

Looking at various sources, this variability of the amount of land per animal becomes evident. For the US, Hitchcock (1914) suggests that the amount of land devoted to cattle would range from five acres and more per animal. For Brazil, information from Nash (1926, 255) (here) also suggest a similar range with the acres of land spanning from four acres per animal up to twenty seven depending on the region. Nevertheless it is worth noting that the majority of estimates were within a range of four and six acres per animal. For Argentina, in The Queensland Agricultural Journal (1899, 268) (here) information is provided on the relative amount of forage for cattle as opposed to that for sheep. It is argued that a cow consumes as much forage as 5 sheep (in Buenos Aires land would carry 2.5 sheep per acre). Based on this information a rough estimate of two acres per animal can be calculated. Based on Smith (2006, 232), in the late 18th century Jamaica, in a particular pen- Mammee Ridge- 1,000 acres were available and accommodated 481 animals and 98 slaves. Consequently a similar estimate of approximately 2 acres per animal can be calculated. Nevertheless, not all the land in each pen was devoted to the animals or in other words to pasture. According to Richards (2003, 452) 54% of the total pen land was devoted to pasture and guinea grass, 30% was woodland and 6% to food. Additionally, for one of the largest pens in Jamaica – Goshen- he provides information that in 1780 1500 animals were kept in 1586 acres. In this case, land devoted to pasture was surprisingly small and covered only 38% of the total area. Consequently, a relatively smaller estimate of one acre per cattle can be calculated. Finally, data on the head of cattle per acre is provided for nine European countries in 1872 in Table 10.

TABLE 10 *Land devoted to cattle, in acres*

Country	Acres per Cattle
Russia	3
Italy	1
France	0.7
Belgium	0.4
Prussia	0.7
Austria	0.8
Spain	1.6
Holland	0.5
UK	0.5

Source: The Farmer's Magazine (1873, 9)

Based on the empirical evidence presented above, I have decided to take the amount of land per animal at two acres. That estimate is actually a little lower than the average estimates of the sources discussed above. Nevertheless, it is consistent with the assertion found in the literature that following a rational based on nutrition, pasture land for cattle should be approximately 5 times higher than that needed for sheep and it should also double the amount of land devoted to hogs. Consequently, it should be noted that this can be considered as the lowest- subsistence level- estimate possible and that more land per cattle could easily have been devoted, especially so in the Americas where the maximum estimates can vary invariably.

Nevertheless, it is important to note that these estimates may actually represent reality to a certain extent. In particular, Lemon (1967:69) has calculated the minimum amount of acres that would have been required in late 18th century Southeast Pennsylvania in order to support an average family of five comfortably. That is estimated at approximately 75 acres of cleared land. The amount of total pasture land (permanent and woodland) that has been estimated is approximately 30 acres and can accommodate 5 pigs, 5 cows and half a steer, 8 sheep and 4 horses. Assuming that the land requirements for horses are the same as those for cattle, and using the footprint estimates for cattle, sheep and pigs calculated in this paper (see also sections 5.2.10 on *Swine/hog/pork* and 5.2.16 on *Wool*), we would get an acreage estimate fairly close to that provided by Lemon, at approximately 27 acres.

5.2.5 Cheese

In order to calculate the ecological footprint of cheese a first estimate of yield per animal needs to be identified as well as an estimate of land devoted per animal.

As regards the cheese yield per animal, according to The American Farmer (1854, 319) (here), in the mid-19th century US an average annual produce would range between 350 to 400 pounds of milk cheese. Kennedy (1864, cxix) (here) reports significantly lower estimates for the US in the 1850s and 60s at approximately 15 pounds per cow. Nevertheless, as it is stressed in the source, this can be considered a very poor performance since a properly fed cow can produce approximately 500 pounds of both butter and cheese per year. Consequently, an average figure of 375 pounds of cheese per animal per year is instead regarded here as a viable estimate.

As regards the amount of land devoted per animal, that is taken to be two acres. A more detailed discussion of how this estimate is obtained can be found under section 5.2.4 on "*Cattle*".

5.2.6 Cochineal

Information on Cochineal pertaining to the 19th century is fairly limited. Nevertheless, its direct ecological footprint could be calculated on the basis of estimates from Leggett (1944: 83). In particular, according to Leggett (1944: 83) cited in Dutton's (1992, 24) thesis *Cochineal: A Bright Red Animal Dye*, (here) "*two hundred pounds of cochineal can be produced from one acre of nopals, and it takes 70,000 of the dried insects to produce one pound (approximately 14,000,000 insects per acre)*". Thus an approximate yield factor of 200 pounds per acre can be established

5.2.7 Eggs

The calculation of the footprint of eggs is a challenging task, due to the unavailability of many sources but nevertheless, some rough estimates can be provided. For the estimation process it is necessary to have first a yield estimate of eggs per fowl and per acre. Also in some cases the traded eggs are reported in units of mass instead of numbers and consequently estimates of the average eggs' weight need to also be provided.

Starting from the annual egg yield per fowl, for different US states in the late 19th century, that varied between 3 to approximately 7 dozens per fowl (USDA Report of the Productions of Agriculture 1880, xvii). Accordingly, for 19th century Britain, in The British Trade Journal (1882, 282) it is stated that 120 eggs can be yield per fowl while there can be 75 fowls per acre. This egg yield per fowl is also corroborated by Nolan (1850, 5) (here). Thus, a rough informed estimate can be constructed of approximately 9000 eggs per acre per year. As regards the eggs' weight, that can vary a lot depending on the breed. However, based on Ward (1911, 231) (here), the average of twenty different breeds can be calculated at approximately 0.13 pounds per egg. This weight per egg is also consistent with data from Drescher (1955, 173)

5.2.8 Ham

As with other animal products, the conversion of ham into land, in other words its ecological footprint is estimated on the basis of the product's output per animal and the land required per animal.

As regards the share of ham per animal, Cuff (1992, 66) argues that in the mid-19th century US the share of different cuts from a pork to its net (carcass) weight were as follows: ham 13%, shoulder 12%, lard 17%, other 41%. Additionally the average carcass weight was 200 pounds per animal (Cuff 1992, 61; USDA Report of the Commissioner of Agriculture 1867, 390 here). Consequently, an estimate of 26 pounds per animal can be calculated.

As regards the ratio of land per animal, that is taken equal to 1 for all the years under study. For a detailed discussion on that ratio see section 5.2.10 "*Swine/ Hog/Pork*".

5.2.9 Hides and Leather

The ecological footprint of hides is not easy to estimate since a lot depends on the type of processing that the leather has already undergone (tanning) and which can significantly alter its weight. Even more, it also depends on the animal from which the hide is obtained, since different animals will have a different bearing on land. Here, we provide a rough estimation on the basis of hides from cattle and particularly oxen. This could be considered as an upwards estimation of its ecological footprint given that land devoted to cattle is approximately five times larger than that devoted to lambs.

Starting from the ratio of hides per animal, based on Stephenson (1837, 168) (here), information on an oxen's hide weight can be obtained for Britain in the early 19th century. It should be noted that oxen's hide weight is in between cow and buffalo weight so it could represent an average hide. According to the source, the hide's weight makes up about 5% of the animal's live weight with the latter ranging between 1400 and 1500 pounds. Thus, the untanned hide weight could be approximately 72.5 pounds per animal.

In order to account for changes derived from the processing of the hide and in particular for dry or wet hides, information from The Food and Agriculture Organization FAO (1994) can be used given that historical sources are unavailable. Based on FAO (1994), wet-salted hides can be almost 90% of the "green hide's" weight, i.e. the untanned hide, after flaying and removing dirt and dung. Additionally, dry salted hides make up approximately 55% of the untanned weight while dry unsalted hides are approximately is 35% of that. Consequently, on average for dry hides the weight can be 45% of the untanned hide. Finally, pickled weight is 50% of the "green hide's weight". Please note that for tanned hides, due to unavailability of sources, the conversion factor used can be the same as for untanned dry hides. This means 45% of the untanned hide's weight which would be 33.6 pounds per animal.

As regards the land devoted per animal, that is taken to be two acres. A more detailed discussion of how this estimate is obtained can be found under section 5.2.4 on "*Cattle"*.

5.2.10 Swine/Hog/Pork

When it comes to the estimation of the land required for a swine, similar challenges as in the estimation for Cattle may arise leading to diverse estimates. The main reason is that different crops give different productivities for the animal while different production practices may also give different results. Additionally, in contrast to cattle, pig production cannot be done only on pasture since forage needs to be complemented by fodder. Lastly, historical estimates are scarce and thus the ecological footprint can be calculated on the basis of estimates from the early and mid-20th century.

A first estimate on land per animal, but relatively more crude, can be provided from the U.S. Bureau of the Census (1956, 63) (here). Based on the source, the number of hogs and pigs per 100 acres of cropland in livestock farms of the US Corn Belt in the mid-20th century can be calculated. The land dedicated to hogs is approximately 2 acres per hog. However, except for being an estimate relatively contemporary, it does not account for the carrying capacity of land and the productivity of various crops but instead it is relatively aggregate. Another way of calculating the land required for a unit of meat production is by accounting for the various crops' productivities in a production system where the animals are let to harvest the grain on their own - "hogging- off". A report from 1913 provides results on the pork yield per acre for different forage crops (Mumford 1913, 27) (here). The results were obtained on the basis of agricultural experiments conducted during the years 1908-1912. For different crops and combinations of them, the pounds of pork per acre may vary significantly. However, the average from all field experiments and from all different crops suggests 262 pounds of pork per acre of forage. Given that the carcass weight of swine in the mid-19th century US was 200 pounds, this would mean that each animal would require approximately 0.8 acres of forage (Cuff 1992, 61; USDA Report of the Commissioner of Agriculture 1867, 390 here). Southwell and Treanor (1949, 41:11) (here) also provide experimental results on US-Georgia, which suggest that during the period 1936-1943, the 8-year average yield of small grains fed to hogs, was around 300 pounds of pork per acre. This would translate into 0.7 acres of forage per animal. In order to account for the higher estimate of 2 acres per animal, for the fact that more land may also be required in order to provide shelter and the fact that in the 19th century land scarcity was less of a limiting factor, a rough estimated ratio of one acre per animal can be calculated here.

5.2.11 Lard

The acreage coefficient of lard is calculated on the basis of its share per swine and subsequently the animal's ecological footprint.

As regards the product's output per animal, in the mid-19th century US the share of different cuts form a pork to its net (carcass) weight were as follows: ham 13%, shoulder 12%, lard 17%, other 41% (Cuff 1992, 66). Accordingly, in the USDA Report of the Commissioner of Agriculture 1867, 390 (here) the share of lard is also reported at 16.2% of the animal's weight. Additionally the average carcass weight was 200 pounds per animal

(Cuff 1992, 61; USDA Report of the Commissioner of Agriculture 1867, 390 here). Consequently, the weight of lard per animal can be calculated at approximately 34 pounds.

As regards the ratio of land per animal, that is taken equal to 1 for all the years under study. For a detailed discussion on that ratio see section 5.2.10 on "*Hog/Swine/Pork*".

5.2.12 Mutton

As with the other animal products the ecological footprint of mutton can be calculated on the basis of its share per sheep and the sheep requirements of land.

As regards the share of mutton per sheep, Bischoff (1842: 264) for the mid-19th century Britain provides estimates for two different scenarios. The amount of mouton per sheep is estimated at approximately 7 stones per animal or 56 pounds per sheep (one stone is taken to be 8 pounds instead of 14 because that is the equivalent for dead meat weight instead of live weight- this is also confirmed by Bischoff's calculations). Also, in Table 11 the average dressed mutton weight per animal is reported for various countries in the early 20th century according to Holmes (1916, 109:276–77). Additionally, according to the source, in the US during 1899-09 mutton weight was around 50% of the animal's live weight.

TABLE 11 A*verage dressed weight of mutton per animal, in pounds.*

Country	Year	Mouton pounds per animal
Argentina	1906/13	156
Australia	1903/12	38.7
France	1900/12	48.7
Germany	1906/11	49
Uruguay	1905/10	51

Source: (Holmes 1916, 109:276–77)

After calculating the amount of sheep necessary for mutton imports, the land requirement for them can be calculated on the basis of an average animal-land ratio for all countries based on the land ratios of England and Argentina. Under the assumption that their agricultural systems represented two extreme scenarios in terms of land availability during the 19th century such an average estimate should be representative for all countries. For late 19th century Argentina, 2.25 sheep per acre is suggested in The Queensland Agricultural Journal (1899, 267-268) (here). For England, the animal to land ratio is taken to be approximately was 4 sheep per acre (Hornborg 2006, 76; Pomeranz 2000, 315). Consequently, an average of 3 sheep per acre can be estimated.

5.2.13 Pork meat

The conversion of pork meat into land is done on the basis of its share in the swine and the animal's land requirement.

Starting from the meat's share in the animal, according to Cuff (1992, 66) and the USDA Report of the Commissioner of Agriculture (1867, 390) (here) that can be estimated in mid-19th century US at approximately 35% of the animals carcass weight. Additionally the average carcass weight was 200 pounds per animal (Cuff 1992, 61; USDA Report of the Commissioner of Agriculture 1867, 390 here). In other words, the share of pork meat can be estimated at approximately 71 pounds per swine.

As regards the ratio of land per animal, that is taken equal to 1 for all the years under study. For a detailed discussion on that ratio see section 5.2.10 under "*Hog/Swine/Pork*".

5.2.14 Skins (goat and lamb)

Given that skins are reported in numbers rather than in units of mass, then their ecological footprint can roughly be calculated on the basis of the animals' acreage coefficient. The land requirement for skins imports of goats and lambs can be calculated on the basis of an average animal-land ratio which is calculated on the basis of estimated for England and Argentina in the 19th century. That average estimate is 3 sheep per acre. For a detailed discussion on land per sheep and relevant sources see section 5.2.12 on "*Mutton*".

5.2.15 Tallow

The conversion of tallow into the land equivalent for its production is relatively complicated because it can be produced from the fat of both cattle and sheep. However, for reasons of simplicity and comparability with hide imports, a crude assumption is made that the tallow referring to British trade is produced only by cattle. In fact this assumption, although arbitrary, may not lead to wrong estimations. The reason is because the tallow output per cattle (116 pounds) is almost 5 to 6 times higher than the tallow output per sheep (20 pounds), while the land required per cattle is 5 to 6 times lower than that required per sheep. In other words, the tallow produced by cattle and that produced by sheep could have the same direct ecological footprint.

More specifically about the tallow output per animal, based on Stephenson (1837, 168) (here) for Britain in the mid-19th century, the tallow made about 8% of an oxen's live weight. As mentioned elsewhere, oxen's weight is between that of a cow and a buffalo so it could be used as an average. Also, note that the live weight of the animal was approximately 1400-1500 pounds. This means that the tallow per animal was approximately 116 pounds. Accordingly, The Farmer's Magazine (1844, 554) gives the weight of a Merino sheep's tallow on average at 20 pounds.

As regards the amount of land devoted per animal, that is taken to be approximately two acres. A more detailed discussion of how this estimate is obtained can be found under section 5.2.4 on "*Cattle*".

5.2.16 Wool

In order to calculate the amount of land embodied in wool, first it is necessary to identify the amount of fleece produced per animal and subsequently use an acreage estimate per animal. In Table 12 various sources and estimates are presented on the weight of wool per animal. These can range between regions but an average of approximately 3 pounds per animal can be considered as a safe estimate. Although it may be a bit high estimate, it should be noted that the fleece from animals other than sheep can be higher. For instance, (James 1857, 453,462) (here) states that fleece per alpaca can range between 5-6 pounds and for mohair wool the fleece weight can be around 4 pounds. Consequently, an average of 3 pounds of wool per animal can be a good estimate for all wool traded.

As regards the land required per animal, a minimum of 2 animals per acre and a maximum of 4 animals per acre can be established. See section 5.2.12 under "*Mutton*" for a discussion on sources.

TABLE 12 *Wool yield, in pounds per animal.*

Country	**Year**	**Pounds per animal**	**Source**
Argentina	c. 1890	4	The Queensland Agricultural Journal (1899, 267-269) (here)
England	c. 1850	3.5-4.5	Hornborg (2006, 76) Pomeranz (2000, 315)
India	c. 1840	1.7	Macgregor (1848, IV:832)
US	c. 1840	2-2.5	U.S. Bureau of the Census (1853, 67) (here)

5.3 Other food, drink and spices

5.3.1 Banana/Plantain

A 19th century acreage coefficient for Bananas can be calculated on the basis of evidence referring to Puerto Rico, Mexico and British Guyana. The conversion factors for each country and year are reported in Table 13 along with the relevant sources. Compared to today's estimate of 13,700 pounds per acre from Fleming (1994) these historical estimates fall within a reasonable range.

TABLE 13 *Banana yield, in pounds per acre.*

Country	Year	Pounds per acre	Source
British Guyana	c. 1820	22500	Pereira (1854, 2:223)
Mexico	c. 1840	16000	Macgregor (1847c, III:1174)
Puerto Rico	1830	22400	Macgregor (1847a, II:1081)

Note: The estimate for Puerto Rico is given in loads in the original source. It is converted to pounds under the assumption of 1,120 pounds per load.

5.3.2 Cinnamon and Cassia Lignea

An average conversion estimate for both Cinnamon and Cassia Lignea can be based on information found for Guyana and Ceylon for the whole 19th century. An average acreage conversion factor of 200 pounds per acre can thus be calculated. The conversion factors for each country and year are reported in Table 14 along with the relevant sources.

TABLE 14 *Cinnamon and Cassia Lignea yield, in pounds per acre.*

Country	Year	Pounds per acre	Source
Ceylon	c. 1867	50-500	Ripley and Dana (1859, 5:257) (here)
French Guayana	1840	50	Macgregor (1848, IV:101)

5.3.3 Cloves

The acreage conversion factor for cloves tree can be estimated for the 19th century on the basis of evidence from the East Indies and specifically the Penang Island (Malaysia). According to Simmonds (1854, 399) in 1843 in two different regions the yield per acre can be calculated at 18.8 pounds and 19.4 pounds. It should be noted that in the original source, the units of land are measured in "orlongs" and those of produce in "piculs" and "catties". They are converted to pounds per acre on the basis that one orlongs equals 1.3 acres and one picul and catty equal 133 pounds and 1.3 pounds respectively. It should be noted that these estimates, although based only on a small island, can be regarded as representative since the region was a center for clove production in the 19th century.

5.3.4 Cocoa (nuts)

The footprint estimate for cocoa nuts can be based on information found for three distinct colonies in the West Indies. The conversion factors for each region and year are reported in Table 15 along with the relevant sources. An average of all three regions for all years can be calculated at 200 pounds per acre.

TABLE 15 *Cocoa nuts yield, in pounds per acre.*

Country	Year	Pounds per acre	Source
French Guyana	1840	209	Macgregor (1848, IV:101)
Martinique	1836	246	Macgregor (1848, IV:100)
Trinidad	1831	156	Simmonds (1854, 27)

5.3.5 Cocoa-nut oil

The footprint estimate for cocoa oil is based on information for Ceylon in the mid-19th century. According to Macgregor (1848, IV:973) in circa 1840 the produce of 4,000 acres would yield 4,000 candies of "copperahs" (the fleshy part of the nut) which in turn could yield 550 tons of oil. The oil yield per acre can be calculated at 307 pounds. Note that 1 candy equals 1,656 pounds while it takes 12,043 pound of cocoa per ton of oil. This yield estimate compares well with early 20th century estimates provided by Sutton (1983, 476) as well as modern day estimates reported in Khan and Hanna (1983, 495).

5.3.6 Coffee

The ecological footprint of coffee can be calculated on the basis of various sources covering the West and East Indies and Latin America in the 19th century. The conversion factors for each region and year are reported in Table 16 along with the relevant sources. An approximate minimum and maximum acreage conversion factor can be calculated on the basis of these estimates. That can be done by taking the average estimates for all years in W. Indies as the minimum and the average of Brazil and Ceylon (which were the most productive regions) as the maximum. Then the yield range spans from around 215 pounds per acre to approximately 550 pounds per acre.

TABLE 16 *Coffee yield, in pounds per acre.*

Country	Year	Pounds per acre	Source
Brazil	1870	1000	The Spectator (1872, 478) (here)
Ceylon	1828/36	450	Martin (1839, 398)
	1840/44	470	Wenzlhuemer (2008, 61)
	1845/49	571	
	1850/54	661	
	1855/59	437	
	1860/64	347	
	1865/69	437	
	1870/74	358-504	Sharma (2007, 25); Wenzlhuemer (2008, 61)
	1875/79	224-291	
	1880/84	190	Wenzlhuemer (2008, 61)
	1885	258	
	1886	179	
Dominica	c. 1772	171	S. D. Smith (1998, 76)
	1836	225	Martin (1839, 73)
French Guyana	1840	224	Macgregor (1848, IV:101)
India	1900/47	200	Kumar and Desai (1983, 2:427)
Jamaica	c. 1772	373	S. D. Smith (1998, 76)
Martinique	1836	212	Macgregor (1848, IV:100)
Puerto Rico	1890	168	Macgregor (1847a, II:1081)
	1899	350	Bergad (1978, 84)
Trinidad	1835	108	Martin (1839, 34)

Note: As regards coffee production in Ceylon, in 1867 coffee rust epidemic attacked the coffee plantation, and by 1871, there was substantial reduction in the yield. By 1893, coffee export of Ceylon was reduced by 93%. For Brazil, the estimate is an average of two estimates reported in the source. Also the estimates for Ceylon are originally compiled from Snodgrass (1966) cited in Wenzlhuemer (2008, 61) and are calculated on the basis of exports rather than produce

5.3.7 Currants

Given the limited availability of sources on the land yield for currants, the conversion is based on the earlier estimate found for the island of Zante in Greece. Greece had been one of the major producers of currant in the 19th century with a large export share to Britain. Based on the U.S. Consular Reports (1884, 649) (here) the yield per acre in the 19th century was approximately 1600 pounds per acre. Similar information is also obtained from the United States Patent Office (1859, 353) (here) according to which the yield varied between 1500 and 3000 pounds per acre.

5.3.8 Ginger

The acreage conversion factor for ginger can be estimated on the basis of yield estimates for ginger in 19th century Jamaica and India. According to Sawer (1892, 95) (here), that was approximately 4,000 pounds per acre. Additionally, based on Ravindran and Babu (2005, 6) for 19th century India the yield was 2,500 pounds per acre.

5.3.9 Hay

An acreage conversion factor for hay in the 19th and early 20th century can be calculated from sources referring to Britain and the US. Mitchell (1988, 168,196) on Britain, gives estimates according to which in 1885 the average of pasture and rotation hay yield was 2.3 tons per acre while for 1907, an average yield was 1.5 tons per acre. Additionally, in Table 17 the yields for various years in the 19th century are reported. An average yield per acre can be calculated at approximately one and a half ton per acre.

TABLE 17 H*ay yield, in tons per acre.*

Country	Year	Tons per acre	Source
Great Britain	1885	2.3	Mitchell (1988, 168,196)
	1907	1.5	
Ireland	1847	1.9	M. E. Turner (1996, 246–47)
	1850	2.0	
	1860	2.0	
	1870	2.1	
	1880	2.0	
	1890	1.9	
	1900	2.0	
	1910	1.9	
US	1866	1.17	USDA (1958, 2–4); Baker (1921, 26); USDA Report of the Productions of Agriculture (1880, xvii)
	1870	1.08	
	1880	1.2	
	1890	1.27	
	1900	1.17	
	1910	1.1	

5.3.10 Hops

The conversion of hops into land is done based on the average of yield factors for England and Canada in the early 19th century and the US in the late 19th century. Table 18 summarizes the conversion factors along with the relevant sources. An average estimate of 740 pounds per acre can be calculated.

TABLE 18 H*ops yield, in pounds per acre.*

Country	Year	Pounds per acre	Source
Canada, Vermont	1833	750	Krakowski (2014, 93)
England	1822/31	700	Marshall (1833, 107)
US	1889	780	Porter and Wright (1895, 73) (here)

5.3.11 Molasses

The calculation of the footprint of molasses is done on the basis of how much sugar is required for a unit of product. Then, the acreage conversion factors for sugar can be used. That is taken at a fixed ratio of 6,300 pounds of unrefined sugar per acre. For more on the conversion of sugar see section 5.3.20. As regards the amount of molasses per unit of sugar various estimates along with the relevant sources are presented in Table 19. A ratio of 0.03 imperial gallons of molasses per pound of sugar can be calculated according to estimates pertaining to the mid-19th century West Indies.

TABLE 19 M*olasses per sugar yield, in imperial gallons per pound of sugar.*

Country	Year	Gallons per pound of sugar	Source
Guyana	1840	0.03	Macgregor (1848, IV:101)
Martinique	1836	0.02	Macgregor (1848, IV:100)
Puerto Rico	1830	0.03	Macgregor (1847a, II:1081); Haas (1936, 101)
Trinidad	1800	0.04	Deer and Dickinson (1947, 20)

5.3.12 Nutmegs

The acreage conversion factor for nutmegs is based on estimates for the 19th century W. Indies and specifically Guyana. In Macgregor (1848, IV:101) it is stated for 1840 that 4.9 acres for nutmegs were cultivated and gave a produce of 1.8 hundredweights. This translates to approximately 41 pounds per acre. Due to the unavailability of other sources this yield factor can be used as proxy for the ecological footprint of this product.

5.3.13 Olive oil

In Amate (2012) and Amate et al. (2013, 371) information for the mid-18th and 19thcentury Spanish oil producing region can be obtained. According to the source, olives yield per hectare barely surpassed 600 kilograms while between 1750 and 1850 the average yield increased from 200 to 1000 kilograms per acre. Similar information is also obtained from Garrido and Calatayud (2011, 602) for the province of Castellón. Given that approximately

5.5 kilograms of olives produce a litter of oil the oil yield per acre can be calculated at 109 litters. Expressed in imperial gallons, it is 23.9 per acre. Accordingly, Cussó et al. (2006, 56) provide a yield estimate for Spain in the 1870s at 80 liters per acre. Due to unavailability of more sources these estimates can be used to calculate a proxy estimate of the direct ecological footprint of olive oil.

5.3.14 Onions

The footprint of onions can be calculated on the basis of limited estimates from the US and Britain. For 1905, based on information in the USDA Farmer's Bulletin (1905, 18) (here) the yield per acre in Southwestern US, varied between 326 bushels per acre to 700 bushels per acre with or without irrigation and fertilization methods. A somewhat lower estimate is provided for an early 19th century English Bedfordshire, at 200 bushels per acre (Beavington 1975, 24) Thus an average of approximately 500 bushels per acre can be calculated.

5.3.15 Palm oil

Due to the unavailability of abundant historical sources, the conversion of palm oil into land is done on the basis of both modern and historical estimates. According to Nkongho et al. (2014, 2) referring to the non-industrial oil sector in Cameroon approximately 0.8 tons of palm oil per hectare is the annual produce or 713 pounds per acre. This yield factor could be used as a proxy estimate for the 19th century given that it refers to a pre-industrial production structure. A similar estimate is also obtained from a mid-19th century source which suggests 800 pounds per acre Pharmaceutical Journal (1855, 264) but does not designate a particular geographical region. More modern- day estimates for Africa and Asia range between 1100 to 4000 pounds per acre (Valencia et al. 1993, 2201; O'Brien 2009, 3)

5.3.16 Pepper

The acreage conversion factor for pepper is based on an estimate from the 19th century on East Indies and specifically Penang, Sumatra and Java. The yield factor is 1,165 pounds per acre (Balfour 1873, IV:509) (here). A similar average yield for circa 1820 of 1,175 pounds per acre for both Penang and Bengkulu, Sumatra can be calculated from Bulbeck (1998, 65) (the yield for Penang was 2,040 pounds per acre while that of Bengkulu 310 pounds).

Additionally, for Singapore in circa 1850, an estimate of approximately 1,577 pounds per acre can be calculated (Jackson 1965, 79).

5.3.17 Pimento

The conversion of pimento into land is done on the basis of estimates from the W. Indies in the mid-19th and late 19th century as this region was a major exporter. The estimates along with the relevant sources are presented in Table 20. An average estimate of 500 pounds per acre can be calculated for estimating the ecological footprint of the product.

TABLE 20 P*imento yield, in pounds per acre.*

Country	Year	Pounds per acre	Source
French Guyana	1848	157	Macgregor (1848, IV:101)
Jamaica	c.1820	220	Higman (2001, 192–93)
	1871	955	Flückiger (1879, 288) (here)

Note: For Jamaica, the yield estimate from Flückiger (1879, 288) is calculated on the basis of exports rather than produce. Given that most if not all of the produce was exported this is not expected to significantly bias the estimate.

5.3.18 Potatoes

The conversion factor of potatoes can be calculated on the basis of various estimates presented in Table 21. An approximate minimum and maximum conversion factor could range between 4,000-10,000 pounds per acre.

TABLE 21 P*otatoes yield, in pounds per acre.*

Country	Year	Pounds per acre	Source
Australia, Whales	1835	2800	Macgregor (1850, V:145)
	1840	9540	
	1844	7390	
Austria	1909/13	8859	Eddie (1968, 213)
Belgium	1909/13	16630	
Bulgaria	1909/13	3542	
Canada, Prince Edward Island	1847	3808	Macgregor (1850, V:322)
Denmark	1909/13	13231	Eddie (1968, 213)
France	1815/24	10320	Newell (1973, 714–15,18-19)
	1865/74	14745	
	1909/13	7646	Eddie (1968, 213)
Germany	1909/13	12223	
Great Britain, England	1770	24000	Nunn and Qian (2011, 600)
Great Britain	1909/13	12972	Eddie (1968, 213)
Hungary	1909/13	7111	

TABLE 21 P*otatoes yield, in pounds per acre (cont.)*.

Country	Year	Pounds per acre	Source
Ireland	1670	4400	Iomaire and Gallagher (2009, 155)
	1800	22000	
	c.1830	13500-18000	Davies (1994, 561)
	1847	16128	M. E. Turner (1996, 245–47)
	1850	10304	
	1860	5152	
	1870	8960	
	1880	8064	
	1890	8960	
	1900	5376	
	1910	9632	
Italy	1909/13	5139	Eddie (1968, 213)
Netherlands	1830/40	10867	Macgregor (1847b, I:902)
	1909/13	12749	Eddie (1968, 213)
New Zealand, Auckland	1857	17637	Hargreaves (1959, 65)
Romania	1909/13	7628	Eddie (1968, 213)
Puerto Rico	1835	2705	Macgregor (1847a, II:1081)
S. Africa, Cape of Good Hope	1836	2576	Simmonds (1854, 495)
Spain, Catalonia	c.1870	3567	Cussó, Garrabou, and Tello (2006, 56)
US	1800s	6720	Davies (1994, 561)
	c. 1791	4850	Gallman (1972, 199)
	1800	4850	
	1866	5470	USDA (1959c, 27); USDA Yearbook (1907, 652)
	1870	4490	
	1880	5030	
	1890	3990	
	1900	5200	
	1907	5600-5990	

Note: For 1800 US, the units in the original source are bushels per acre. They have been converted to pounds on the basis of 52.5 lbs per bushel. The estimates from Eddie (1968, 213) are expressed in quintals per hectare. They are converted to pounds on the basis of 220.462 lbs per quintal. Potato bushels are converted to pounds on the basis of 52.5 lbs per bushel.

5.3.19 Raisins

Given the limited availability of sources on the land yield of raisins, the conversion is based on that for currants. The yield per acre is taken to be 1500 pounds. For more information regarding the sources see section 5.3.7 "*Currants*".

5.3.20 Sugar

Throughout the 19th century sugar production from beet roots increased in significance while as regards British trade, that was dominated by beet-root sugar exports from other

European countries in the early 20th century. During the second half of the 19th century and even more so in the later part of it, beet root production in many European countries had increased significantly. Heavily subsidized by the state, beet sugar production in Germany, France, Belgium, Austria, Russia and the Netherlands had increased to such an extent that by 1880, beet-sugar made almost 50% of total world sugar production. The corresponding share was just 5% in the 1830, while from 1880 up until the First World War, when it again started to decline, beet-root sugar's share mostly fluctuated between 40-50% of the world's sugar production (the rest made up by cane) (Deerr 1949, 2:490). Consequently, in terms of British trade, it is necessary to provide estimates of acreage conversion factors on the basis of both cane sugar and beet-root sugar in order to account for the changes in the 19th century.

TABLE 22 B*eet-root sugar yield, 1903-1905.*

Country	Average kilograms of beets per acre	Average refined sugar yield per acre, in kilograms	Average unrefined sugar yield per acre, in kilograms	Average unrefined sugar yield per acre, in pounds	Average refined sugar yield per acre, in pounds
Austro-Hungary	8890	1264	1378	3038	2787
Belgium	10350	1360	1490	3286	2998
Denmark	9950	1350	1542	3400	2976
France	10250	1250	1363	3005	2756
Germany	10850	1640	1812	3995	3616
Holland	9250	1300	1434	3161	2866
Italy	9500	1180	1264	2786	2601
Russia	5450	805	910	2007	1775
Sweden	9900	1400	1535	3383	3086

Source: Based on information from S. W. Lewis (1905, 39) (here)
Note: The refined sugar is calculated based on the ratio of approximately 1:1.1 between raw and refined sugar according to (Jodidi 1911, 8).

TABLE 23 Beet-root sugar yield, 1906-1908.

Country	Average tons of beets per acre	% of raw sugar	% of refined sugar	Tons of Raw sugar per acre	Tons of refined sugar per acre	Pounds of raw sugar per acre	Pounds of refined sugar per acre
Austria	10.4	15.6	14.1	1.6	1.5	3527	3306
Belgium	11.75	15	13.5	1.8	1.6	3960	3527
France	10.3	13.2	11.9	1.4	1.2	3000	2645
Germany	12.5	15.7	14.1	2	1.8	4409	3968
US	9.7	12	10.8	1.2	1.0	2650	2200

Source: based on information from Jodidi (1911, 8)
Note: The percentage of refined sugar is calculated based on the ratio of approximately 1:1.1 between raw and refined sugar according to Jodidi (1911, 8).

5.3.20.1 Beet-root sugar

In Tables 22 and 23, the yields per acre of refined beet-root sugar are estimated for various European countries between 1903-1908 according to information from Jodidi (1911, 8) and S. W. Lewis (1905) (here). It should be mentioned, that although these estimates cover the early 20th century, other estimates pertaining to the 19th century may suggest that yields did not change significantly. For instance, estimates for 1899 in Germany are reported at 10,724 kilograms of beets per acre, for circa 1850 France and Northern Germany sugar yields are noted to have ranged between 3,700 and 4,400 pounds per acre while for Austria at 2,200-3,300 pounds per acre (Perkins (1981, 80). Accordingly, beet-roots yield per acre for France is estimate at approximately 6 tons per acre in 1812 when the beet-root industry was established, while for 1877 Germany the sugar yield is estimated at approximately 3,000 pounds per acre (F. S. Harris 1919, 12,14). For European countries for which conversion factors are not available, an average yield factor can be used. For raw or unrefined sugar, that can be 3,726 pounds per acre while for refined, that can be 3,287 pounds per acre. The conversion ratio between refined and unrefined beet sugar is approximately 1:1.1 according to Jodidi (1911:8) (here). For non-European countries, historical estimates are scarce.

5.3.20.2 Sugar Cane

As regards the footprint of refined sugar produced by cane, in Table 24 the acreage conversion factors identified for various countries are presented along with the relevance sources. According to these, minimum and maximum estimates can be established for various regions.

For sugar produced in the Americas, an approximate minimum and maximum average yield of refined sugar can range between 1200 pounds per acre and 3200 pounds per acre. It should be noted that for some regions such as the Hawaiian Islands, Cuba, Peru, Brazil and Guiana, these range estimates may not represent the higher productivity that was observed in the first decade of the 20th century. As regards the Hawaiian Islands, the relatively higher productivities are probably explained by the cultivation of the endemic extremely high yielding canes (Deerr 1949, 1:28). For sugar produced in Australasia, approximate minimum and maximum yields can be 2600 pounds per acre and 3500 pounds per acre respectively. Again, this range may not represent productivity in Java in the late 19th, early 20th century when it increased significantly. For sugar from African countries and other than these reported here an average of minimum and maximum estimates of 1600 and 2600 pounds per acre can be used. This range is very close to the "stylized" figure that Rönnbäck (2009) provides (1,900 pounds per acre) based on yields for Jamaica and Barbados in the 17th century.

Another thing that needs to be noted is the conversion ratio between refined and unrefined cane sugar. This ratio is taken to be 1:3, meaning that unrefined sugar loses one third of its weight when refined. This conversion factor is based on two different sources from the mid and late 19th century. In particular, Macgregor (1848, IV:543) argues that the proportion of clayed sugar to "*Goor*"/"*Gur*" is 7 to 24. Similarly, in Watt (1893, 6:134,341) (here) it is stated that the W. India muscovado sugar loses about 1/3 of its weight when clayed while it is also stated that the ration between "goor" and refined or crystallized sugar is 2.5 or 3 to 1. Deerr (1949, 1:59) takes this ratio at 2:1 after 1890.

TABLE 24 *Refined cane sugar yield, in pounds per acre.*

Country	**Year**	**Pounds per acre**	**Source**
Australia	1882	2195	Geerligs (1912, 337-9); Griggs (2004, 26)
	1885	3248	
	1890	3786	
	1895	3472	
	1900	2867	
	1905	2845	
	1910	3875-5645	F. S. Harris (1919, 330-1); Geerligs (1912, 339)
Cochin China	1989	2366	Geerligs (1912, 73)

TABLE 24 R*efined cane sugar yield, in pounds per acre (cont.)*

Country	**Year**	**Pounds per acre**	**Source**
India	c. 1840	2600	Macgregor (1848, IV:543)
	1870	1755	Broadberry, Custodis, and Gupta (2015, 64)
	c. 1890/1910	600-2600	Geerligs (1912, 44-46); Blyn (1966, 283–87); Broadberry, Custodis, and Gupta (2015, 64)
	1900/47	2900	Kumar and Desai (1983, 2:427)
Java	1834	1210	Deerr (1949, 1:219)
	1840/44	1812	Geerligs (1912, 133-135); Galloway (2005:7, 21)
	1844/49	2370	
	1850/54	2605	
	1855/59	3017	
	1860/64	3358	
	1865/70	3860	
	1880	4682	
	1888	7298	
	1893	6300	
	1896	6850	
	1900	7000	
	1905	8137	
	1910	3242-8960	
Japan	1910	3242-3360	F. S. Harris (1919, 330-1); Geerligs (1912, 86)
Philippines	1896	3520	Palmer (1908, 20) (here)
	c. 1910	3640	Geerligs (1912, 99)
Egypt	1835	2761	Macgregor (1847a, II:231)
	1905/06	1560	Geerligs (1912, 296)
	1907/08	2850	
Mauritius	1801	700	Deerr (1949, 1:184)
	1840	1174	Macgregor (1850, V:129)
	1842	1311	
	c. 1910	2462	Geerligs (1912, 309-10)
Mozambique	1909	3178	Geerligs (1912, 301)
	1911	2068	
Natal	1860	3136	Deerr (1949, 1:192)
	1866	1194	Graves and Richardson (1980, 226)
	1893	2678	

TABLE 24 *Refined cane sugar yield, in pounds per acre (cont.)*

Country	Year	Pounds per acre	Source
Réunion Island	1825	2089	Geerligs (1912, 325-28)
	1833	2644	
	1840	3234	
	1846	1635	
	1851	1566	
	1856	1725	
	1860	1970	
	1882	1570	
	1890	1666	
	1901	2740	
	c. 1910	1518	
Spain	1600s	2240	Deerr (1949, 1:81)
	1910	3360-4256	F. S. Harris (1919, 330-1); Geerligs (1912, 144)
Argentina	1858	900	Deerr (1949, 1:135)
	c. 1910	1700-2800	F. S. Harris (1919, 330-1); Geerligs (1912, 286)
Barbados	c. 1910	1214	Geerligs (1912, 215)
Brazil	c. 1650	2500	Deerr (1949, 1:108)
	c. 1910	10000	Geerligs (1912, 278)
Cuba	1860	1378	Dye (1994, 636)
	1877	1974	
	1900	2000	Ayala (1995, 99);
	1904	6150-10960	Geerligs (1912, 170-1); Dye (1994, 636)
	1908	4112	Geerligs (1912, 170-1)
	1912	4494	F. S. Harris (1919, 330-1)
Dominica	1835	1254	Martin (1839, 73)
British Guiana, Demerara	1891	3234	Geerligs (1912, 261-2)
	1895	3330	
	c. 1910	3500-3800	
Dutch Guiana	c. 1910	8500	Geerligs (1912, 266)
French Guyana	1840	1624	Macgregor (1848, IV:101)
Guatemala	c. 1910	1890	Geerligs (1912, 245)
Hawaiian Islands	1895	6356	Geerligs (1912, 350-1)
	1900	8662	
	1905	8942	
	1910	9407	
	1911	11782	F. S. Harris (1919, 330-1)
Jamaica, St Andrews	1753	790	Ryden (2000, 48)
Jamaica	1798	1200	Deerr (1949, 2:333)
	1906	1867	Geerligs (1912, 221)
Martinique	c. 1732	850	Deerr (1949, 1:233)
	1836	1277	Macgregor (1848, IV:100)

TABLE 24 *Refined cane sugar yield, in pounds per acre (cont.)*

Country	Year	Pounds per acre	Source
Nicaragua	1906/07	800-2340	Geerligs (1912, 248-9)
Peru	c. 1910	3500-6700	Geerligs (1912, 270-2)
Porto Rico	1830	3137	Macgregor (1847a, II:1081)
	1899	1250	Crist (1948, 180); Geerligs (1912, 199-200)
	1908	2000-4266	
St. Croix	c.1910	2912	Geerligs (1912, 243-4)
US	1840	2000	Macgregor (1847c, III:439)
US, Louisiana	1905	2400	Geerligs (1912, 155)
US, Louisiana	1911	2531	F. S. Harris (1919, 330-1); Follett (2005)

Notes: For Australia, the yields between 1882 and 1900 refer to Queensland, while that of 1905 and the lower estimate of 1910 are the average of Queensland and New Wales. For India the 1840 figure is the average of the estimates between two Bengal regions. In the original source the information refers to "goor" or unrefined sugar. It has been converted to refined here based on the conversion ratio of 1:3.4 reported in this source. Bighas have been converted to acres on the basis of 0.3 acres per bigha. The estimates for 1890-1910 India are the averages of 6 different Provinces and are converted from "goor" to refined sugar based on a 1:3 ratio. For 1834 Java, the units in the original source are converted on the basis of 1bouw=500 square rods=72,000 sq. feet= 1.65 acres and 1 pecul=133 pounds. For Philippines in 1910 is calculated as the average of different yields ("ratooning processes") described in the source. For Egypt, the conversion from feddans and cantars in the source to acres and pounds is done on the basis 1.038 acres per feddan and 110.23 pounds per cantar. Also, the yield of 1905/06 is calculated on the basis of 1903/04 acreage. For Natal, the figures are refer to raw sugar in the original source. They are converted to refined sugar on the basis of approximately 30% weight loss. For 1910 Spain, the lower estimate is obtained from Geerligs based on the lower cane yield of 15 tons per acre and a sugar content of 1%. For 1753 Jamaica, the estimate refers to the average of 25 plantations in the St. Andrews parish. Also, the yield is converted from hogsheads to pounds on the basis of 1,621 lbs per hogshead Ryden (2000, 54). For Martinique, the 1732 yield is based on area under cultivation from 1731. For 1905 Louisiana is calculated based on an average percentage yield of sugar from those provided in the original source.

5.3.21 Tea

The conversion of tea into land is done based on a yield estimates per acre for India and Ceylon and an average yield of 200-500 pounds per acre can be used. The relevant sources and yield estimates are presented in Table 25.

TABLE 25 *Tea yield, in pounds per acre.*

Country	Year	Pounds per acre	Source
Ceylon	1881	158	Wenzlhuemer (2008, 83)
	1885	531	
	1890	750	
India, Assam	c.1850	140	Nath (2005, 8–9)
	c. 1870	200	
India	1885	320	Wickizer (1951, 429); Nath (2005, 8–9)
	1891	344	Blyn (1966, 293)
	1895	346	
	1900	399	
	1905	423	Blyn (1966, 293); Kumar and Desai (1983, 2:427)

5.3.22 Tomatoes

For the footprint of tomatoes, a contemporary acreage conversion factor from the early 20th century US can be used due to the unavailability of sources. In particular, for 1929 the yield per acre for the country as a whole was 117 bushels or 113 imperial bushels (USDA 1931, 49) (here). Given that one tomato bushel equals 60 pounds a yield factor of 6,780 pounds per acre can be estimated.

5.3.23 Wine

The estimation of the land requirements for the production of a unit of wine can be done based on data for various countries throughout the 19th century. Table 26 summarizes information from various sources. An average estimate of 300 imperial gallons per acre could be used.

TABLE 26 *Wine yield, in imperial gallons per acre.*

Country	Year	Gallons per acre	Source
Australia, Whales	1845	100	Macgregor (1850, V:145)
Austria	c. 1845	450	Macgregor (1847b, I:13–14)
France	1819	195	Macgregor (1847b, I:366); Simpson (2011, 66)
	1824	180	
	1827	189	
	1862	200	Simpson (2011, 66); Loubère (1978, 165)
	1870/79	250	
	1880/89	142	
	1890/99	236	
	1900/09	338	
Hungary	c. 1845	550	Macgregor (1847b, I:13–14)
Portugal	c. 1840	155	Macgregor (1847a, II:1171)
Prussia	1832	152	Macgregor (1847b, I:587)
	1833	274	
	1834	389	
	1835	364	
Spain	c. 1870	120	Cussó, Garrabou, and Tello (2006, 56)
US, Mississippi	1840	200-400	Macgregor (1847c, III:419)

Note: For Portugal the yield refers to the islands Fayal and Pico while in the original source the data is reported in "pipes". They have been converted to imperial gallons on the basis of 105 gallons per pipe.

5.4 Raw materials

5.4.1 Bark (for tanners)

Due to limited information available, the acreage conversion factor is based on data from the UK and the US. The relevant sources and yield estimates are presented in Table 27. An average estimate of 4,000 pounds per acre can be calculated.

TABLE 27 *Bark yield, in pounds per acre.*

Country	Year	Pounds per acre	Source
Great Britain	c. 1800	3200	J. Smith (1805, 138) (here)
	c. 1810	3360-4480	Sinclair (1814, II:248)
US	c. 1870	4600	McGregor (1988, 76); McGregor (1989, 11); Long (1991, 74)

Note: The data in J. Smith (1805, 138) are reported in Dutch stones. They are converted to pounds on the basis of 16 pounds per stone. The estimate for the US has been calculated on the basis of approximately 10 cubic feet of bark per cord (Worthington and Twerdal, 1950, 3) and an average estimate of 625 kilograms per cubic meter (see section 5.4.3 under "*Coal*").

5.4.2 Bark (Peruvian)

The acreage conversion factor for Peruvian Bark can be estimated based on the sources presented in Table 28. An average estimate of 250 pounds per acre can be calculated.

TABLE 28 B*ark (Peruvian) yield, in pounds per acre.*

Country	Year	Pounds per acre	Source
Jamaica	c. 1860	253	Edwards (2014, 73)
Java	c. 1865	530	Russell (1943, 607)
Unknown	c. 1870	300	Youmans (1873, II:381) (here)
	c. 1880	200	Hamilton (1883, 36) (here)

Note: The estimate for Java could be considered a high estimate since it was a product of hybrid and is also referred to the sources as "*the world's best cinchona trees*".

5.4.3 Coal

The conversion of coal into land is done on the basis of wood. In other words, what is asked is how much natural wood would have been required to substitute for a unit of coal on a sustainable yield basis. That conversion factor is taken to be 3.5. That is based on the calorific content of wet wood and coal. In particular, based the Irish Department of Agriculture, Food and the Marine and the calorific content of wet wood of 45% moisture is approximately 9.4 Gigajoule per tonne or expressed in calories, 2.25 million kcal per tonne. Additionally, based on Wrigley (1988, 54–55) the calorific content of coal is 8 million kcal/ton. Consequently, the conversion factor can be calculated at 3.5 units of real (not dry) wood per unit of coal. This is also consistent with the conversion ratio provided in Kofman (2010, 4), which on average for 45% and 55% moisture content in wood is 3.3.

It should be mentioned that Wrigley (1988) provides a conversion ratio of coal to wood at 1:2 based on the heat output of burning wood and coal. A similar ratio can also be derived from Krajnc (2015, 15). Nevertheless, these conversion factors refer to dry wood with low moisture content and not natural standing wood which contains higher moisture content but also a lower calorific value. Since the conversion aims at identifying the amount of standing timber, it is also more relevant to use the conversion factor of 3.5.

The next step is the conversion of natural wood into land. That is done on the basis of a minimum and maximum yield of world average tons of wood mater per unit of acre. Previous similar studies have used yield estimates which ranged between 1.2 tons per acre up to 3.2 tons per acre. In particular, Pomeranz (2000, 276) used data from Smil (1983, 36) where he argues that for naturally grown forests, the global annual yield could be 1.45 tons per acre. Wrigley (1988, 55) has used an average of 2 tons per acre. For the US, based on the US Congress, Office of Technology Assessment (1983, 148–50) (here), an average minimum and maximum annual yield of naturally grown wood per acre can be calculated. That would range between 1.2 tons per acre and almost 1.8 tons per acre respectively. More specifically, in the study, the "commercial" natural timberland is presented for 1977 along with the areal production capacity of it measured in cubic feet per acre per year. By "commercial" what is considered is the amount of naturally grown timberland which is capable of producing at least 20 cubic feet per acre per year. The vast majority of this area has a productivity which ranges between 50-85 cubic feet per acre per year. Also, by far the most commonly grown tree is Oak. Oak has a density of 47 pounds per cubic foot. It thus can be calculated that the minimum and maximum yields could range between 1.2 tons per acre and almost 1.8 tons per acre respectively. However, it could be argued that these estimates are relatively high for the UK. Based on historical and contemporary information on Britain from Churche (1612, 29), Houghton (1727, 1:100-1), Warde (2007) and the UK Forestry Commission (2002, 64) woodland yields are reckoned to be approximately 3.3 cubic meters of solid timber per hectare or 0.85 tons per acre (given that 1 cubic meter of wood is on average 625 kilograms). However, Clark (2004, 51) who used modern estimates of productivity of coppiced woodland in England, reports a higher yield estimate of 1.27 tons per acre of dry wood. In order to account for a margin of error and given the aforementioned higher estimates, a higher conversion factor of 1.2 tons per acre can also be used when referring to coal in the UK.

Consequently, based on these estimates, a minimum and maximum annual yield can be established for British *"coal-wood"* which can range from 0.85 tons per acre to 1.2 tons per acre.

5.4.4 Cotton

The direct footprint of cotton can be calculated with the use of acreage conversion factors of cotton from different sources. In Table 29 the conversion factors identified for various countries are presented along with the relevant sources. Depending on the region, a minimum and a maximum yield can be calculated for the 19th century.

For the US, the minimum and maximum yield factors can be calculated at 180 and 220 pounds per acre respectively. For Egypt, the minimum and maximum yield factors are 200 and 350 pounds per acre while for the minimum and maximum estimates are 45 and 70 pound per acre respectively. For Asia, the minimum and maximum yield factors can vary between 80 and 180 pounds per acre. Finally, for regions other than the ones specified in Table 29 minimum and maximum estimates can be calculated on the basis of averages from the data presented here. That means a minimum of 140 pounds per acre and a maximum of 210 pounds per acre. These general estimates are also corroborated by Mulhall (1899, 158) (here).

TABLE 29 *Cotton (ginned) yield, in pounds per acre.*

Country	Year	Pounds per acre	Source
Bahamas	1785	112	Saunders (1990, 333)
	1786	110	
	1787	109	
	1788	110	
Ceylon	1828/36	180	Martin (1839, 398)
China	1620	105	R. C. Allen (2009, 535-6)
	1820	132	
Egypt	c. 1835	213	Macgregor (1847a, II:229)
	1879	313	A. Richards (1978, 729)
	1880	175	Mulhall (1899, 158) (here)
	1885/89	326	A. Richards (1978, 729)
	1898-1905	350	U.S. Bureau of the Census (1906, 53)
French Guyana	1840	67.7	Macgregor (1848, IV:101)
India	c. 1600	161	Moosvi (1987, 65,80)cited in Broadberry, Custodis, and Gupta (2015, 64)
	c. 1840	182	Macgregor (1848, IV:748)
	c. 1870	160	Moosvi (1987, 65,80)cited in Broadberry, Custodis, and Gupta (2015, 64)
	1891	57	Blyn (1966, 288); Misra (1987, 11)
	1895	76	
	1900/05	70-106	Blyn (1966, 288); U.S. Bureau of the Census (1906, 52) (here); Mulhall (1899, 158); Heston (1973, 310); Misra (1987, 11)
Martinique	1836	67.1	Macgregor (1848, IV:100)
St. Lucia	c. 1835	44.5	Martin (1839, 34)
Trinidad	c. 1835	68.8	Martin (1839, 34)

TABLE 29 *Cotton (ginned) yield, in pounds per acre (cont.)*

Country	Year	Pounds per acre	Source
US	1737	40	Chaplin (1993, 304)
	c. 1800	124-216	Macgregor (1847c, III:454); U.S. Bureau of the Census (1960, 281); Whartenby (1977, 54); Gallman (1972, 199); Rasmussen (1962, 583)
	1810	140-148	Whartenby (1977, 54)
	1820	140-236	Chaplin (1993, 304–5); Whartenby 1977, 54)
	1830	155-225	Whartenby (1977, 54)
	1840	147-249	U.S. Bureau of the Census (1960, 281); Whartenby (1977, 54); Rasmussen (1962, 583)
	1850	180	McDonald and McWhiney (1980, 1096); Hornborg (2006, 76)
	1866	121.5	USDA (1955a)
	1870	208	
	1879-1905	180-220	U.S. Bureau of the Census (1906, 49) (here); USDA Report (1880, xvii); USDA (1955a); Mulhall (1899, 158) (here); Rasmussen (1962, 583); Hart (1977, 316); Fogel and Engerman (1977, 281)
	1890	196	USDA (1955a)
	1900	195	
	1908	204	

Note: The estimate from Heston (1973, 310) is the average of various Bombay districts. For India, the yields for 1600 and 1870 are most probably reported in seeded cotton. They are converted to ginned cotton here on the basis that ginned cotton is approximately 3 times lighter than seeded cotton (McDonald and McWhiney, 1980, 1096)

5.4.5 Flax

The estimation of flax's footprint is relatively complicated. The reason is that in the trade statistics, dressed and undressed flax may be reported under the same name but the yield factors of dressed flax (flax fiber) and undressed (retted) flax may vary significantly.

Bernard (1851, 18–19) provides such information on flax manufacture at different stages with the loss of weight that occurs in each. According to the study, the yield of raw flax per acre in Ireland has been in the mid-19th century 40-45 hundredweights per acre of flax straw. When removing the seed, there was a loss of weight of 20-25% so that the yield of pure flax straw before retting (dipped into water) would be 32 hundredweights per acre. After retting, a further weight loss occurs of 20-25% from the pure flax, meaning that the yield of retted (undressed) flax straws would be 24 hundredweights per acre. An average of flax fiber per hundredweight of retted flax straw would be 20-22 pounds. Consequently, based on this information, the flax fiber per acre would be 504 pounds per acre or approximately 4.5 hundredweight per acre. In fact, this estimate of flax fiber yield per acre is very consistent with those from other sources for Ireland near 1850. This strengthens the assertion that dressed (fiber) flax per acre, can be five times heavier than the unprocessed retted straw per acre. From A. J. (Warden 1867, 13) (here) and M. E. (Turner 1996, 245), the yield of flax fiber per acre for the period 1847-19014 can be calculated. That ranged on average between 3 to 5 hundredweights per acre. Consequently, for the production of flax fiber, a significant loss of weight occurs from the initial harvested flax straws, such that the undressed flax can weight approximately five times more than the dressed (fiber) flax. This ratio of 1:5 between dressed and undressed flax is also the one used here.

As regards the acreage conversion factors of flax fiber (dressed) in various countries, an estimate from Gallman (1972, 199) for the 1800s US suggests 100 pounds per acre for dressed flax. Accordingly, for circa 1790 Scotland, (W. H. K. Turner 1972, 134) gives an estimate of 400-450 pounds per acre. For Argentina in c. 1900 J. R. Smith (1903, 136) provides an estimate of approximately 550 pounds per acre. Other estimates are presented in Table 30 pertaining to 1880 and covering various European countries. The yield figures of flax fiber in all these countries are adequately covered by the range of estimates for 19th century Russia found in the Science Journal (1891, 309–10) *Flax Culture in Russia*. It is stated that the average yield for the entire region in the 19th century may range from 300 to 600 pounds of flax fiber per acre or 2.7 to 5 hundredweights of fiber per acre.

Thus these estimates from Russia can be used as minimum and maximum acreage conversion factor estimates for all countries. Consequently, an average yield of both dressed and undressed flax for this period could be 9 to 15 hundredweights per acre.

TABLE 30 *Flax yield in 1880, in hundredweights per acre*

Country	**Acres**	**Fiber produce, in long tons**	**Flax fiber, in cwt per acre**	**Undressed flax, in cwt per acre**	**Average of dressed and undressed flax, in cwt per acre**
Austria - Hungary	245090	50463	4,12	20,6	12,35
Belgium,	140901	29580	4,20	21,0	12,60
Denmark	6292	787	2,50	12,5	7,50
Egypt,	15000	1875	2,50	12,5	7,50
France,	162099	36969	4,56	22,8	13,68
Germany,	329962	57432	3,48	17,4	10,44
Great Britain	8985	1398	3,11	15,6	9,34
Greece	957	119	2,49	12,4	7,46
Holland,	44114	7386	3,35	16,7	10,05
Ireland,	157534	24508	3,11	15,6	9,33
Italy,	200356	22953	2,29	11,5	6,87
Russia,	2000000	250000	2,50	12,5	7,50
Sweden	33639	4205	2,50	12,5	7,50

Source: Koelkenbeck (1883, 25) (here)
Note: Then undressed flax yields are calculated on the basis that undressed flax is five times heavier than flax fiber.

5.4.6 Gutta percha

Due to the limited availability of information on the commodity, the acreage conversion factor of Gutta Percha can be done on the basis of the earliest conversion factors found which refer to the early 20th century Java. In The Tropical agriculturist (1909, 107) (here), it is stated that the planting of 2,240 acres are expected to yield 59,048 pounds of dry gutta percha per year. Nevertheless, significantly higher estimates are presented in Table 31 based on Williams (1964, 17) for the years 1916-1920. An average of 350 pounds per acre can be calculated.

TABLE 31 *Gutta Percha yield, in pounds per acre.*

Country	**Year**	**Pounds per acre**	**Source**
Java	1916	278	Williams (1964, 17)
	1917	359	
	1918	364	
	1919	390	
	1920	401	

5.4.7 Hemp

When converting hemp into land area, one needs to be cautious due to the yield differences between dressed (fiber) and undressed (unprocessed) hemp per acre. As in the case of flax, there is a significant loss of weight in the manufacturing process. Based on Davis (2007, 218), Franck (2005, 185) and Fessenden (1826, 4:5) here it can be estimated that the weight of hemp fiber is approximately 8-9 times less than that of undressed or retted hemp. Consequently, in respect with British trade, when dressed and undressed hemp are reported together an average yield of the two can be used as a proxy acreage conversion factor.

Now, turning to the yields per acre, various estimates have been found mainly for the mid-19th century. Rhind (1866, 419) (here), argues that in general the produce averages from 4 to 5 hundredweights per acre of clean hemp (fiber) and 6 to 24 bushels of seed. For France, A. J. Warden (1867, 312) (here) gives the average produce of hemp fibre in 1841 at 3 hundredweights per acre and in 1852 at 4 hundredweights per acre. For the US, Hopkins (1951, 109) states that for Kentucky the average produce of hemp in 1849 was 650 pounds per acre. Accordingly, Gallman (1972, 199) provides an estimate of 700 pounds in 1800s US. Given that the estimates for France and the US are very close to the general ones provided by Rhind (1866, 419), the latter ones can be used as proxy estimates for the product's ecological footprint. An average yield for both dressed and undressed would thus be 21.25 hundredweights per acre.

5.4.8 Indigo

The direct ecological footprint of indigo can be calculated on the basis of estimated from India from various sources. Watt (2014, 4:405) pertaining to the late 19th century estimates for different regions in India, different yields per acre. An average estimate of 16.6 pounds of indigo dye per acre can be estimated. For the early 19th century, G. R. Porter (1833, 362) (here) provides an estimate of approximately 8 pounds per acre in Bengal which is consistent with the yields for lower Bengal provided by Watt. Also, for India between 1891 and 1910 an average yield estimate per acre was approximately 14.5 pounds while the yields ranged between 11 and 18 pounds (Blyn 1966, 310). Finally, in M'Cann (1883, 104) an estimate of 12 pounds per acre is given for Bengal. Given these estimates a minimum and maximum yield per acre at 14 and 17 pounds per acre can be estimated.

It should be noted that indigo yield estimates pertaining to the 19th century are also available for the US (Chaplin 1993, 203; Hurt 2002, 47; D. B. Warden 1819, 2:482; Simmonds 1854, 461; Cummins 1988, 41) since indigo cultivation there was already in place from the 18th century. These yield estimates are however in some instances even seven times higher than the ones reported for India. Interestingly, none of these sources provides clear accounts which distinguish between dye or indigo leaves. On the contrary, the study by Watt on India provides very detailed calculations of yields for both dyes and leaves. Additionally, when it comes to British trade, Indigo from India is more relevant. Consequently, in respect with British trade and the ecological footprint of indigo, only the range of acreage conversion factors from India should be considered.

5.4.9 Jute

The conversion of jute into land is done on the basis of jute fiber yields per acre found from various sources for India. Table 32 summarizes information from the different sources. An average estimate of approximately 1700 pounds per acre can be calculated. This is consistent with Buchanan (1999, 34), where it is generally stated that jute can yield up to four times as much fiber per acre as a crop of flax. Given that flax fiber yield per acre ranged between 2.7 and 5 hundredweights this means that jute's yields per acre would be 10.8 to 20 hundredweights or 1200 to 1700 pounds per acre

TABLE 32 *Jute yield, in pounds per acre.*

<table>
<tr><th>Country</th><th>Year</th><th>Pounds per acre</th><th>Source</th></tr>
<tr><td>India, Bengal</td><td>1872</td><td>1206</td><td>Ray (2012, 109)</td></tr>
<tr><td rowspan="4">India</td><td>c. 1890</td><td>1000-2500</td><td>Southern Farm and Home Magazine (1873, 137) (here)</td></tr>
<tr><td>c.1895</td><td>1000</td><td rowspan="2">Blyn (1966, 292)</td></tr>
<tr><td>1901</td><td>1321</td></tr>
<tr><td>1906</td><td>1049-1500</td><td>B. C. Allen (1912, 110); Blyn (1966, 288)</td></tr>
</table>

Note: The yield for 1872 is provided in "maunds" in the original sources. It is converted to pounds on the basis of 82.28 lbs per maund.

5.4.10 Linseed

The acreage conversion estimate of linseed can be calculated on the basis of various sources. Table 33 presents the estimates for various regions along the relevant sources. A minimum and maximum estimate can be calculated at 5 bushels and 12 bushels per acre respectively on the basis of these.

TABLE 33 *Linseed yield, in bushels per acre.*

Country	Year	Bushels per acre	Source
France	1840	10.55	Macgregor (1847b, I:424)
	1840	8.3	A. J. Warden (1867, 312) (here)
	1852	7.5	
India	c. 1891	4.5	Blyn (1966, 307)
	1895	4	
	1900	5	
	1905	5	
Russia	c. 1850	10	Science Journal (1891, 309–10)
US	1889	7.9	USDA (1959)
	c. 1890	10-12	Dodge (1895, 13)
	1902/07	9.2	USDA Yearbook (1907, 677)

5.4.11 Madder (root)- Dye

Given the unavailability of historical information, contemporary estimates can be used for the estimation of an acreage conversion factor for Madder root dye. Based on Saxena and Raja (2014), the yield of roots from the 3-year-old plant is between 3–5 tons per hectare (or 1.2-2 tons per acre) and about 150–200 kg of dye. Thus the yield for madder dye can be calculated at 1.4 hundredweights per acre and for madder root at 31.8 hundredweights per acre. Similar yields of dry root (not dye) per acre are provided in Chenciner (2000) and are presented in Table 34.

TABLE 34 *Dry Madder root yield, in tons per acre.*

Country	Year	Tons per acre	Source
England	18th & 19th century	0.5-1.6	Chenciner (2000); Ure (1867, III:8); Simmonds (1854, 482); Young (1771, IV:482)
France		2.5	
Netherlands		2.7	
Russia		0.7-1	

5.4.12 Oil (linseed, hempseed, rapeseed)

Historical information on oil output per unit of seed for different types of seed is fairly limited. For this reason, the estimation of various oilseeds' ecological footprint can be calculated on the basis of acreage conversion estimates for linseed, which in this case can be used as a proxy. In fact, as regards British trade, linseed oil was actually dominating seed oil trade. Based on information from Mayes (1861, 96) (here) for Australia in can be calculated that 27 pounds of linseed could have been required per imperial gallon of oil or expressed in tons 6,280 pounds of linseed would have been required (given that 1 imperial gallon of linseed oil equals 0.0043 metric tons). It should be noted, that based on modern-day estimates, the yield of rapeseed oil per acre (400 lbs) is approximately double that of linseed oil (200lbs) (Khan and Hanna 1983, 496; Carioca et al. 2009).

5.4.13 Mahogany

Given that this tree is not subject to silviculture, it is very difficult to find statistical production estimates for the estimation of its ecological footprint. For this reason other sources which might not provide very accurate figures have been employed. In Murray (1839, III:284) it is stated that the largest log ever cut in Honduras was of 15 tons while the largest log ever brought in Glasgow was approximately 8 tons. Then based on Arno (1995, 24) (here), Anderson (2012, 5) and (Platt 1938, 23) three trees per acre can be considered as a rough average estimate of the standing volume for mahogany. Consequently, a tentative estimate could be 24 tons per acre.

5.4.14 Petroleum

The ecological footprint of petroleum can be estimated on the basis of coal by converting the product into units of equivalent coal. According to the International Energy Agency (IEA) (here) 1.4286 tons of coal equal one ton of oil. Subsequently, for the conversion of coal into land, see section 5.4.3 on "*Coal*".

5.4.15 Potash

The conversion of potash into land is done on the basis of a yield estimate per unit of wood and subsequently on the annual estimates for forest land as these are described in section 5.4.22 under "*Wood/Timber*".

As regards the wood requirements per unit of potash an average estimate can be calculated based on various sources. Although ash-burning was not a precise art, and different figures may be available in the literature, an average estimate of approximately 1.6 cubic meters of wood per kilo of potash is a representative estimate. In Table 35, the estimates for various countries from which this estimate is derived are presented along with the relevant sources. This estimate of approximately 1.6 cubic meter per kilo of potash is also corroborated by North's (1994, 9) work on the 19th-century Baltic region.

TABLE 35 *Potash yield per cubic meter of wood, in kilograms.*

Country	Year	Kilograms	Source
Canada	c. 1800	0.625-0.8	Knoppers and Nicholls (1981, 61) Radkau (2007, 115)
Czech, Bohemia	c. 1800	0.5-1	Jiří Woitsch (2006, 9)
Finland	c. 1850	0.66-2.8	Kunnas (2007, 295)
Sweden	c. 1800	0.6-0.5	Tirén (1937, 2:256–58); Sundberg et al. (1994, 36); Åhman (1983)

Additionally, using the acreage conversion ratios for wood discussed in section 5.4.22 (1 cubic meter per acre and 1.25 cubic meters per acre respectively). The minimum and maximum acreage conversion estimates for potash can be calculated at 625 kilograms per acre and 0.781 kilograms per acre.

5.4.16 Rapeseed

The conversion estimate of rapeseed into land is based on estimates for the Netherlands and China in the 19th century. These are reported in Table 36 along with the relevant sources. An average estimate of 17.5 bushels per acre can be used for the estimation of the direct ecological footprint of rapeseed.

TABLE 36 *Rapeseed yield, in bushels per acre.*

Country	Year	Bushels per acre	Source
China	1620	18.3	R. C. Allen (2009, 535-6)
	1820	18.3	R. C. Allen (2009, 535-6)
Netherlands	c. 1840	17.5	Macgregor (1847b, I:902)

Note: The Netherlands estimate is a 10-years average. For China, units in the original source are reported in shi and mu. They are converted to bushels per acre on the basis that one mu equals 0.151 acres and one shi 157.896 pounds (Chin-keong 1983, xvii)

5.4.17 Rubber/ Caoutchouc

The conversion of rubber or caoutchouc into land can be done on the basis of acreage conversion estimates from Ceylon, Malaysia and India. The estimates are mainly from the early 20th century, when rubber trade and production was actually at its peak. According to Schultes (1993, 482) the earliest planting in Ceylon and Malaysia could yield 450 pounds of rubber per acre per year. Additionally, according to Schidrowitz (1916, 45) in 1910 Malaya the yield ranged between 300 and 400 pounds per acre. Similar range of estimates are reported for later in the early 20th century- in the 1920s and 1930s (Barker 1939, 9; Kellet 1949, 422; Rae 1938, 330). For India in circa 1930, data from Gupta (1992, 198) suggest a yield of approximately 200 pounds per acre. Finally, for the early 20th century, an average world estimate of 400 pounds per acre is given by Oenslager (1932, 979).

5.4.18 Silk (Raw, waste, thrown)

The estimates used in the study are based on sources covering France, the US and China for the early and mid-19th century. Table 37 presents information early 19th century France on silk output per acre. The data in the table is based on estimates of cocoon yields from Macgregor (1847b, I:419) and are converted to silk yields on the basis of approximately 250 pounds of cocoons per acre. This yield of cocoons per acre is an average estimate which reflects adequately Ma's (2004) estimate for the late 19th century Lower Yangi Delta (150 lbs per acre) and Li's (1981, 16,25) estimates (approximately 400 pounds per acre). Additionally, according to Perrin (1839, 600) (here) and Barbour and Blydenburgh (1844, 33–35) for circa 1840, a not too high estimate of 51 pounds per acre is suggested for the US while the lowest estimate is noted at 22 pounds per acre. Given these different estimates, a minimum and maximum yield of raw silk can be calculated between 22 pounds per acre and 51 pounds per acre respectively.

TABLE 37 F*rench Silk yield, in pounds per acre.*

Years	Cocoons collected, in pounds	Raw silk spun, in pounds	Raw silk, in pounds per acre
1810	8979854	773004	21.5
1815	7675817	679369	22.1
1820	11529933	1000390	21.7
1822	7885954	638883	20.3
1824	18329147	1478998	20.2
1830	16928036	1485065	21.9
1833	19823584	1657929	20.9
1834	16081303	1430887	22.2
1835	19859144	1931282	24.3

Source: Macgregor (1847b, I:419)

As regards silk waste, it is a by-product in the process of making raw silk. In Simmonds (1873, 109) (here) it is stated that for every pound of raw silk produced, there are left 12-14 pounds of silk waste. This is the ratio which can be used in order to convert silk waste into raw silk.

Finally, in order to find the footprint of thrown silk, a weight loss from raw silk of 25% is considered. This is based on Baer, Sabbioni, and Sors (1991, 165), where it is argued that the weight loss of silk by removing the sericin (natural gum) can vary but the average is about 25%. Applying this reduction on the average of the minimum and maximum yield of raw silk (36.5 pounds per acre) gives a conversion factor for thrown silk at 27.4 pounds per acre.

5.4.19 Tobacco

An acreage conversion factor for tobacco can be calculated on the basis of approximare minimum and maximum yield estimate which applied throughout the 19th and early 20th century in most countries. In Table 38, information for various countries and from different sources is presented. An average minimum and maximum acreage conversion factor can be calculated at 780 and 1300 pounds per acre respectively while the average for all regions would be approximately 1000 pounds per acre.

TABLE 38 T*obacco yield, in pounds per acre.*

Country	**Year**	**Pounds per acre**	**Source**
Algeria	1881	462	USDA (1938, 73)
	1890	371	
	1905	712	
Argentina	1890	942	USDA (1938, 66)
	1905	758	
Australia, Whales	1835	748	Macgregor (1850, V:145)
	1840	1263	
	1844	820	
	1907	724-850	USDA Yearbook (1907, 674) USDA (1938, 89)
Austria	1880	991	USDA (1938, 21)
	1885	1205	
	1890	1400	
	1895	1413	
	1900	1290	
	1905	1099	
Belgium	1895	1894	USDA (1938, 24)
	1900	2119	
	1905	2170	
Bulgaria	1897	657	USDA (1938, 41)
	1905	625	
Canada	1900	946	USDA (1938, 5)
	1910	932	
France	1840	993	USDA (1938, 30-31)
	1841	1017	Macgregor (1847b, I:386)
	1862	1271	USDA (1938, 30-31)
	1871	1131	
	1880	1062	
	1890	1285	
	1905	1342	
Germany	c. 1840	672-1008	Macgregor (1847a, I:588
	1871	1412	USDA (1938, 26)
	1880	1920	
	1890	1879	
	1905	2014	
Guatemala	1898	547	USDA (1938, 15)
Hungary	1870	871	USDA (1938, 33)
	1880	1134	
	1890	919	
	1905	988	

TABLE 38 *Tobacco yield, in pounds per acre (cont.)*

Country	**Year**	**Pounds per acre**	**Source**
India	1891	695	Blyn (1966, 295)
	1895	690	
	1900	654	
	1905	747	
Italy	1871	764	USDA (1938, 38)
	1880	1101	
	1890	1080	
	1900	1196	
	1905	1158	
Jamaica	1907	555	USDA (1938, 13)
Japan	1884	847	USDA (1938, 48)
	1892	887	
	1905	1133	
Netherlands	c. 1860	1937	USDA (1938, 23)
	1870	1808	
	1880	1908	
	1890	1621	
	1900	1877	
Puerto Rico	1830	1490	Macgregor (1847a, II:1081)
Romania	1889	628	USDA (1938, 33)
	1905	456	
Tunisia	1905	1121	USDA (1938, 71)
Turkey	1884	1135	USDA (1938, 44)
	1890	661	
	1905	716	
Uruguay	1905	579	USDA (1938, 70)
US	1866	803.3	USDA (1938, 6-7)
	1870	814	
	1875	817	
	1880	722-896	USDA Report (1880, xix) (USDA 1938, 6-7)
	1885	749	USDA (1938, 6-7)
	1890	761	
	1895	741	
	1900	788	Palmer (1908, 18) USDA (1938, 6-7)
	1910	817	USDA (1938, 6-7)
USSR	1903	1268	USDA (1938, 19)
	1907	1376	

5.4.20 Turpentine oil

The conversion of turpentine oil into land is done on the basis of information for the late 19th century US. More specifically, based on Fernow (1899, 155–56) (here) "*4,000 acres of timber land during four years' working produce 120,000 gallons of spirits of tupertine, or 7.5 gallons per acre*". This translates to 6.2 imperial gallons per acre or 54.4 pounds (given that 1 US gallon of turpentine oil weights 7.25 pounds).

5.4.21 Turpentine (common/crude)

Due to the unavailability of more information, the conversion of crude turpentine into the amount of land necessary for its production is done on the basis of estimates for late-19th century US. Based on Bastin and Trimble (1896, 253) (here) the yield of 200 acres of crop, would in four years yield 271,600 pounds of crude turpentine. This means approximately 340 pounds per acre per year.

5.4.22 Wood/Timber

As regards the conversion of wood or timber volumes into land, Smil (1983, 36) provides a yield estimate of 2.5 cubic meters of wood per hectare per year or in other words approximately 1 cubic meter per acre as a world average. This is also the conversion factor that Pomeranz (2000, 314) argues that is used for his conversion of UK wood imports in the early 19th century into land. Additionally, Warde (2006, 37) provides yield estimates for the 18th century Europe ranging between 0.8 and 1.6 cubic meters per acre.

Based on a report made by the US Congress, Office of Technology Assessment (1983, 148–50) (here), an average yield estimate of natural forest can be calculated based on the weighted average of yields at different natural forest areas. The calculated average (conservative) yield estimate of wood for the natural forest area of the whole US would be approximately 1.25 cubic meters per acre per year. This estimate is very close to that provided by Smil (1983, 36). Additionally, it is in accordance with the estimate used in modern Ecological Footprint analysis as reported by Wackernagel and Rees (1998, 81).

Consequently, based on these sources the minimum and maximum annual yields for wood can be estimated 1 and 1.25 cubic meters per acre respectively. Expressed in tons per acre (assuming a wood density of 850-1000 kg of wood per cubic meter), the yields range between 0.85 tons per acre and 1.2 tons per acre (these are also reported under the conversion of "C*oal*" in section 5.4.3). Note that for timber reported in loads, that can be converted into cubic feet on the basis that one load equals 50 cubic feet (Hutchison 2012, 582).

5.5 Manufactured articles

5.5.1 Beer

In order to get the footprint of beer, what needs to be calculated is the amount of malt or barley used per unit of beer produced. Subsequently, the land required for barley can be estimated as it is described in section 5.1.1 on "*Barley*".

Muldrew (2011, 75) (here) provides a literature review with different estimates from writers in the 18th century, presenting evidence on the quantity of malt used for the unit production of beer. These estimates tend to vary between the different types of beers- small, strong and middle - depending on how much malt is used in each type. According to Muldrew, William Ellis in his work provides ratios of 7.8 pounds per gallon, 4.7 pounds per gallon and 1.9 pounds per gallon for strong, middle and small beer respectively. Other estimates from Michael Combrune give ratios of 8.75 pounds per gallon, 5.3 pounds per gallon and 1.9 pounds per gallon respectively. Finally, Muldrew (2011:76) discusses estimated from other authors. Here the conversion factors are based on the figures from Ellis. Additionally, since the type of beer traded (strong, medium, small) may not be reported, an average of these can be calculated at 4.8 pounds of of malt per gallon of beer. Given that, the export barrel of beer was 36 gallons (Mulhall 1899, 595) this means 173 pounds of malt per barrel. It should also be noted that with the malting process, barley loses approximately 8% of its weight (Walsh 1874, 343 here and Morton 1855, 2:301 here). This means that expressed in barley terms, the amount of barley per barrel of beer would be 188 pounds. Expressed in bushels per barrel, that ratio would equal three bushels.

5.5.2 Cotton Manufactures

The calculation of cotton manufacture's ecological footprint can be done on the basis of acreage conversion factors for raw cotton (see section 5.4.4). In other words, the manufactures need to be converted to their raw cotton equivalent. Based on information from the final report on the third census of production of the United Kingdom 1924 (HMSO 1931, 38–39) the cotton weight per yard of piece goods made for sale can be calculated. That was approximately 5 yards of cotton cloth per pound of raw cotton. Or in other words, 0.2 pounds of raw cotton per yard of cotton manufacture. That is a rough conversion factor which can be used. It should be mentioned that this was the average of both unbleached and colored piece goods. It is acknowledged, that the amount of cotton may vary with the type of product but as mentioned previously this is a proxy estimate. In fact, this estimate is very close to those reported for the 19th century by Riello (2013) which ranged between 0.2-0.3 pounds per yard.

5.5.3 Cotton Yarn

The conversion of cotton yarn to land is done on the basis of raw cotton (see section 5.4.4). Due to lack of information, the conversion of cotton yarn into cotton can be done on the basis of information on yarn output per unit of raw cotton for 19th century England. In particular, based on Blaug (1961, 377), 1 ton of raw cotton produced 890 kilograms of cotton yarn for the period 1828-1861. This calculation is based on the loss of weight between the raw cotton imported (for home consumption) and the yarn produced. For the years 1862-1865 the share of loss was 10%, 9%, 8%, and 7% respectively, while after 1865 it is taken at 6%. This means that after 1865 1 ton of raw cotton produced 940 kg of yarn.

Thus an average for the whole 19th century would be approximately 0.9 tons of cotton yarn per ton of raw cotton. The same conversion factor is also obtained from an original 19th century source and specifically Baines (1835, 367) (here). It is stated that the weight loss that occurs in spinning is equal to 1.75 oz per pound of raw cotton. In other words, the weight loss is equal to 0.1 pounds from raw cotton.

5.5.4 Jute Manufactures

The conversion of jute manufactures to land is done on the basis of raw jute (see section 5.4.9). Due to the lack of information on the amount of raw jute per yard of jute manufactures, the same conversion factor as that for wool can be used (see section 5.2.16). In other words, it can be assumed that 0.75 pounds of jute are included per yard of jute manufactures. It is acknowledged that this is a very crude estimate.

5.5.5 Linen yarn

The calculation of land required for linen yarn can be done on the basis of yield estimates for flax fiber. An average yield for the 19th century may be considered to range from 300 to

600 pounds of fiber per acre while an average yield of 450 pounds can be used. For a detailed discussion on sources see section 5.4.5 under "*Flax*".

5.5.6 Paper

The conversion of paper into land is done on the basis of pulp. Due to the unavailability of historical sources contemporary estimates are used. In particular, Bolton (1998, 70) (here) provides information regarding the amount of paper per unit of pulp. According to the study, that is a ratio of 1.6 to 1. In other words, one imperial ton of pulp can produce 1.6 imperial tons of paper.

After converting the amount of paper to its pulp equivalent, the conversion into land can be done on the basis of an average acreage coefficient of pulp. That is the average between the mechanical and the chemical process. Following the discussion in section 5.5.7 this can be estimated at 0.34 imperial tons of pulp per acre. Consequently, the acreage conversion factor for paper can be calculated at 0.54 imperial tons per acre.

5.5.7 Pulp for paper (of wood)

Due to the difficulty of identifying sources pertaining to the 19th or early 20th century, the conversion of wood pulp into land is done with the use of contemporary estimates on the amount of wood required. In Bolton (1998, 70) (here) it is stated that by the mechanical pulping process, 2.5 cubic meters of wood are required for the production of one metric ton of pulp. In imperial units this translates to 2.54 cubic meters of wood for one imperial ton of pulp. Accordingly, with the chemical process, 4.5 cubic meters of wood are required for one metric ton of pulp. In imperial units that would be around 4.6 cubic meters of wood per imperial ton of pulp.

For the conversion of wood into land, an average conversion ratio of 1.1 cubic meters per acre can be used (see section 5.4.22 on "*Wood/Timber*" for a discussion on sources). Consequently, expressed in imperial tons of pulp per acre, the yield factor referring to the mechanical process will be 0.44 imperial tons of pulp per acre. Accordingly, the yield factor for the chemical process will be 0.24 imperial tons of pulp per acre.

5.5.8 Silk Manufactures

The conversion of silk manufactures into land can be done on the basis of the weight loss that occurs by processing the silk. As mentioned before in section 5.4.18 for the thrown silk, that is approximately 25%. Based on Baer, Sabbioni, and Sors (1991, 165), the weight loss of silk by removing the sericin (natural gum) can vary but the average is about 25%. Applying this reduction on the average of the minimum and maximum yield of raw silk (36.5 pounds per acre acre) would give a conversion factor of 27.4 pounds per acre.

In case silk manufactures are reported in yards, they need to be converted into pounds. Due to lack of information and sources on an average amount of pound per yard, the conversion into pounds is done using an approximate conversion factor based on the ration that applies in wool manufactures. This translates to 0.75 pounds of raw silk per yard.

5.5.9 Wool Manufactures

Wool manufactures' direct ecological footprint can be calculated on the basis of raw wool. When wool manufactures are not reported in pounds, it is difficult to know what the amount of their wool equivalent would be. As regards British trade, wool manufactures before 1861 are reported in both "yards" and "pieces" in the export trade statistics.

The only source which has been identified for the 19^{th} century and provides such information are the estimates provided in Bischoff (1842, 2:245). Referring to 1829, Bischoff provides estimates of the amount of wool per yard which range between 0.25 and 2 pounds. Additionally, based on the final report on the third census of production of the United Kingdom 1924 (HMSO 1931), it can be calculated that the amount of wool per yard of different manufactures was approximately 0.75 pounds per yard. This estimate falls within the range obtained from Bischoff. Given that it would be plausible for there to be a shift towards lighter fabrics, and since Bischoff's estimates refer to the earlier 19^{th} century, the conversion factor of 0.75 pounds of wool per yard may provide a better proxy.

As regards the conversion of piece goods into pounds of raw wool, it is first necessary to identify the relationship between "pieces" and "yards". That is possible by looking at adjacent years in the trade statistics when they change registering wool manufactures from pieces into yards. In particular, for the years 1861 and 1862, the export manufactures are reported in both units. It can thus be calculated that for all woolen and worsted manufactures, each piece equals approximately 30 yards. Given the 0.75 pounds of wool per yard, the conversion factor for piece goods can be calculated at 22.5 pounds of wool per piece good.

5.5.10 Wool Yarn

In order to find the direct land requirements of a unit of wool yarn, it is necessary to first identify the extent of weight loss that occurs in the manufacturing process from raw wool to the yarn. A weight loss of approximately 35% on weight from raw wool to clean wool can be estimated. In fact, based on Salvucci (1987, 56) (here) and Bischoff (1842, 2:239) one can conclude that almost 50% of the raw wool's weight is lost when cleaned (in the form of grease). However, based on evidence in W. S. Lewis (1915) (here), this share of weight loss may capture the higher boundary, applying mostly to merino sheep fleeces. In fact, Lewis's evidence on 49 different fleeces of South Australian and New Zealand sheep suggest a weight shrinkage which instead ranges between 20% and 50%. For this reason an average estimate of 35% may be more appropriated. After identifying the quantity of raw wool, its conversion to land can be done with the used of the acreage conversion factors discussed in section 5.2.16 under *"Wool"*.

6 Conclusion

The aim of this paper has been to provide an empirical basis which allows researchers to calculate the direct ecological footprint for various products which were traded throughout the 19th century. The special focus is placed on commodities traded within/by the British Empire. In particular, acreage conversion factors for more than 80 products have been identified with the use of both contemporary and historical sources.

Various methodological challenges have been identified in the process of drafting this study which should be discussed. Primarily, it should be acknowledged that such an endeavor, since it involves the calculation of land coefficients throughout space and time can never be fully exhaustive. Some products, due to the unavailability of sources, have been covered to a lesser extent both geographically and chronologically while in very few cases, contemporary estimates from the 20th century have been used. Also, for two manufactured products for which historical information of their production process was unavailable, proxy estimates from another product have been used for the raw material inputs.

Nevertheless, for what economic historiography considers as relatively more "important" products, it can safely be argued that the land coefficients presented here cover most of the significant historical regions of production. Additionally, the chronological span is significantly broad for most of them increasing their external validity. When possible, information has been collected for products from both parts of the Atlantic, South East Asia and Australasia. Constituting an extensive research endeavor based on secondary literature, this paper naturally covers more the products and areas that have bene researched extensively in economic history. At the same time though, it also sheds lights into products whose historical production processes are not so well documented and in this way highlights potential future areas of research in environmental, economic and agricultural history.

Since the current study is not focusing on any particular product or region and given that it is rather exploratory in character it is difficult to draw conclusions upon a particular research question. Nevertheless, some of the evidence presented here could constitute the basis for future research on the issue of agricultural progress and increased productivity throughout the 19th century. They also allow us to make some general remarks upon the “fate” of particular geographical regions. In fact, when considering the average of all products, no systematic differentiation in productivity across various geographical regions is observed. The evidence seems to follow the general patterns of specialization driven by factor endowments and land productivity. Some regions, such as for instance the West Indies, demonstrate higher or comparable productivities in products endemic to their environment.

These types of observations raise interesting questions and strengthen the role of this paper as a basis for future research in the field of environmental economic history, agricultural history and trade.

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