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ECONOMIC HISTORY SERIES NO. 19

# Development constrained

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ESSAYS ON LAND AS A FACTOR IN NINETEENTH-  
CENTURY INDUSTRIALIZATION AND TRADE

*Dimitrios Theodoridis*

**DEPARTMENT OF  
ECONOMY AND SOCIETY**



UNIVERSITY OF GOTHENBURG  
SCHOOL OF BUSINESS, ECONOMICS AND LAW

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Essays on land as a factor in nineteenth-century  
industrialization and trade

Dimitrios Theodoridis

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This thesis is dedicated to the memory of my brother, Vangelis.



## ABSTRACT

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This dissertation consists of an introductory chapter, four research essays and one essay that describes the collected dataset. The first essay examines how the balance of land embodied in British trade developed during the nineteenth century and provides the first all-encompassing accounts on this topic. It is shown that the contribution of vertical expansion has been far larger than that of horizontal expansion. The former thereby contributed significantly more than the latter to overcoming British land constraints and fostering economic development throughout the nineteenth century.

The second essay examines the contribution of colonies and colonialism in abolishing Britain's land constraints. It is found that land embodied in trade from British colonial and former colonial territories represented the lion's share of total land embodied in imports from overseas territories. The commodities that contributed the most to this process of territorial expansion were the European settlements in British North America and Australia. The results also provide circumstantial evidence that the institution of colonialism could have contributed to consolidating nineteenth-century industrial specialization by providing advantages additional to the terms of trade associated with factor endowments.

The third essay provides a sustainability assessment of Britain's socio-economic system during the nineteenth century, using the ecological footprint methodology. It is found that the economic development of the new industrial socio-economic system was already unsustainable during the period under study, and the socio-economic system thereby represented a system in overshoot. British society was consuming resources to an extent that other European late-industrializers would only reach approximately 100 years later. Additionally, the empirical evidence illustrates that the relationship between globalization, industrialization and sustainable development may be more dynamic and multifaceted than some previous research has assumed.

The fourth essay performs a comparative analysis of agricultural productivity in Senegambia in relation to that found in the plantation complex in the Americas. The aim of the essay is to examine the region's capacity to produce an agricultural surplus, and what implications this might have had for the transatlantic slave trade. It is found that differences in land productivity between Africa and the Americas were very large, indicating a very low agricultural productivity in Senegambia. It is argued in the essay that this low agricultural productivity also could have served as a motivation for the transatlantic slave trade.

**KEYWORDS:** Economic development, industrialization, 19th-century, land, land productivity, coal, colonies, trade, empire, colonialism, slave trade, ecological footprint, ghost acres, sustainability





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# Overview

This thesis is an investigation of industrial expansion and trade from a specific perspective: that of environmental history, using land as the main analytical category. The role of land has been understood in different ways historically. The historical passage from agrarian to industrial economies in Western Europe in the late eighteenth and nineteenth centuries marks a breaking point in our understanding of land and its importance in the socio-economic system. This thesis investigates this transition empirically through a series of research papers each of which focuses on the role of land for industrialization, trade and sustainability during the period of heavy industrialization between 1800 and the First World War.

Eighteenth- and nineteenth-century scholars and commentators such as Thomas R. Malthus (1766–1834) and David Ricardo (1772–1823) paid special attention to the physical constraints of economic growth and were highly concerned with land as a key factor in explaining contemporary economic growth, mainly in Britain. Both recognized limits to growth, since a fixed supply of land could cause decreasing returns to scale for all factors of production. More specifically, according to Malthus a negative feedback loop ensured that in the absence of technological change or change in the availability of land, the size of the population would be self-equilibrating at low levels – this was termed the *Malthusian trap*. In pre-industrial societies, most households' economic welfare was tightly attached to land and more specifically to landholding. Ownership of and access to natural capital in the form of land determined the amount of wealth and income for each household. At a macroeconomic level, land in large quantities and of good quality dictated the levels of population growth and production of non-food commodities, and thus the levels of prosperity and welfare a society could achieve. From the vantage point of today, however, one could argue that such contemporary concerns began to fade. This was especially true during the first half of the twentieth century when the importance of land in economic terms declined. Although the starting date of the agricultural revolution is highly debated in economic history, by the early nineteenth century agriculture had increased output per capita, allowing for an agricultural surplus that enabled the growth of a secondary and tertiary sector. With the Industrial Revolution and the beginning of modern economic growth, the share of incomes attributable to land was declining and so was the share of agricultural land in total wealth. The aspect of resource constraints resurfaced throughout the 1920s

and 1950s (Bashford 2014) but became more prominent only in the 1960s and 70s, along with the entire discourse on environmental concerns, through the writings of George Borgström (1965) and Paul Ehrlich (1968), among others, and the “resource constraints view” was explicitly re-developed by the Club of Rome in their (1972) *Limits to Growth* report.

This thesis forms an empirical investigation of the changing role of land during the early phase of the industrial era and investigates the idea of a decline in the importance of land historically, in absolute terms. As the research results presented here demonstrate, from a resource endowment perspective and a sustainability perspective, the role of land was reduced but this was achieved to a great extent via structural changes in resource endowments and the acquisition of land from overseas territories. In this sense, land remained central as a factor of production whose supply had been diversified during the industrialization era of the nineteenth century.

Due to lack of empirical evidence, arguments for the declining importance of land tend to overlook the distributional effects that have historically arisen through globalization and trade, as well as through technological and structural changes. Since the eighteenth century, but even more so from the nineteenth century onwards, globalization and trade expanded the geographical scope of societies to a global frontier and extended the constraints of land supply beyond the national territories. In this way, economic output that required inputs of land could be altered in three ways. Land in a particular geographical entity could be saved or augmented through: 1) technical change (e.g. crop rotation or new crops) leading to productivity growth 2) *vertical* expansion through structural changes in the resource endowments (substitution of resources, e.g. coal for wood) and 3) *horizontal* expansion through colonialization and trade. The first factor has been dealt with in much previous research. The essays included in this thesis focus mainly on the latter two options throughout the nineteenth century.

*Development constrained – Essays on  
land as a factor in nineteenth-century  
industrialization and trade*



*Lower Pool, with Tower Bridge under construction.* This is an early photograph (1886-1894) of Thame's Lower Pool that depicts the Tower Bridge under construction and the vibrant industrial and trade activities in the city of London. Reproduction by permission of © Museum of London.

# Development constrained – Essays on land as a factor in nineteenth-century industrialization and trade

## Introduction

In recent decades, economic development has stopped being considered as primarily dependent on the accumulations of man-made and human capital. In addition to what has been termed *total factor productivity* (TFP), i.e. productivity-inducing innovations and institutions that increase output per unit input, another form of capital has firmly entered the sphere of scholarly debate. This has been termed *natural capital* and is considered to also affect the performance of the system of production, consumption, investment, saving and welfare (Willebald et al. 2015). The term is actually used today to capture the sum of exhaustible and renewable resources as well as ecosystem services that are necessary for economic growth (Missemer 2018).

It can be argued that the resumption of the debate on natural resources reflects in part the resurgence in recent academic but also popular discourse of the Malthusian doctrine. According to Malthusian theory, population cannot grow indefinitely but is bound to physical constraints and the limited availability of resources. Once population increased above a threshold level, this would lead to decreases in income and the level of birth rates, restoring the population to its long-term equilibrium level at which birth rates would equal death rates (Malthus 1798). For Robert Malthus, the most important constraint was the limited access to land, since in late eighteenth- and early nineteenth-century England this constituted the main type of resource scarcity.

The reason for the resurgence of such skepticism about the capacity of natural resources and population growth today is twofold. It has mainly been driven by climate change, with its adverse effects on the natural environment, and by the accompanied skepticism about Earth's capacity to perpetually support an ever-growing population in the future. Rising environmental concerns and today's unfavorable impact of economic activity on the environment, underline the importance of natural capital for a country's growth (Wackernagel and Rees 1996; Monfreda et al. 2004; Dasgupta and M Ler 2000; Arrow et al. 2012).

Rightfully one might ask what does this all have to do with history and even more so with economic history? It is the ambition and overarching aim of this thesis to investigate the role of natural resources and specifically that of land for economic development throughout the nineteenth century. This was a period of strong industrialization, which also marked the passage to the post-Malthusian era, in which economic growth has primarily been explained by technological progress and productivity improvements, while the role of land was gradually reduced. This was achieved via changes in three main areas i.e. technological change in agriculture; changes in the energy regime (vertical expansion); and trade expansion and colonization of new, uncharted territories (horizontal expansion). This thesis examines the relative significance of the latter two pathways for relieving land constraints, for giving rise to particular trade activities and for explaining the long-term sustainability of the industrial socio-economic system that emerged in the nineteenth century.

Economic historiography has put emphasis on various factors when discussing the industrialization process. These have varied from culture and institutions, to technology, geography and natural resources. The focus in this thesis is placed on the role of geography and natural resources. The historical analyses conducted in the following essays focus mainly on the industrialization process in Britain and the transatlantic slave trade during the period of modernization from the nineteenth century until the First World War. The broader intention is to demonstrate how changes in the resource base were affected by industrial transformation, but at the same time how such changes complemented productivity-driven technological change and fostered economic development. In this process, this compilation thesis engages more closely with already existing debates in economic history, but also aims to historicize modern-day research and place contemporary global processes in a historical perspective.

## **Aim and Contribution**

As Robert Allen has argued, the Industrial Revolution took place in a rather rich country while it was stimulated by expensive labour and cheap energy (Allen 2009). Although the empirical evidence upon which the cost of labor was based has been criticized recently (Stephenson 2017), very few have doubted that coal set Britain apart from all other major economies as early as the early modern period. Gregory Clark's figures comparing pre-1800 England with other economies in 2000 suggest that England was already richer than many

“undeveloped” countries are today (Clark 2007). However, this did not necessarily mean that it was healthier in terms of life expectancy or that it was relieved completely from its resource constraints. As expressed by Kander et al. (2013, 144), “the ‘organic economy’ did not end with the Industrial Revolution, and indeed has no prospect of ending: humans still need to eat”. However, what did indeed end or rather change was the functioning of the economy, or what other researchers have identified as the “metabolism” of the socio-economic system (Fischer-Kowalski 1998; Fischer-Kowalski and Haberl 1993). This was achieved by changes in the interplay and relative importance of two basic resources: coal and land, and this is where the broader focus of this thesis is placed.

Although the functioning of the system’s capacity was to a great extent increased by improvements in technology and productivity, these changes had to be complemented by changes in the material resource base, mediated by vertical and horizontal expansion. The aim of the present thesis is thus to investigate the material circumstances that underpinned industrialization.

Each essay of this thesis constitutes a step toward this overarching aim. As a whole, the thesis is also an attempt to bridge the gap between overlapping scholarly debates in the fields of ecological economics and economic history.

The essays in this study contribute to the scholarly debates in economic history concerning nineteenth-century industrialization in two ways. The first is by assessing quantitatively, the increasing importance and changing role of land during the nineteenth century’s intense industrialization. This is achieved by analyzing the relative contribution of land to industrialization both directly, through the import and export of commodities that required land for their production, and by indirectly shaping the patterns of other key trade activities such as the slave trade. A secondary, but equally important ambition, is to draw the reader’s attention to the environmental consequences of early industrialization and historicize current-day research on the relationship between increased consumption and limited resource capacity.

## Research Questions

The overarching research question for the whole work is:

*“What role did natural resources, and specifically land, play in economic development during the era of the First Industrialization?”*



This overarching research question can be further specified in particular research questions that are addressed in the different papers. These are:

Paper 1: *What contributed more, in a strictly quantitative sense, to overcoming land constraints in Britain: domestic fossil energy or overseas land? How did this vary over time and what form did these land resources take?*

Paper 2: *Did colonies contribute significantly to horizontal expansion and abolishing Britain's land constraints?*

Paper 3: *What was the UK's historical ecological footprint during the period 1832–1907? How did the globalization process of the nineteenth century affect its (un)sustainability?*

Paper 4: *Was agricultural productivity in Senegambia lower than that in the plantation complex in the Americas? What were its implications for the region's capacity to produce an agricultural surplus and for the transatlantic slave trade?*

Paper 5: *How much land was required to produce highly traded early modern commodities?*

This is an exploratory study and establishes coefficients for the land requirements of various early modern commodities. It builds a dataset of coefficients that could benefit further research, mainly in the fields of environmental history, economic history, agricultural history and the history of technological progress, but also constitutes the necessary input for the research papers included in this thesis.

## Limitations

The essays in this dissertation cover mainly the nineteenth century and the first decade of the twentieth century. This is the time when the industrial era is established as the new socio-economic paradigm. Studying this period, however, also means that half of the conventionally recognized timespan of the Industrial Revolution (1780–1820), between 1780 and 1800, is not covered by this thesis. The reasons for this exclusion are mainly data constraints, which are discussed in further detail later in the data section. Undoubtedly, this constitutes an important limitation of this dissertation. This is because many of

the changes in the composition and magnitude of trade and the use of natural resources and land had already been underway during the early modern period and contributed significantly to the transition in the industrial era. The lack of empirical evidence from this time period therefore makes it harder to draw conclusive arguments on the causal relationship between trade, the changing role of land and what sparked the Industrial Revolution. This means that the empirical evidence of the thesis may not contribute directly to answering what initiated the industrialization process, but rather what were the ecological circumstances that sustained it. Any arguments regarding the initial conditions can only be substantiated on the basis of circumstantial empirical evidence drawn from 1800 onwards.

Three of the four research essays in the thesis are concerned with the industrialization process and focus on Britain. Consequently any generalizations on the changing role of land during the industrial era for the rest of the Western European are not easy to make. This is especially true due to the peculiar ecological circumstances that characterized British land, which was uniquely endowed with coal. Undoubtedly, other countries such as France, Spain and the Netherlands also constituted major colonial powers and empirical evidence on the ecological circumstances that underpinned their trade and industrialization have so far been lacking from the debates in economic history. In this respect, to what extent the relative role of horizontal and vertical frontier expansion was of equal importance for the industrial transformation of other Western European empires, remains an open question for future research.

As briefly noted above, the empirical investigation of this thesis mainly focuses on two out of the three variables involved in the interplay between industrial transformation and land use. These are horizontal and vertical expansion. The third variable, however, that of technical change, which was also important during the nineteenth-century industrial transformation, is not covered empirically in this thesis since it has been dealt with in much previous research and thus exceeds its scope. Having said that, a brief review of such previous discussions is included in this chapter. The rate of technology improvements in agriculture were important, and along with the other two variables of horizontal and vertical expansion, provided the space (both literally and metaphorically) for the industrial transformation to take place. Technological improvements were in many cases also linked to trade in that there were additional resources that could be traded for and augmented land productivity in the metropolis without, however, imposing land requirements elsewhere. In many cases, it is not clear whether such commodities should be considered as technological

innovations or simply as additions to the resource stock, and for this reason they do not constitute an empirical part of this dissertation. Although some tentative estimates on the land relief that came with technological change are provided for some fertilizers that feature in economic historiography, like guano, no all-encompassing analysis is provided. Future research that could extend the analysis in this direction would provide very valuable insights as to the relative importance of all factors during the industrial era and would thus refine even further the debate on the relative importance of domestic versus external forces for industrialization.

## Definitions of key concepts

### *Development*

The concept of *development* carries the notions of growth, change and advance and therefore makes its appearance with the advent of industrial capitalism in the late eighteenth and nineteenth centuries. The emergence of the concept coincides with the passage from agrarian to industrial economies and the accompanied sustained increases in economic output that occurred mainly in the nineteenth century. In other words, the concept of development denotes the changes that occur in the productive forces of the economy, which subsequently lead to material progress. For this thesis, the concept of economic development is used to denote exactly these types of changes that occurred in the nineteenth-century's socio-economic context.

### *Ecological footprint*

The term *ecological footprint*, according to its originators Mattis Wackernagel and William Rees, refers to “the land (and water) area that would be required to support a defined human population and material standard indefinitely” (Wackernagel and Rees 1996, 158). Although this is the broader definition of the concept, methodologically it is used to assess a population's, economic activity's or product's demand on nature, expressed in units of land, under a prevailing technology. It is described in more detail in the method section.

### *Ghost acres*

The concept of *ghost acres* was first coined by Georg Borgström (1965, 75) to describe “the computed, non-visible acreage which a country would require as a supplement to its present visible agricultural acreage in the form of tilled land in order to be able to feed itself”. In other words, the term is used to describe the amount of land equivalent in acres required by a nation to produce the equivalent amount of food it obtains via trade in commodities and via fishing activities. The concept is very similar to that of the ecological footprint, since both describe the ecological demand of economic activities in terms of land units.

### *Embodied land*

The term is used to describe the amount of land equivalent that is taken up for the production of a given amount of a particular commodity. It can be measured in areal units such as acres or hectares.

### *Colony and colonialism*

It is very common to find that in the literature the terms *colonialism* and *imperialism* are used interchangeably (Etherington, 1984). It could be argued, however, that the term imperialism is more generic than that of colonialism and has come to indicate various forms of economic domination and exploitation of relatively weak underdeveloped countries by powerful and wealthy developed economies. Colonialism has historically been one of the starkest manifestations of imperialism, and has commonly been used specifically to denote the political and territorial control of one country by another. It is one of the devised methods of exercising state power for the purpose of gaining economic advantages beyond the domestic territories. Consequently, when the term colony is used in this research, I am referring to a region or country which is politically controlled by another, while the term colonialism is used to denote the practice of this system of political control.

### *Land relief*

The term *land relief* is used to describe the process by which pressures and constraints on an economy and society, imposed by land scarcity, can be alleviated

or relaxed. This can be achieved through *technical change* (e.g. crop rotation or new crops), 2) *vertical expansion* through structural changes in the resource endowments (substitution of resources, e.g. coal for wood) and 3) *horizontal expansion* through colonialization and trade.

### *Vertical expansion*

The concept of “vertical frontiers” is introduced by Edward Barbier (2011) in his work *Scarcity and Frontiers*. *Vertical (frontier) expansion* refers here to structural changes in the use of resource endowments and specifically to the process of fossil fuel and mineral exploitation that can bring about a direct change in the use of land. In the nineteenth-century context, it is used to describe the exploitation of coal deposits. Coal was available as a punctiform source, meaning that deposits were concentrated in seams providing a condensed energy source which, compared to using firewood, freed up land for other purposes.

### *Horizontal expansion*

The concept of “horizontal frontier” is also introduced by Edward Barbier (2011) in his work *Scarcity and Frontiers* to describe arable land and biomass energy. The concept of *horizontal (frontier) expansion* is used in this research to describe the process of expansion overseas or overland and is closely associated with the colonization process. It is directly linked with trade and contributes to territorial expansion.

## **Contributions to co-authored papers**

In the following section, the contributions to the co-authored papers included in the dissertation are discussed in more detail. The aim is to primarily acknowledge the work provided by third parties and secondarily delineate the share of my involvement in each study. Only the two papers that have been co-authored are discussed.

### **Paper 1: Trade and overcoming land constraints in British Industrialization – an empirical assessment**

*co-authored with Paul Warde and Astrid Kander*

This paper was accepted for publication in the *Journal of Global History* in January 2018. The original paper's idea was provided by my second supervisor, Professor Astrid Kander, and Dr. Paul Warde and has been an integral part of the dissertation since the beginning of my doctoral studies. It constituted a smaller part of the larger project, “*Who did the dirty work?*” on energy embodied in European trade, which was financed by the Swedish Research Council (Swedish: Vetenskapsrådet – VR) during the period 2014–2016. The idea for this paper was further refined in collaboration between all three authors while I contributed the largest share in the research design of the study. As regards the data collection involved in the paper, I had the principal responsibility for most parts and specifically the trade figures and the land embodied in imports. The coefficients on coal embodied in exports were in the most part developed by Dr. Paul Warde, as part of the larger project “*Who did the dirty work?*”, and were provided for the drafting of this study. Regarding the processing of the data and the generation of the results I had the principal responsibility. Finally, the drafting of the paper, the development of its argument and the review of previous relevant research were the result of collaborative effort by all three authors. During the publication process, valuable comments and criticism were provided by two anonymous referees that significantly improved the quality of the paper. During the revision round of the paper, contributions were provided by all three authors, while I had the principal responsibility for the revised text.

**Paper 4: African agricultural productivity and the transatlantic slave trade: evidence from Senegambia in the nineteenth century**

*co-authored with Klas Rönnbäck*

This paper was accepted for publication in the *Economic History Review* journal in January 2018. The original paper's idea was provided by my main supervisor, Associate Professor Klas Rönnbäck, at a later stage of my thesis work. The research design of the paper was developed jointly. I had the main responsibility for the collection and analysis of the empirical evidence that is presented in the paper. As regards the writing of the study and the development of its arguments, these were developed in collaboration by both authors. During the publication process, valuable comments and criticism were provided by two anonymous referees that significantly improved the quality of the paper. I had the principal responsibility for the revisions in the paper, although both authors contributed to the formation of the revised text.

# Theoretical points of departure

## Natural resources and economic development

When discussing the role of natural resources, we are implicitly trying to tackle the question: how has natural resource exploitation led to economic development historically? The important recent work from the economist Edward Barbier (2011) *Scarcity and Frontiers*, the edited work by Badia-Miró, Pinilla, and Willebald (2015) *Natural resources and economic growth* and the work by Ronald Findlay and Mats Lundahl (2017) *The economics of the frontier* provide a comprehensive historical account of the role of natural resources. In what follows, a brief review of these and other works is provided to illustrate the main theoretical propositions that describe the natural resources and economic development nexus.

One of Barbier's central arguments is that resource scarcity can create the socio-economic conditions for economic development. Increasing resource scarcity entails the rising cost of resource exploitation, which creates the economic incentives for innovation and conservation. In essence, this argument is aligned with John Habakkuk's (1962) original thesis that linked rising wages in the nineteenth-century US labor market with the emergence of labor-saving technologies. The thesis has also recently been extended in Robert Allen's (2009, 137) work to explain the "induced invention" of labor-saving technology in nineteenth-century Britain as a result of a cheap energy and high wage structure. The proposition, which instead focuses on natural resources, is however founded on Ester Boserup's (1965) seminal work *The Conditions of Agricultural Growth*. Boserup's paradigm reversed the Malthusian argument, which focused on the expansive character of economic development. Her central point was that industrialization and the subsequent increases in population that emphasized problems of resource scarcity, could lead to further technological change and intensification of production particularly in agriculture (Boserup, 1965). In other words, she did not regard population growth as an endogenous process restricted by the limited capacity of agriculture but rather as the driving motive for technological change. It is only under prevailing circumstances of population density that certain types of technical change will occur and in this way population growth causes the intensification of production in agriculture (Boserup 1965, 41). This change can be achieved by a more intensive use of labor,

and thus, as Boserup explicitly states, intensification causes the productivity of land to rise and the productivity of labor (and thus its returns or wages) to fall.

Aside from scarcity-induced innovations and new resource conservation techniques, however, past societies have also resorted to expansive strategies for obtaining and developing new resources. In addition to resource scarcity, new resource frontiers were crucial drivers for economic development.

As argued by Barbier (2011, 2–3), before the First World War, the connection between natural resource exploitation and economic growth was more prevalent, direct and strong than in the period afterwards. In particular, the period 1870–1914 is regarded in economic historiography as the “Golden Age of Resource Based Development” when natural resource abundance formed the main precondition for national industrial development. Decreasing transport costs and the intensification of trade throughout the nineteenth century had brought about a large transformation of land and utilization of natural resources in many resource-rich regions around the world that facilitated economic development. This has historically meant the exploitation of new “frontiers” for natural resources or else the exploitation of areas that were endowed with a unique abundance of natural resources and land relative to labor and capital (Barbier 2011, 7; Findlay and Lundahl 2017).

Various theories have attributed a central position to this process of natural resource exploitation for economic development. Frederick Jackson Turner’s seminal 1893 essay *The Significance of the Frontier in American History* introduced the notion of *frontier development*, analyzing how “free land” and its cheap exploitation westwards was responsible for American development in the nineteenth century. Extending this thesis, Walter Prescott Webb (1952) in his 1952 work *The Great Frontier* explained global economic development from 1500 to 1900, when the frontier closed, on the basis of frontier expansion in North and South America, Australia, New Zealand and South Africa. Also, Eric Jones’ (1981, 81) work *The European Miracle* extended Webb’s thesis to describe four “ecological zones” that contributed to European economic development. These were the ocean fisheries and whale and seal fisheries of the north Atlantic ocean; the boreal forests of the Baltic and Scandinavia; the tropical lands that enabled the production of key raw materials and luxury food commodities such as sugar, tobacco, indigo, cotton and rice; and the arable and pasture lands in North America and South America, South Africa and Australia and the steppes of Southern Russia. Additionally, resource exploitation in the form of land use in agriculture has historically been of key importance to long-term economic development in Africa. In addition to its main role in feeding the population,



it has also been crucial for providing the means for economic development and diversification. The ability of agriculture to produce a surplus is fundamental since it generates the potential for forward and backward linkages in an economy. In particular, the agricultural sector can supply the factors of production (labor and capital) to the secondary and tertiary sectors while it can also function as a (domestic) market for the output from these sectors (Federico 2005, 223). Consequently, scarcity of natural resources and specifically of land of good quality and in large quantities can lead to a backward unproductive agricultural sector that can have bleak long-term consequences for economic development and diversification. For instance, such a proposition has been put forward in the by now classic work of Anthony Gerald Hopkins (1973) *An Economic History of West Africa* in which the low agricultural productivity in African regions is regarded as one of the explanations for Africa's external slave trade.

Other theories that have viewed natural resource use as a "blessing" also emanated from the "golden age" of late nineteenth-century development and were based on the export-led growth hypothesis (Willebald et al. 2015). Such theories have included the "staples theory", developed originally in the 1930s, 40s and 50s by Harold Innis (1930, 1940), and the "vent for surplus" concept originally developed by Adam Smith and revised by Myint (1958). The central proposition in both was that trade provides the means for gaining economic advantages, by exploiting surplus resources once an economy moves from isolation to international trade. The staples theory stipulates that economies could develop around an export-oriented primary sector. This can have a widespread economic impact, dictating the development of an economy's infrastructure, institutions and other industries as well.

Overall, the strategy of resource frontier expansion can, according to Barbier (2011, 10), be divided into four distinct phases. The first phase involves the exploration and discovery of new areas of land and natural resources, and the small-scale exploitation and extraction of these resources. The second phase involves the establishment of large-scale extraction methods and the development of transport networks which render the further exploitation of resources economically viable. The third phase involves the large-scale agricultural transformation of land and its permanent settlement. Finally, the last phase is that of industrialization and urbanization whereby the abundance of land and natural resources relative to capital and labor disappears, signaling the closing of the frontier.

Although these theoretical propositions of resource exploitation were developed to describe the historical joint development of North America and Western

Europe, they failed to account for the evident sluggish development of many Latin American, Asian and African economies from the nineteenth century onwards. Particularly after de-colonization and independence, this has given rise to theories that attributed a dual role to natural resource abundance for economic development. In particular, natural resources started to be regarded either as a “blessing” or as a “curse”, in each case fostering or impeding economic development (Willebald et al. 2015, 2).

The main proposition for the relatively more “pessimistic” theories has been that although specialization in primary export-oriented production could provide the means for economic development, this may not be sustained in the long run. International commodity price shocks, unbalanced trade and changes in international demand could render this strategy of resource-based development precarious. The economy could find itself locked into a primary type of production if it had not created forward and backward economic linkages that would allow it to industrialize. This pessimistic view of the potentially damaging role of natural resources on economic development has been propagated by neo-Marxist and “dependency” theorists, but has also been given consideration by liberal and interventionist schools of thought (Findlay and Lundahl 2017, 316–17). The latter have placed more stress on the active role of institutions and policies for effective resource-based economic development.

Barbier (2011) and Willebald et al. (2015) also stress that, due to this historical discrepancy, natural resource and frontier expansion is not tied up with economic development in any deterministic way, but that this relationship is conditional. It is conditional on institutional developments that can act as catalysts for this relationship. Barbier’s (2011: 20) proposition of what he calls the “frontier expansion hypothesis” is a synthesis of previous theoretical propositions and stipulates that two conditions need to be met for effective economic development. The first condition is that frontier expansion should yield substantial economic returns. The second condition is that the earnings from such resource-based development should be reinvested in other activities that diversify the economy and create forward and backward economic linkages; stimulate the generation of innovations; and promote industrialization.

Regarding the first condition of gaining substantial economic gains through frontier expansion, Barbier (2011) synthesized three distinct theories which propose ways in which it can be satisfied. The first is Evsey Domar’s (1970) *free land hypothesis* based on which frontier expansion can be associated with institutional developments in the labor market such as serfdom and slavery, which decrease the cost of labor. The second way is described by Guido di

Tella's hypothesis, which stipulates that in addition to enslaved labor, additional economic advantages can be gained through the discovery of new lands, agricultural and mineral resources, new technologies, the establishment of monopolies, and additional windfall gains in the form of resource price booms for land and primary commodities (Di Tella 1982). A third channel by which frontier expansion and natural resource exploitation can be associated with substantial economic gains is through what Kenneth L. Sokoloff and Stanley L. Engerman (2000, 223) termed as "factor endowments". By this they meant not only the quantitative characteristic of relative land abundance but also the qualitative aspect of natural resources, that is: the type of soils; the environmental conditions; and the density of native populations. These factor endowments constitute the initial conditions for the development of distinct institutions and patterns of socio-economic inequality that dictate long-term economic development.

Overall, the theories that have been developed historically premise that natural resources can be of major significance for economic development. Resource frontier expansion was pivotal to economic development during the nineteenth century's transition to an industrial era. That does not of course mean that natural resource use is the only deterministic factor. Trade relations, international prices, innovations, the accumulations of physical and human capital and, more importantly, effective institutional arrangements provided the conditions by which natural resource use could lead to a sustained path of economic development. But since this thesis focuses on the material conditions for economic development, natural resource use is what is empirically examined here.

## Colonialism and economic development

There are no explicit theories of colonial expansion or colonialism, and in historiography the process of territorial annexation for colonization has been discussed as part of theories that have dealt with imperialism. Colonialism was regarded as one of the devised methods by which the state could exercise its power in order to obtain economic advantages in foreign parts of the world. Original theories of imperialism were not only trying to say something about empire building, but also about the expansive tendencies of capitalism and the heightening military rivalries among European nations in the late nineteenth century. As mentioned earlier, conflating the two terms could be problematic,

since the term imperialism is more generic and denotes the use of state power against other countries in general and not only for the colonization process. Here, however, the intention is not to equate imperialism with colonialism. The aim is rather to briefly review theoretical propositions that have historically been put forward for imperialism, since these can prove useful when discussing colonialism. For this purpose, a large body of theories of imperialism discussed in Norman Etherington's (1984) work *Theories of imperialism* and in other literature, are briefly reviewed below mainly in reference with their relevance to colonialism.

Etherington's work provides a comprehensive and thought-provoking review of the theories that were devised from the turn of the nineteenth century onwards. In his view, the early theories of imperialism originated in the writings of late nineteenth-century capitalists who were trying to influence policies for the future rather than explain the past.

The main proposition that was central in the early writings about imperialism was the need for an outlet market that would act as a safety valve for saturated industrial growth. Adam Smith recognized the role of colonies in providing new markets through the establishment of monopolies but did not, however, value highly any wide socio-economic advantages derived from it. In his view, colonialism could be beneficial for early capitalists – “a particular order of men” – but on a nationwide level it constituted a significant cost (Smith 1776, II:221–25). For other early theories in the late nineteenth and early twentieth century, imperialism was considered a necessity since it provided the means for the occupation of new “fields” that could allow for the full employment of capital. Such “fields”, found among the “semi-civilized and barbarian races”, could provide fertile ground for the consumption of new goods, as well as for the investment of profits (Etherington 1984, 10–11). Socialist theories that were developed through the writings of early twentieth-century theorists, such as Gaylord Wilshire, Normal Angel, Henry Noel Brailsford and of course John A. Hobson's (1902) critical work *Imperialism: a study*, all understood imperialism as a necessity of the capitalist system, which instigated the use of military power by the state with the purpose of acquiring military and economic advantages in other markets. The central idea was that imperialism was motivated by a surplus of capital in search of new investment markets, due to the saturation of capital in the domestic industries.

As regards the particular value of colonialism, the theoretical views varied. Some, like Norman Angel, regarded it as a total cost with no benefits at all, while others, such as Henry Noel Brailsford, acknowledged that despite the significant

cost of empire (composed mainly of expenditures for the administration and defense of the colonies), a small elite of people – the governing class – benefitted from it. They did this by obtaining access to profitable investment opportunities abroad but also because the possession of colonies could prove beneficial in providing contracts and employment for the workforce of the mother country, since in any annexed territory most jobs were given to citizens and firms of the controlling nation (Etherington 1984, 88,94). It is worth stressing, however, that when it comes to the value of land acquisition, both Brailsford and Angell recognized the conquest of new territory as a beneficial form of promoting trade and bringing wealth, primarily to societies that were at an agricultural stage of civilization, but less so to the “modern” societies that the writers considered themselves to live in. Annexation of new territory with the use of armed force was not the main aim, since in Brailsford’s words, “land hunger is not the malady of the modern world” (Etherington 1984, 95). Increasing armaments were only useful for exercising pressure upon the ruling population in other territories so that the full employment of capital was ensured.

Theories of imperialism by central European writers, and specifically Germans such as Rudolf Hilferding and Rosa Luxemburg, also revolved around the necessity of capital to find employment in new markets abroad. For Marxists, such as Nikolai Bukhari, Karl Kautsky and specifically Lenin’s study *Imperialism*, which was written in the aftermath of the First World War, the focus was also placed on the role of capital and the capitalistic elite. It was acknowledged that competition between various blocs of capital in a world that had already to a great extent been partitioned could have disastrous effects. This was because, in the absence of more “free lands” that could be acquired with minimum use of force in order to secure capital investments, trade and competition for the provision of raw materials culminated in disaster. In this sense, the period of armed aggression and international tension from the turn of the nineteenth century was seen as a natural outcome of capitalist development. Their rhetoric diverged, however, over the argument that this type of imperialism was able to produce “superprofits” that in part could also be used in order to bribe labour leaders and to allay revolutionary tendencies (Etherington 1984, 134–39). For other early twentieth-century theorists of imperialism such as Thorstein Veblen and Joseph Schumpeter, the phenomenon was also primarily explained by the connections of individual capitalist businessmen with the constitutional governments that led to “objectless” forcible expansion with no nationwide gains (Etherington 1984, 153).

After the Great War, however, some theorists of imperialism started to focus more on the role of colonialism and empire building. Leonard Woolf (a former British colonial officer who joined the socialist Fabian Society) marked a breaking point with his writings on imperialism in his 1919 study *Empire and Commerce in Africa*. By extending the study to the colonization of the nineteenth century he attached imperialism more closely to the idea of colonialism and empire building. He did not make any profound connections between “surplus” investment capital and imperialism, as others before him had done. Instead he saw “economic imperialism” as an unsubstantiated venture based on the “beliefs and desires” of the designers of national policies (Etherington 1984, 177–81). Other contemporary writers also focused more on factors other than capital investment as drivers of colonialism. These varied between the need for a market for surplus manufactured goods and the rising demand for tropical products mediated by decreasing transportation and telecommunication costs in the nineteenth century (Etherington 1984, 185–88).

After the Second World War, theories of imperialism continued to be re-interpreted even further and diverged significantly from the original theories of imperialism devised at the turn of the twentieth century. With the lifting of restrictions on the accessibility of government records, new studies such as those by Ronald Robinson, John Gallagher and Alice Denny’s 1961 *Africa and the Victorians* and Fieldhouse’s 1961 *Imperialism: an historiographical revision* started to challenge the older theories of economic imperialism. In light of the lack of empirical evidence to support the connection between capitalist investment interests and territorial annexation, these new studies portray imperialism and more specifically colonization as an irrational process, motivated primarily by “strategic reasons”. The emphasis is placed increasingly upon nationalism, the rising rivalries between European states and militarism as explanations for imperialism.

Studies by neo-Marxist scholars also formulated new theories of imperialism. These were mainly motivated by the failure of newly independent countries to demonstrate patterns of sustained economic growth with the end of colonialization. The new theories shift their attention from the effects of capitalist expansion on Europe to the effects of such expansion for underdeveloped countries. The work of some of these theorists, such as the works by Paul Sweezy and Paul Baran, went on focusing on the workings of the capitalist system, diversifying their views by playing down the role of the state in obtaining economic advantages overseas, but without putting a special focus on colonialism. The

capitalist system was regarded more as an “obstacle rather than an impetus to development” (Etherington 1984, 239–40).

Other theories, however, focused more on empire building and colonialism in order to explain the poor economic performance after independence. New theories and concepts were devised which put emphasis on the economic, political and trade relations that had been established during the period of colonization and which impeded post-colonial development. Concepts such as those of *neo-colonialism*, *underdevelopment*, *unequal exchange* and a *world system* which divides the world into core, semi-peripheral and peripheral countries, were developed by, in many cases ideologically driven, neo-Marxist writers such as Walter Rodney, Ander Gunder Frank, Arghiri Emmanuel and Immanuel Wallerstein. Being concerned more with the role of colonialism for economic development in the world “periphery” rather than the national empires, these theories gradually divert from the original interpretations of imperialism and formed what is today labeled “dependency theory” (Etherington 1984, 241–58).

More recently, in their by now classic work on *Gentlemanly capitalism*, Peter J. Cain and Antony G. Hopkins also examined imperialism theoretically, focusing on British imperialism throughout the nineteenth century (Cain and Hopkins 1986, 1987, 1993). In their studies, imperialism and colonization (imperialism’s “formal” expression) are not principally attached to the industrialization process of the nineteenth century. Although the role of capitalist elites is again considered as the main driving force for imperialism, this is born out of industrialization. In their view, manufacturers and industrialists are not the primal agents of imperialism. Instead, they stress the importance of what they term as “gentlemanly capitalism”. This was an economic system founded upon the culture and norms of landed capitalism of the late seventeenth century and was consolidated by the alliance between “landed” and “moneyed” interests in England from the eighteenth century onwards. In other words, in their theory the focus is placed upon the land owners or else the landed aristocracy and their counterparts found in the emerging financial service sector in the City in London. The role of the former was central in driving imperialism until the middle of the nineteenth century when the colonial system shifts and is increasingly determined by the financial centers in London.

Other more recent works that have attempted to provide theoretical propositions on the role of imperialism in European long-term economic development have based their discussions on a costs and benefits analysis. One such comprehensive work is the essay from Patrick O’Brien and Leandro Prados de la Escosura 1998 *The costs and benefits for Europeans from their empires over-*

*seas*, which reviews a series of empirical studies on the costs and benefits of imperialism for various European empires. O'Brien and Prados de la Escosura do not single out any common factor as an explanation for imperialism in Europe. They argue that imperialism and empire building provided an additional impetus to the European economy as a whole, but not necessarily for each national economy. They do not support economic determinism, which focuses on the underemployment of capital as an explanation for empire building and trade in the nineteenth century. Rather the contrary, since they stress that the economic significance of colonialism and empire building for European empires was rather low in monetary terms, possibly below two percent of GNP (O'Brien and Prados de la Escosura 1998, 67). Furthermore, the returns on imperial investments for the acquisition, development and defense of colonies are regarded as sub-optimal and inferior to those made on domestic markets.

Reviewing the “real and substantial” gains from imperialism for the long-term development of Europe, O'Brien and Prados de la Escosura (1998, 55), recognize that these could be described as a “tangible bounty”. These gains took the form of foodstuffs, raw materials and minerals whose direct significance, however, is as they argue “impossible” to quantify. Their interpretation of imperialism and colonialism tends to view the phenomenon more as an unsubstantiated venture based on beliefs rather than actual benefits. Accordingly, they favor instead explanations that focus on rather local indirect benefits that have accrued at the micro-level and which could have benefitted mainly what previous theories have described as a capitalist elite. For Britain, the largest imperial power of the nineteenth century, the significance of imperialism for the development of an industrial market economy, although relatively bigger than for other European economies, is regarded as “important but not (to an) overwhelming extent” (O'Brien and Prados de la Escosura 1998, 51–52). Instead, according to the authors, more credit should be given to Britain's endogenous forces, namely the productive and responsive agriculture, the cheap availability of coal-based energy, the flexible institutions and more importantly, the human capital (skills, capacities and attitudes of the workforce) that had developed via internal and intra-European trade, which made imperialism less of a necessity.

This brief theoretical overview of imperialism in itself demonstrates that the topic is far too complicated and its themes cannot be exhaustively discussed here. It also demonstrates, however, that the recurrent objective of the historiography concerned with the phenomena has been to substantiate its socio-economic determinism. All previous work has in essence tried to answer why has imperialism and colonialism occurred. Overall, it could be argued



that the various theoretical standpoints have historically provided nuanced explanations which have varied between two main standpoints. The first has regarded imperialism and colonialism as a necessity for the long-term survival and expansion of the industrial capitalistic socio-economic system of the nineteenth century while the second has been viewing these phenomena as blind, “objectless” and potentially unsubstantiated ventures mainly driven by the beliefs and desires of a small elite. Additionally, when contrasted with the domestic forces at play in each imperial economy, empire building has mostly been regarded as relatively less important.

Undoubtedly, most of the theoretical propositions have contributed much to our historical understanding of the colonization process. Usually, however, much of the theoretical discussion has revolved around the monetary aspects of empire. The empirical investigation of its materialistic underpinning, although stressed in many previous works, has been given relatively less attention and has not yet been conducted in a comprehensive all-encompassing manner. This is one of the contributions this thesis aspires to make.

## Economic-historical context

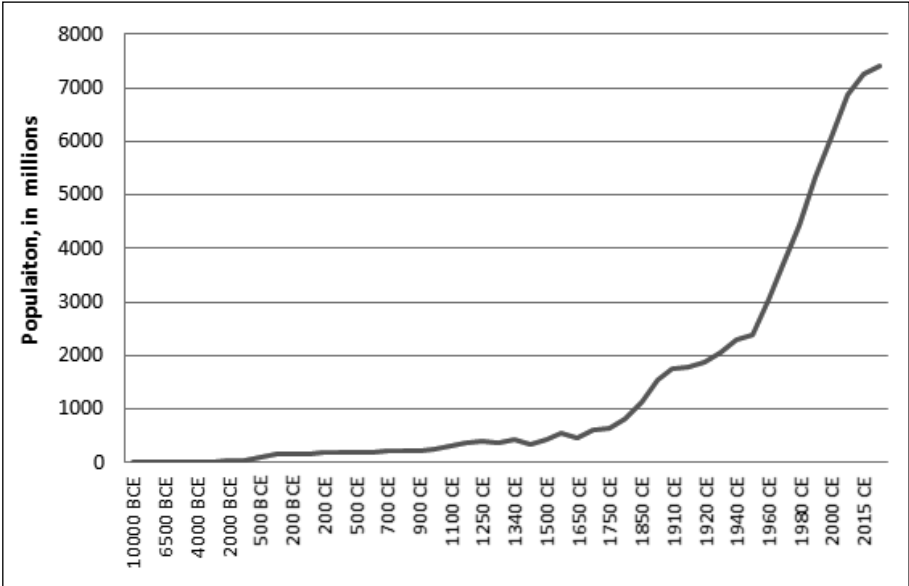
The European continent, and even more so its northwestern regions, were historically placed in a disadvantageous position in terms of agriculture. Compared to East Asia, this region was characterized by dry agricultural methods of cultivation which provided a much lower yield of produce per unit of land and by extension supported lower population densities (Kander et al. 2013, 46–48). However, as the basic narrative in economic historiography suggests, from the late eighteenth century this disadvantage would start to disappear, with far-reaching implications for the importance of land and population. A mechanism of negative feedbacks on population briefly described earlier and referred to in historiography as the *Malthusian trap*, ceased to apply from 1800 onwards, and this change occurred first in this geographical area and specifically in Britain.

This unprecedented historical event happened during the period of the Industrial Revolution in Britain and spread during the rest of the nineteenth century to the rest of Western Europe, initiating a distinct and diverging pattern of growth and prosperity for this part of the world (in contrast with the rest of the world and particularly the East). The change in population growth, being more prevalent in Northwestern Europe, had in fact been underway since the Middle Ages but intensified significantly with industrialization (Kander et al. 2013, 83). In fact, it could be argued that the initial conditions of relatively disadvantaged and less intensive agriculture provided the motives for intensification and acted as the ecological explanation for the earlier mechanization of agriculture in these regions.

This historical narrative is best captured by Figure 1, which shows world population growth over approximately the last 10,000 years. Although much of the pre-1800 pattern is based on conjectural estimates, very few if any would doubt that the change which occurred from the late eighteenth century until the onset of the First World War was unprecedented. Over a period of five centuries between ca. 1300 and ca. 1800, the population of England rose from 5.8 million people to 8.7 million while comparably low growth rates were also observed in other European countries during this period (Clark 2007, 21). It was only from 1800 onwards that population grew in an unprecedented manner. Population in the UK and Ireland increased threefold between 1800 and 1910, rising from approximately 16 to 45 million, while similar growth patterns were observed in other European countries such as Germany, Denmark and

the Netherlands (Mitchell 2003, 1988). Much of this change was the product of nineteenth-century industrialization, which in addition to technological improvements and structural changes also entailed changes in the resource base of the economies, i.e. the energy mix and the use of land.

Figure 1. World population, 10,000 BCE - 2017 CE



Source: U.S. Census Bureau and Inklaar et al. (2018)

Various theoretical propositions have been made by scholars as to the role of domestic versus external factors that were responsible for this change at the birthplace of the Industrial Revolution, i.e. Britain. Economic historians and other scholars with a keen eye on economic history focused on cultural (Landes 1969; Cain and Hopkins 1986, 1987; Mokyr 2009; McCloskey 2010), institutional (Acemoglu et al. 2005; Acemoglu and Robinson 2012; van Zanden 2008), technological (Clark 2007; Mokyr 1990), economic (Findlay and O'Rourke 2007; Allen 2009) as well as geographic and resource factors (Diamond 1997; Jones 1981; Pomeranz 2000; Morris 2010; Wrigley 1988, 2010, 2016) as determinants of industrialization. Of course, these different propositions are not mutually exclusive. Most would agree that it is difficult to separate their relative explanatory power since the Industrial Revolution is “overdetermined” (in Joel Mokyr’s words). Focusing on one case can, however, enhance our understanding

without necessarily decreasing the power of other competing explanations. In this regard, the focus here is on the role of geography, natural resources and land expansion in vertical and horizontal frontiers.

## Technological change and agriculture

Global land use has altered significantly since the early eighteenth century, with the global area of agricultural land growing dramatically by a factor of 4–5 from 1700 to 1980 (Meyer and Turner 1992, 42). During the nineteenth century, with the exception of western Europe and core areas in China, the total stock of land for agricultural purposes rose significantly and it was only after the 1930s that its growth rate slowed down (Federico 2005, 35–38). For Western Europe, the domestic land frontier had already been closed and thus changes in its stock were difficult to come by. But this did not necessarily mean that land output constituted a fixed constraint. On the contrary, this was to a great degree conditioned by technological change. Following Boserup's paradigm, which reversed the Malthusian argument, industrialization and the subsequent increases in population led to technological change and the intensification of production in agriculture (Boserup, 1965).

Nevertheless, when we look at agricultural production during the nineteenth century, it was characterized more by a pattern of “extensive” growth through an increase in inputs, in contrast with twentieth-century production, which was much more driven by increases in total factor productivity (“intensive” growth) (Federico 2005, 221). Pressure on land in Europe was prevalent and increased throughout the nineteenth century. This is for instance evident from the rising wheat and timber prices in England from the seventeenth century until the early nineteenth century (Kander et al. 2013, 92,108,119). Additionally, using comparable data on population from Mitchell (2003, 3–8, 1988, 11) and arable land estimates from Federico (2005, 33–34), Mulhall (1899, 7), and Musel (2009, 271) for various European countries in the nineteenth century, rough ratio estimates of arable land per person can be estimated. The pressure on land in the UK and Ireland was already significantly higher from the early nineteenth century. By 1850, the UK and Ireland had the lowest level of arable land per person in Western Europe, with comparable, but still slightly higher figures found only in Belgium. In 1850, arable land per capita in the UK and Ireland was 0.7 acres, while the figure found in other European countries at the same time was at least twice that: Denmark had 3.5 acres per capita, France

2.4 acres per capita, Germany 1.8 acres per capita, Italy 1.4 acres per capita, the Netherlands 1.5 acres per capita, Portugal 1.2 acres per capita and Spain 2.6 acres per capita. Later on in the nineteenth century and up until the onset of the First World War, this relative positioning of the UK and Ireland was maintained despite the convergence of all European countries towards lower levels of arable and tree crop land per capita.

Consequently, Britain was facing the most severe pressure and scarcity in Western Europe. Nevertheless, it is only fair to ask to what extent and where was this situation of scarcity prevalent? From a global comparative perspective, Britain and specifically England was still far better off in terms of agricultural productivity (van Zanden 1991). Did this show any signs of improvement? It could be argued that Britain had already exploited its productivity frontier, at least in terms of yield per acre, by the 1830s. Looking for instance at wheat yields, productivity reached a plateau in the early decades of the nineteenth century (at approximately 30 bushels per acre) and from then on remained stable or slightly decreased until the early twentieth century (Turner, et al. 2001, 137–40). In this sense, Britain could be characterized as the least Malthusian society in northwestern Europe, but had already reached its frontier capacity in the early nineteenth century. So how did the relationship between industrialization and technology-induced land change develop during the rest of the period?

The years between 1840 and 1880 were labeled by Victorians as a period of “high farming” and during this time productivity improvements were taking place in agriculture. As reported by Paolo Malanima, the declining trend in agricultural output per capita from the mid-eighteenth century until the early nineteenth century was partly countervailed by agricultural intensification (Kander et al. 2013, 100–103). This took the form of colonizing new areas, introducing new crop varieties, new cultivation systems based on fertilizers, field rotation and drainage, and introducing coal-based mechanization (Kander et al. 2013, 100–103; Williamson 2002, 139). In other words, extensive land use did not necessarily mean that innovations were absent. The question is rather if these were “enough”.

By the nineteenth century the process of domestication of new animal species had long been completed (Diamond 2002) while by the mid-eighteenth century there had been the latest discovery of a new plant, the sugar-beet (Federico 2005, 85), but its cultivation did not become significant until the second half of the nineteenth century. Nevertheless, the European colonists were introducing their cultivation methods and crops in all the places they settled and “biological innovation via worldwide transfer” had reached its limit toward the

end of the nineteenth century (Federico 2005, 86; Olmstead and Rhode 2008). Some important crops such as maize and potatoes, which provided a higher energy content per cultivated hectare, were already widespread in northwestern Europe by the eighteenth century and it was only in northern Europe (Sweden and Norway), and southern and eastern Europe (Italy, Russia and Poland) that the potato was introduced much later in the nineteenth century (Kander et al. 2013, 104).

Other breakthroughs in agriculture had been the enclosure movement and the “new husbandry” practices along with the cultivation of leguminous plants. These allowed the integration of different types of land uses – for growing feed and corn – and an increase in the supply of nitrogen, substantiating the “agricultural revolution” (Overton 1996; Federico 2005; Chorley 1981). However, the “revolutionary” character of these changes and more importantly their connection with the Industrial Revolution has been strongly contested by some scholars. Robert Allen (2004) suggests that the developments in British agriculture had already diffused much earlier, between the seventeenth and the mid-eighteenth centuries and thus agrarian change may have contributed comparatively little to industrial change.

Other innovations that concerned agriculture were chemical products in general and fertilizers in particular. The use of manure, bones, guano, Chilean nitrates and potash, constituted the main sources of nitrogen and phosphorus nutrients, which are vital for the growth of plants. Until the early twentieth century most of the nitrogen was provided by organic sources, while before the nineteenth century the only way to increase the supply of nitrogen was by increasing the use of leguminous plants, since their contribution to the process of nitrogen fixation from the air is essential. Chorley (1981, 92) has estimated that more than one third of the growth in total output per hectare in Northern Europe from the 1750s well into the nineteenth century was actually due to the supply of nitrogen from legumes. In the case of phosphorus, the main source of which was manure in the early nineteenth century, this nutrient was also obtained from bones (both domestically sourced in Britain and imported) but their significance started to diminish in relative terms from the 1840s onwards due to fierce competition from the new fertilizer – guano (Thompson 1968; Cordell, et al. 2009).

From the 1830s onwards, Chilean nitrates and guano imports from Peru started to make significant contributions to fertilizer use in Britain. The use of natural fertilizers was central, with Peru exporting approximately 12.7 million metric tons of guano during the period (Cushman 2012, 45–47). Their actual

contribution to productivity increases is however suggested to have been more apparent than real (Turner et al. 2001, 142). In fact, the real breakthrough with fertilizer use did not come until the early twentieth century and the invention of the Haber-Bosch process in 1909 (named after Fritz Haber and Carl Bosch, the German chemists who invented it), which industrialized the production of nitrogen-based fertilizer and contributed more than fifty percent to the rise in the world's population from 1.6 billion in 1900 to more than 7 billion today (Marks 2012).

Apart from biological innovations and fertilizers, other incremental innovations, mainly in agricultural machinery, continued to occur throughout the nineteenth century, and in this sense agriculture was far from a static sector. But mechanization had a significant effect in raising agricultural output and most importantly saving labor only after the First World War. Some major innovations such as the cotton gin (in 1793) and the wheat thresher (in 1786) were already in place from the late eighteenth century, but the vast majority of incremental innovations that concerned the processing of commodities occurred in the late nineteenth century. For instance, process innovations such as those for coffee and separating the butter from milk did not occur until after the 1860s. Additionally, significant product innovations such as the combines, the first milking machine and the first cotton picker were introduced after the 1880s and became widespread only after the First World War (Federico 2005, 91–92).

Consequently, Britain, despite maintaining a high productivity compared with other Western European countries, had relatively smaller changes in productivity between 1870 and 1910. Although Germany, Denmark, Belgium and the Netherlands were adapting to the changing circumstances in European agriculture more quickly (such as falling agricultural prices and rising agricultural wages), Britain was unable to move much further in the efficiency frontier and in this sense missed much of the late nineteenth-century's "green revolution" centered on chemical fertilizers and new concentrated animal feeds (van Zanden 1991, 230). Even though the use of organic fertilizers and machinery was more widespread in Britain than in other European countries, according to van Zanden (1991) most of the productivity increases were driven by structural changes, and specifically by the expanding market of the urban sector which stimulated higher demand.

Based on Federico's (2004, 129) review of estimates of the growth rates of agricultural production and population before 1870 in various countries, England stands out as the only case where the growth rate in agricultural production could not keep pace with population growth. For European countries

such as Denmark, Belgium, France, Germany, and the Netherlands the growth rate in agriculture was at least 1.5 times higher than that of population growth while in contrast, for English agriculture the rate of growth of output was approximately 30 percent lower than that of population growth.

Why then did Britain fail to effectively adopt the late nineteenth century's land-saving innovations? van Zanden (1991, 236) suggests that the price of inputs (fertilizers) fell relatively slower than the price of land; the structure of British agriculture was different, with relatively larger holdings; and the institutional setting in Britain did not move in the direction of credit agricultural cooperatives (that could supply working capital) as it did in continental Europe. Additional explanations, centered on coal technologies, can also be traced and are discussed further below.

**Table 1. Agricultural product per capita in European countries, 1500–1800 (1500=1).**

	England	Germany	Spain	Italy	France	Poland	Belgium	Netherlands	Austria
1500	1	1	1	1	1	1	1	1	1
1600	0.7	0.76	0.81	1	0.78	0.78	0.78	0.84	0.6
1700	0.85	0.67	0.94	0.96	0.76	0.87	0.87	0.84	0.71
1750	0.92	0.67	0.81	0.81	0.78	0.82	0.82	1.02	0.82
1800	0.68	0.76	0.75	0.66	0.78	0.9	0.9	0.96	0.68

Source: Adapted from Kander et al. (2013, 88 table 4.4)

Despite these endogenous forces, however, it is hard to say whether the causality did not also run in another direction, i.e. that much of the land relief was already provided from abroad or from the changing resource base, so that Britain with its Empire faced comparably lower land pressure than other European countries and thus possibly a lower opportunity cost. By empirically investigating the role of horizontal and vertical frontier expansion during this period, this thesis provides part of the empirical evidence for tackling this question.

Overall, it can be argued that although some improvements were taking place in agriculture throughout the nineteenth century these were still relatively constrained to extensive rather than intensive land use. Britain, along with Denmark, was leading the “efficiency frontier” in 1870, demonstrating among the highest agricultural outputs per capita and yields per hectare (van Zanden 1991, 220). However, most of the innovations resulted in increasing labor rather than land productivity. As shown in Table 1, by the nineteenth century, agricultural output in Britain and to a lesser extent in other European countries was starting to decline. Although nitrogen-fixing crops had increased



land productivity, it was only in 1913 that “the most important innovation” of the twentieth century, the industrial Haber-Bosch process, was developed to synthesize ammonia and produce a chemical nitrogen fertilizer that would increase actual land yields (Smil 2001). Until then, most mechanical inventions of the nineteenth century were mainly related to post-harvest processes and thus could increase the crop yield per unit of land only indirectly (Pomeranz 2011).

## Trade and industrialization

Advancements in technology, which on one hand were responsible for productivity changes in agriculture, were also responsible for changes in trade. The nineteenth century saw an unprecedented expansion in world trade activity which would have actually been unimaginable without decreases in transport costs. These were made possible by technological improvements and innovations such as the transition from sail to steam. Only with the fall of transport costs did it become profitable to transport goods with a higher volume to value ratio and expand trade activity beyond the limited market of luxury goods. The evidence of falling transport costs is central in the literature concerned with the first wave of globalization. Although the exact timing of this globalization is debated in economic history (see for instance O’Rourke et al. 1996; O’Rourke and Williamson 2002; Rönnbäck 2009; Federico 2012), very few would doubt that the nineteenth century saw significant reductions in transport costs. This not only applied to the Atlantic economy (North 1958; Stemmer 1989; O’Rourke and Williamson 2002) but also to the Black Sea (Harlaftis and Kardasis 2000) and Sino-Japanese region (Yasuba 1978). Any criticism of this argument would mostly focus on the rate of these cost reductions (K. G. Persson 2004).

Turning to the importance of trade and horizontal expansion for industrialization, some scholars argue that its contribution was of lesser importance compared to technological improvements. Its main function was to contribute an extended market, which fostered export-led industrialization (Clark 2007, 313–15). In other words, trade is seen as a mediating factor for the expansion of an already developed and accumulated capital stock. Large-scale industrial production, technological improvements in transportation and the development of a mercantilist culture are instead emphasized more as preconditions for trade (Barbier 2011, 275;323; van Zanden and van Tielhof 2009; Mokyr 2009). Additionally, any gains from colonialism have

been regarded as relatively indirect and of microeconomic significance, while the macro-economic significance for the national economies is difficult to measure. As O'Brien and Prados de la Escosura (1998, 67) argue, the importation of raw materials from other continents and specifically the colonies allowed for the development of import substitution policies for manufactured goods that were previously purchased from Asia and the Islamic world (for instance silk and cotton textiles but also foodstuff such as refined sugar, roasted coffee and processed tobacco). In this way, imperialism provided the basis for new capital formation and the development of employment in new industries. Another contribution came from the diversification of European diets and the material culture of European households. The consumption of spices and other luxury goods, such as sugar, tea, coffee and chocolate, along with the addition of staple foods such as potatoes and maize, made significant calorific additions to the European population and raised the propensity for labour among the national workforce. A third contributing factor was the growth of major ports in Europe such as Seville, Lisbon, Antwerp, Amsterdam, London, Liverpool and Hamburg, as well as the development of a maritime culture that revolved around the shipbuilding industry, shipping and commercial and financial services. Finally, a fourth benefit came from the exploitation of precious metals from South America and Africa and specifically imports of silver and gold. The influx of bullion was essential for the development of the European and international monetary system. Additionally, the contribution of international trade as a mediating factor for alleviating the resource constraints of Britain throughout the late eighteenth and nineteenth centuries is regarded as relatively limited and its importance becomes evident only during the second half of the nineteenth century (Wrigley 1962, 2010).

Without disregarding these arguments, trade and industrialization are, instead, viewed here as mutually reinforcing and linked with one another by bidirectional causality. The reason is that a unidirectional perspective tends to bias the role of trade and downplay the role of imports as an, at least equally important factor for industrialization. If slack resources were still domestically available then the role of trade ought indeed to have been relatively insignificant. As we briefly observed, however, for Britain the pressure on land was rising in the nineteenth century and any productivity improvements would have to be complemented by other forms of frontier expansion, i.e. horizontal and vertical expansion. Trade during the nineteenth century could provide an outlet for horizontal expansion and industrialization, and

although there is ample evidence for its rising economic importance, no systematic analysis has estimated its actual contribution in extending the horizontal frontier. The only study in this direction is the important work by Kenneth Pomeranz *The Great Divergence*, which also constitutes a great inspiration for the current thesis. Pomeranz provides tentative estimates on the land relief that was provided by horizontal expansion and this amounted to between 25 and 30 million acres (Pomeranz 2000, 276).

Turning to the changes that occurred in trade, in Findlay and O'Rourke's (2007, 430) view, the decades following 1780 up until the First World War, which brought this period's "liberal economic order" to an abrupt halt, marked dramatic changes in trade activities. Recently, Federico and Tena Junguito provided new estimates of world trade, which go back to the beginning of the nineteenth century. According to these, during the period 1817–1913, trade increased in absolute terms steadily and at a high rate. Growth was higher during the first half of the period between 1817 and 1866 (3.97% per annum) than the second half (3.07% per annum between 1867 and 1913) (Federico and Tena Junguito 2016, 34). Additionally, in relation to global production, the period 1800–1913 saw a rapid expansion in world trade as its share increased from 3 to 33 percent of global production (Kenwood et al. 2014, 79).

European trade shifted from its earlier preoccupation with small quantities of high-value luxury goods to the mass trade of bulky commodities for a growing and increasingly affluent population (M. Williams 1993, 180). Britain during this period held the central position, accounting for one fifth of global and approximately one third of European imports and exports (Mulhall 1899, 128). More specifically, according to Yates (1959) in 1876/80, northwestern Europe accounted for almost 50 percent of global exports, while the United Kingdom and Ireland contributed 34 percent to this share. By the onset of the First World War, the share of exports from northwestern Europe had marginally decreased to 46.5 percent, while the United Kingdom and Ireland now accounted for 28 percent of this share. As regards imports, again in 1876/80 Europe was the biggest importer, accounting for 54.4 percent of global imports, while the United Kingdom and Ireland played by far the most influential role, accounting for more than 40 percent. By the First World War, Europe's role had slightly decreased to 51.7 percent, with the United Kingdom and Ireland now accounting for almost one fourth of this trade. Regarding the earlier part of the nineteenth century, estimates from Bairoch (1993) suggest that the role of the United Kingdom and Ireland

was equally important. For the benchmark years 1830 and 1860 the United Kingdom's share of exports in the European total was approximately one third. Furthermore, although European exports to, what Bairoch calls, the "Third World" made up only a relatively small share, at 21 percent, the UK's share was significantly higher and 40 percent of its exports were directed to less-developed economies during the period 1800–1938.

Besides the trade in commodities, economic historiography has also examined the role of the slave trade for the Industrial Revolution in Britain. As will be shown in one of this dissertation's essays, land availability constituted a determining factor for this type of economic activity as well.

The seminal study by Eric Williams (1944) *Capitalism and slavery* was the first to examine the role of slavery in industrialization, suggesting that slavery and its related trade activities helped the financing of and provided material support for the Industrial Revolution in Britain. Following up that study, almost half a century later, Joseph Inikori's (2002) *Africans and the Industrial Revolution in England* work reinvigorated the debate. His study stressed the central role that intercontinental trade played in the development of the Industrial Revolution in England and more importantly the role of African slave labor in this process. The role of British-controlled trade activities dominated this trade and by the mid-nineteenth century made up approximately 60 percent of the total value of American export commodities (Inikori 2002, 182). The contribution of African slave labor to this growth in commodity production and trade has been very significant. Inikori's work has demonstrated that out of the total value of export commodities produced in the Americas between 1500 and 1850, at least half was produced by African slave labor. According to these, the higher estimate refers to the eighteenth century, when the contribution of slave labor reached more than 80 percent, while by 1850 that contribution had decreased to a still high share of 70 percent. This led him to make a somewhat exaggerated statement, that "the Americas were indeed an extension of Africa in 1650–1850" (Inikori 2002, 197).

## The shift of energy regimes

In addition to horizontal expansion through trade, the focus in this thesis is placed on the role of vertical expansion for industrialization. For this reason, it is important to briefly review what changes occurred in the resource base

during the late eighteenth and throughout the nineteenth centuries and their relevance for industrialization.

There is a large body of scholarly work that has empirically analyzed the importance of energy transitions for different countries in Europe and has contributed to the field of energy history with unique empirical evidence on historical estimates of energy consumption and different energy carriers for various European countries (Kander 2002; Malanima 2006; Gales et al. 2007; Warde 2007; Bartoletto and Rubio 2008; Lindmark and Andersson 2010; Henriques 2011; Hölsgens 2016; Nielsen 2017). Within Europe, Britain was the first to lead the transition to a new energy regime in the nineteenth century. Apart from changes in technology and the gradually increasing role of trade, another major breakthrough occurred in the resource foundations of the economy. The first Industrial Revolution was synonymous with radical changes in the underlying energy regime and specifically with the shift on a large scale from organic to inorganic energy sources, i.e. coal, which opened up a new vertical resource frontier (Wrigley 1988, 2010, 2016; Wilkinson 1988; Warde 2007; Sieferle 2001; Kander et al. 2013).

Although the motives behind this shift to coal have marginally been disputed (Malm 2016) and its contribution partly questioned (Clark and Jacks 2007), most scholars in economic history would generally regard it as a natural process that was central to industrialization, with strong forward and backward linkages. This transition was associated with structural changes in the labor market as well as technological changes that meant the abandonment of artisanal production in favor of large-scale industrial establishments (O'Rourke et al. 2013; Allen 2009). Despite these immediate effects on the industrial scene, however, this energy transition also had far-reaching implications on the use of land and by extension the material conditions that underlined societies.

Prior to the onset of the Industrial Revolution in Britain, earlier societies and economies were mainly based and functioned under an *organic economy regime* that dictated population expansion and economic growth (Wrigley 1988, 2010). Anthony Wrigley was the leading scholar to link the Industrial Revolution with the underlying energy regime in the 1960s, identifying the cut-off point in time for the change in energy regimes as the early decades of the nineteenth century, and characterizing the preceding period as an “organic economy” and the latter as a “mineral-based energy economy”. It should be mentioned, however, that the term “advanced organic economy” was also introduced to account for the relatively more productive character of British agriculture in the late eighteenth and early nineteenth centuries (Wrigley 1962, 1988, 2010, 2016).

The transition from agricultural or traditional energy carriers (food, firewood and feed) to non-agricultural and modern energy carriers (water, wind, coal and peat) had already started in the late sixteenth century in England but culminated in the nineteenth century with the widespread adoption of coal for mechanical power (Kander et al. 2013; Malanima 2006). The use of coal for heating purposes in England had already made significant contributions to this transition by substituting for firewood, which meant that the vertical frontier was already alleviating land constraints between the sixteenth and eighteenth centuries (Kander et al. 2013, 61,114; Sieferle 2001, 102–4). As recently argued by Paolo Malanima, coal had both a “land-augmenting” and a “labor-augmenting” effect on society, which significantly contributed to overcoming the land and subsequently labor constraints of the pre-industrial economies (Malanima 2016). Malanima identifies two distinct phases in this contribution. The first covers the period from the late sixteenth century until the beginning of the nineteenth century, during which the use of coal was primarily land-saving, acting as a substitute for firewood. The second period from circa 1830 onwards marks the contribution of coal to mechanical work and thus its additional effect on saving labour. From the beginning of the nineteenth century, coal was responsible for 80 to 90 per cent of total energy consumption in Britain, a share which other European late industrializers such as Germany, France and the Netherlands would achieve only from the 1880s onwards (Kander et al. 2013, 137).

Consequently, to summarize the transition, what marked the difference between the two periods was the widespread use of coal in Britain’s energy mix and more importantly its use for the production of steam-based mechanical power rather than just for heating. Coal provided a solution to the constraints of the “areal” organic economy by providing energy in a “punctiform” manner which had less territorial restrictions (Kander et al. 2013, 136). Coal was mined vertically beneath the earth’s surface rather than requiring the horizontal land area of photosynthesizing plants and served as stored solar energy in a very concentrated form.

This coal-based energy regime meant that production processes stopped being mutually exclusive. As argued by Sieferle (2001, 25), coal abolished the problem of “alternative land uses” for obtaining energy in the nineteenth century. If for instance in the old organic regime there was a lack of mechanical energy and an abundance of heating energy (from wood), the only means of substitution would be to fell an area of woodland and use it as pasture. The biomass of plants could be transformed to mechanical power only through

animals, and again this had to be provided in a specific form, i.e. hay or grain. As a new energy source, coal transformed these processes and thus also transformed the way land was utilized.

It would be a mistake, however, to conclude with the presumption that coal had only a land-saving effect. What Stanley Jevons, in his defining nineteenth-century study, *The Coal question*, labeled as a “rebound effect” mechanism, signaled that modern economic growth was also inherently *extensive* (Jevons 1865). The rebound effect implied that improvements in energy efficiency that came about by the use of coal made energy services cheaper and consequently triggered the expansion of consumption of such services, in the end leading to even greater levels of coal consumption. Growth in the economy was actually dependent on an ever-greater transformation of nature (Marks 2012, 71). The importance of traditional energy carriers did decline, but only in relative terms, since their absolute consumption rose to unprecedented heights (Kander et al. 2013, 144). For instance, the study by Lindmark and Andersson (2010) on nineteenth-century Sweden has, on the basis of different assumptions about consumers’ behavior than the study by Kander (2002), argued that firewood consumption increased during the industrialization process of the late nineteenth century compared to the earlier part of the century. This was driven by higher living standards which countervailed technology-based efficiency improvements. It should be noted, however, that in a more recent publication Lindmark and Olsson-Spjut (2018, 29–30) have partly revoked this thesis of increased firewood consumption for energy after refining their assumptions on the price elasticity of per capital heating.

Aside from the effect of higher income elasticities, however, technological bottlenecks also continued to impose constraints and strengthened the drivers for horizontal frontier expansion and extensive growth. For instance, one major explanation for the slow development of new machinery in agriculture during the nineteenth century was the constraint in the supply of power. Although the steam engine could increase productivity in processing, because it was fixed in one location, it did not solve many of the problems in mechanizing agricultural fieldwork. Coal- and steam-based technologies of the nineteenth century that centered on the prime mover faced significant mobility constraints and were thus not very good at substituting for much of the animal power used in agriculture. As argued by Federico (2005, 92), steam plows and steam tractors had been invented back in the early and late nineteenth century, but were rather cumbersome and difficult to use. Animals still needed to be employed in agriculture, taking up land for fodder which could otherwise be used for

growing crops. This translated into significant constraints given that the land area needed to sustain working animals is much larger than the land they can actually till (Boserup 1965, 35).

The full mechanization of agriculture, along with other land-saving innovations such as the Haber-Bosch process, would have to wait until much later in the first decades of the twentieth century, and specifically in the 1920s when the oil-burning internal combustion engine became available and the share of artificial fertilizers started to make a significant contribution. These constituted the “macro-innovations”, to use the terminology of Kander et al. (2013, 26), of the second Industrial Revolution, with far-reaching implications not only for agriculture but also for European industry and the transportation sector as a whole, and provided a new impetus for modern economic growth and population expansion. Until then, however, the expansion to vertical and global horizontal frontiers was central for economic development. Growth continued to be extensive and as this thesis aspires to demonstrate, land, acting in complement with technological improvements, continued to dictate the shape of industrial expansion.



# Research design

## Prices and bio-physical indicators

Since this thesis focuses very much on the material conditions underpinning industrialization, most of the analysis has been based on the use of material and ecological indicators – *land* – rather than prices as empirical evidence. As a methodology, this certainly has both advantages and disadvantages. But ultimately, the discussion should revolve around its usefulness in broadening our understanding of processes in economic history which for most part have been researched through the lens of prices.

The potential disadvantage of such a methodology is that it shifts the discussion from a strictly economic sphere to a more socio-economic one, thus making it perhaps less familiar to the mainstream economics disciple. Relative prices and by extension costs, are important as they denote market signals and can explain by “how much, how far, and how strong” economic variables change. We begin by valuing market transactions in monetary terms because we cannot aggregate heterogeneous goods and services into a common measure. These monetary values are then deflated by a measure of price development in order to obtain the change in the volume of goods and services produced, which we actually interpret as the change in the quantity of goods and services available for consumption. What differentiates the approach of this thesis from economics is that the focus is instead placed on the embodiment of land or land footprint of economic activity, in other words, on a deterministic production factor that underpins prices. One could argue that no economists would bother to measure the importance of this component. Land is an immobile factor of production and the cost of land investments is embedded in the price of the commodities.

Although such an argument is valid, it could be argued that an approach which is actually based on bio-physical indicators can act in a complementary way to that based on monetary values. It can provide additional insights as to the significance of particular commodities and regions which, otherwise, cannot be captured by prices. The reason is that in the nineteenth-century institutional context of intense globalization and colonization, where the resource frontier expanded to new ecological zones, prices were not always the product of perfectly competing markets. The price of land was to a very large extent determined by historical factors, including not the least a country’s institutional

legacy. Land was essentially “free” at first, by depriving the indigenous populations, and it was only as the frontier started to close that a true land market appeared. Thus, the institutional setting of colonialism provided a comparative ecological advantage to some nations over others while this also affected the formation of prices and terms of trade. Had there not been the imports that embodied large amounts of “free” land from the colonies, would not the cost (social and economic) have been much higher? The answer is most probably in the affirmative. Had the land been paid for under voluntary contracts, then the prices of the commodities produced on this land would potentially also have been higher.

This dissertation thus complements research that has already been undertaken on the basis of prices. It provides new evidence that has been lacking from economic history on the ecological circumstances that underpinned industrialization and which are not captured by price-based empirical evidence. For instance, prices may not be the only way to reflect the significance of commodities. As suggested by the empirical evidence that this thesis brings to light, low per-unit value goods which have been regarded as less important in economic historiography may not necessarily have been insignificant. Instead, their role as key inputs for industrial economic sectors and activities rendered them important for industrial specialization. Such an approach helps us determine to what extent commodities and economic processes that have been analyzed in economic historiography thus far on the basis of economic indicators, actually reflected the ecological circumstances that underpinned them and vice-versa. This can enhance our understanding of the relative importance of economic and ecological indicators in economic history. Additionally, the examination of economic processes such as that of colonialism from a different, ecological, perspective can prove useful in substantiating a materialistic rationale for its historical occurrence and development.

# Method

The essays in this dissertation employ two distinct methodological approaches to conduct the empirical analysis. The first three of the papers employ a variant of the methodologies that have been developed under the “ghost acres” and “ecological footprint” concepts, while the fourth research paper employs a straightforward comparative analysis approach mainly based on descriptive statistics. Both approaches are discussed in more detail below.

## Biophysical indicators – “ghost acres” and “ecological footprint”

In economic history and environmental history, studies that have tried to assess the importance of land for economic activity during the nineteenth century in a meaningful way have resorted to the concepts of “ghost acres” and “ecological footprints”. A sample of these seminal studies and authors include among others: Jones (1981); Pomeranz (2000); Sieferle (2001); Hornborg (2006); Wrigley (2010, 2016); Rönnbäck (2010); Barbier (2011); Riello (2013); Warlenius (2016)

The concept of “ghost acres” was created in the 1960s by Georg Arne Borgström (1965) in *The Hungry Planet* to describe the physical area that is required to sustain a certain population with food products. Based on the concept, this physical area could take the form of land-, fish- and trade- acres that would have been required to produce an equal amount of food imports domestically. Following a similar rationale to that of “ghost acres”, approximately 30 years later, a couple of scholars, Mathis Wackernagel and William Rees (1996) *Our Ecological Footprint*, reinvigorated the concept by developing an adjacent biophysical indicator of sustainability and nature appropriation which also measures the impact and dependence of economic activity on natural resources in units of land area. This is the familiar “ecological footprint” concept which has drawn much more attention in recent decades and has been widely used in the field of ecological economics. In fact, it has constituted the basis for the development of other adjacent measures that were developed in recent years and translate different types of economic activities, products or services into footprints. One such indicator has for instance been the familiar carbon footprint concept (see for instance Cederberg et al. 2011; Persson et al. 2015). The merits that justify its wide adoption are the simplicity of its calculation method and its ability to provide a direct measure of demand on natural

resources and specifically land that various economic activities or commodities require. It thus provides a high degree of analytical rigor.

Both concepts are based on the same notional principle that land constitutes a major restriction for economic activity. Consequently, for an analysis that focuses on the interplay between economic activity and natural resources, both concepts are useful in assessing the impact and degree of dependence of economic activity on natural resources.

In the essays of this dissertation, a variant of the ecological footprint methodology is employed. The original methodology has been slightly modified in order to account for the historical particularities of the nineteenth century and to accommodate data restrictions when historical evidence has been unavailable. Specific methodological choices are discussed in more detail under each research paper. In what follows, I provide a brief overview of the concept, the variations that have been introduced and a critical review of its limitations.

In modern ecological footprint calculations, the arable-, pasture-, forest-, built-up- land and fisheries area required to satisfy a certain level of consumption of renewable resources is calculated on the basis of actual land units (usually hectares or acres), while the land footprint from the consumption of non-renewable resources, i.e. fossil fuels (such as coal), is calculated on the basis of counterfactual estimates (Wackernagel and Rees 1996; Monfreda et al. 2004; Wackernagel et al. 2004). In brief, in order to estimate the amount of land embodied in a particular commodity, it is necessary to first identify the inputs in land that correspond to each commodity, secondly to use an estimate of productivity or yield per unit of land for the chosen commodity and thirdly, to divide the quantity by the yield/conversion factor to obtain the corresponding ecological footprint estimate. For the calculation of land embodied in different commodities, most ecological footprint studies use standardized conversion factors which assume standardized technologies and land productivity among countries. In this way footprint estimates are expressed in standardized “global hectares” (Monfreda et al. 2004). This facilitates comparisons between countries, but masks the range of potential productivities and technology that exists. The essays in this thesis use instead a maximum and minimum estimate of productivity to show a range of possible demand for land and to combat uncertainties regarding data quality. It should be pointed out, however, that the figures for land productivity cannot capture technical change, since for some geographical regions and commodities, long-term estimates are lacking. This is a limitation of this dissertation and an area of future research that would expand on the work conducted in Paper 5.

Besides this change, the research papers in this dissertation exclude the two categories of land area for buildings and fisheries, due to data unavailability. Consequently, the main analytical categories that are discussed in the thesis are those of arable-, pasture-, forest- and energy/fossil fuels- land. The exclusion of areal estimates for infrastructure and fisheries undoubtedly constitutes a limitation for this thesis, but this was rendered necessary due to limited availability of historical estimates. Future research that would extend the analysis to these two categories and provide estimates on their ecological significance would be a valuable contribution to the field.

As regards the counterfactual estimates for fossil fuels, these can be calculated on the basis of three different approaches for determining the ecological footprint. Each approach is built on a different rationale. The first method assesses the area of forest growth that would have been required to act as a sink for the released carbon dioxide. The second method calculates the land that would be required to substitute for fossil fuels through the use of a biologically produced substitute (for example methanol from wood). The third approach estimates the necessary land area to rebuild fossil capital at the same rate as the fossil fuel is consumed. Since in all essays the main concern is with constraints and resource availability, I follow the second approach of biomass substitution. Thus, I calculate the area needed to replace fossil fuels with their energy equivalent in wood, based on a sustainable forest yield. Although firewood was not the only substitute for fossil fuels in the nineteenth century, it was certainly the more plausible alternative. Also, this methodological choice has been employed in other studies that have estimated the areal impact of energy fuels in the nineteenth century (Wrigley 1988, 2010, 2016; Siefeler 2001; Pomeranz 2000; Warlenius 2016). According to Wackernagel and Rees all three methods do give roughly the same result in units of land. Nevertheless, as they suggest, “the CO<sub>2</sub> assimilation method results in the smallest ecological footprint attributable to fossil fuel consumption”.

Turning to the limitations of the ecological footprint concept, a good review of its main advantages and weaknesses is provided in the discussion papers published in 2000 under the “Commentary Forum: The Ecological Footprint” in the journal of Ecological Economics, and in Mcmanus and Haughton (2006), which summarize many of those points. In brief, as Costanza (2000) has rightly argued, any controversies surrounding the concept mainly arise when one moves from the simple statement of the results to their further interpretation as an indicator of something else. In particular, the ecological footprint is an indicator with two functions. It quantifies the demand of economic activity on

bio-productive land, while according to its creators (Wackernagel and Rees) and many other researchers that have resorted to it, it can also be used as a measure of sustainability and thus provide policy recommendations. Based on a critical review of the concept, it could be argued that for most researchers (Costanza 2000; Deutsch et al. 2000; Mofatt 2000; van Kooten and Bulte 2000; White 2007; Mcmanus and Haughton 2006) the ecological footprint serves better its primary purpose while its use as a policy tool is sensitive to the context within which it is used.

As regards more specific considerations of the concept, some researchers have stressed that it may be inherently biased against trade. That is, that it neglects the role of comparative advantages between countries and regions which are built upon environmental and resource endowments and technical change (van den Bergh and Verbruggen 1999; Costanza 2000; Ayres 2000; Mofatt 2000; Andersson and Lindroth 2001). Other criticism that the concept has received concerns its validity as a sustainability indicator, given that it does not account for all ecological damage and other types of pollutants, such as harmful gases, toxic waste, soil erosion, and loss of biodiversity (Ayres 2000; van Kooten and Bulte 2000; Rees 2000; Andersson and Lindroth 2001).

Although this criticism is justified to some degree, it could be argued that it again concerns the utility of the concept mainly as a policy tool rather than an indicator of the strength of the economy-environment nexus, and thus does not constitute a major limitation for this dissertation. Following Rees's (2000, 373) characterization of the ecological footprint as an "ecological camera" which "provides a snapshot of a population's current demands on nature... under prevailing technology and social values", it is used in this dissertation to explain the changing role of land for modern economic growth during the first industrialization era and to provide a tentative assessment of sustainability aspects of the first industrial nation.

## Comparative descriptive analysis

In the fourth research paper of the dissertation, descriptive statistics and a comparative perspective are employed in order to identify differences in agricultural productivity between plantations in West Africa and the Americas. A special emphasis is placed on new evidence that the paper provides on agricultural productivity in Senegambia. On the basis of information on the area of the plantations, the amount of labor and their produce, comparative estimates on

land and labor productivity are constructed. Additionally, weighted averages of productivity and ranges of potential values are constructed for the whole region. The small sample of slave plantations from which the data is drawn does not allow for other methodological approaches such as regression analysis. That having been said, however, where possible some tentative correlation estimates are provided, but they do not constitute the main methodology of the paper. The summary statistics are compiled from archival material and secondary sources collected in Paper 5, and are presented in various tables.

# Data

A wealth of data has been employed in this dissertation. Before providing an overview, however, valuable contributions from third parties should be acknowledged. It should thus be noted that Dr. Paul Warde provided some of the data on nineteenth-century coal coefficients, which account for an important part of the dataset upon which Paper 1 is based. More information on this data can thus be found in Warde (2016). Additionally, a report by the Commissioner of Inquiry on the Western Coast of Africa, available in the British National Archives, Colonial Office (CO), used in drafting Paper 4, was provided by my supervisor, Klas Rönnbäck. The remaining data in this dissertation was compiled by me.

A major empirical contribution of this thesis is Paper 5, which constitutes the main data base for all the research papers included. The paper presents historical data on land yield estimates and direct land footprints for 81 early modern commodities that were traded throughout the world. Being developed in conjunction with the research papers of the dissertation, the main focus is placed upon products that were heavily traded by and within the British Empire during this period. The methodological steps that have been followed for the calculation of an acreage conversion factor for each product are analyzed in detail under each commodity. Additionally, the commodities are grouped into five broad product categories. These include i) grain and flour commodities; ii) animals and animal products; iii) other food, drink and spices; iv) raw materials; and v) manufactured articles.

Various sources have been used for compiling the data in Paper 5. The primary sources that have been used include official statistics and government reports from the nineteenth and early twentieth century which have been made available via online libraries such as the “Internet Archive”, “HathiTrust Digital Library”, “The Making of the Modern World” and “Google Books”. As regards secondary sources, data from a plethora of previous academic work has been collected. This includes numerous nineteenth-century books and contemporary journal article publications as well as more recent research, mainly in the fields of environmental and economic history. The wealth of sources that has been employed does not allow their detailed presentation here (for more on sources, see Paper 5). What should be stressed, however, is the search strategy that has been followed for identifying and gaining access to the various sources. In general, a two-step process was followed by which most sources were identified



through web search using *Google* and *Google scholar* search engines. In the first step, Google scholar was used for the identification of research published in secondary sources such as scientific journals and the search term used was; “product name” + “yield” + “per” + “acre” + “19thcentury”. The first 100 search results were reviewed under each product. In the second step, a general Google search was conducted to identify primary nineteenth-century sources as well as other secondary sources not covered by the first search strategy. A search term such as “product name” + “per” + “acre” + “country name” was used. Additionally, the search results have in most cases been confined by limiting the Google search to a “Book search” and also by adjusting for a specific time period in the nineteenth century or early twentieth century. It should be noted that in order for a source to be used, it should have been accessible either online or in printed form. As a general rule, anecdotal evidence has been disregarded. Nevertheless, when information was scarce or no data was available such evidence has been considered, checking through more than one other source for its validity. Overall, 81 commodities are included in this paper, however their geographical and chronological coverage varies significantly depending on the availability of historical information.

In addition to the data compiled in Paper 5, further primary archival material has been obtained from two archives, one in France and another in Britain. In particular, these include material from the British National Archives and from the French Archives Nationales d’Outre-mer. The material from the British National Archives pertains to historical trade statistics and has been used in Papers 1–3. This source is available online and had to be transcribed and digitized by me. The material from the French archives was employed in drafting Paper 4. It refers to agricultural data from early nineteenth-century plantations in Senegal and is not available in electronic form. It thus had to be collected via an archive visit and was subsequently digitized.

As regards the trade data, exports, imports and imports decomposed by commodity and by country of origin have been digitized from the British National Archives for specific benchmark years. These include the following: 1812, 1820, 1832, 1849, 1850, 1870, 1880, 1899 and 1907. Due to the time-consuming task of digitization, benchmark years were selected in order to capture key events of the nineteenth century, such as the pre-and post-Napoleonic wars era, trade liberalization from 1840s onwards, and the golden era of international trade and resource-based economic development from 1870 until the onset of the First World War.

Table 2. Main data sources used in each paper (other than Paper 5)

Papers	Sources
Paper 1	British National Archives, <i>Trade and Navigation accounts</i> , House of Commons Parliamentary Papers
	Baines (1835) <i>History of the cotton manufacture in Great Britain</i>
	Bischoff (1842) <i>A comprehensive history of the woolen and worsted manufactures</i>
	Mitchell (1988) <i>British Historical Statistics</i>
	Warde (2016) <i>Energy embodied in traded goods for the United Kingdom, 1870–1935</i>
Paper 2	British National Archives, <i>Ledgers of Imports Under Countries – CUST 4</i>
	Etemad (2007) <i>Possessing the World</i>
Paper 3	British National Archives, <i>Trade and Navigation accounts</i> , House of Commons Parliamentary Papers
	Mitchell (1988) <i>British Historical Statistics</i>
	Musel (2009) <i>Human appropriation of net primary production in the United Kingdom, 1800–2000</i>
	Iriarte-Goñi and Ayuda (2012) <i>Not only subterranean forests</i>
	Church (1986) <i>The history of the British coal industry</i>
Paper 4	French Archives Nationales d’Outre-mer, <i>Sénégal et Dépendances, Section XIII Agriculture, Commerce, and Industry; Section XX Statistique</i>
	British National Archives, Colonial Office 267/173, <i>The Commissioner of Inquiry on the Western Coast of Africa</i>

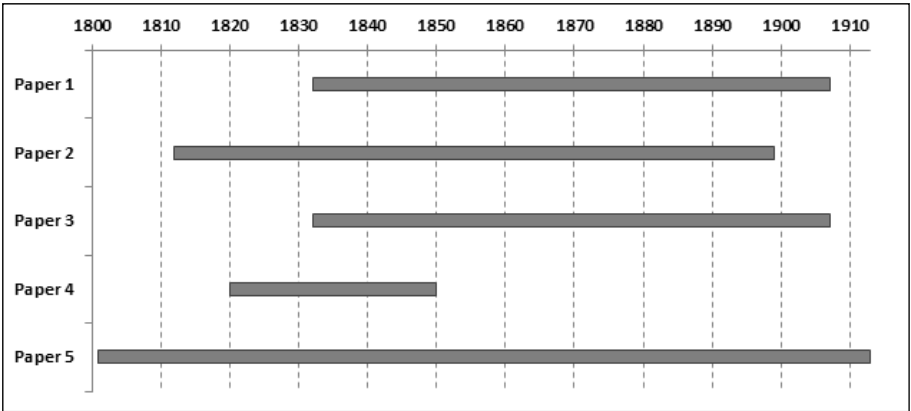
Table 2 summarizes the archival material and the additional main sources that have been used in each paper, except for Paper 5, which provides the basis for all these works.

During the compilation of the data used in the dissertations, special attention was paid to issues of validity and reliability. The main priority has been that the interested reader is able to identify easily the sources used for the construction of the data so that the studies have a high degree of reproducibility. Undoubtedly, some sources are better than others and this can create problems with the reliability of the results. To avoid such problems, as far as possible, for the land conversion factors, data from more than one source has been used in order to corroborate their reliability. Of course, this is very difficult to do with official statistics or with historical estimates of previous scholarly work, for the simple reason that in some cases they constitute the only source of historical evidence. 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 in the case of trade data due to smuggling or false entries, but these are not expected to be significant enough to bias the results. In fact, any

criticism of the reliability of British trade data has mainly focused on their valuation and the period before the 1780s (Schlote 1952; Davis 1979).

A final point to discuss concerns the geographical and chronological scope of the papers in the dissertation. Starting from the trade data, these mainly pertain to the United Kingdom of Britain and Ireland throughout the nineteenth century. For some benchmark years, namely 1812 and 1820, only trade data for Great Britain are available, meaning that Ireland is excluded from the trade statistics. This undoubtedly constitutes a limitation, but any potential biases that may arise are discussed in more detail in Paper 2 where this limitation applies. As regards the data on land productivity and the land conversion factors of various commodities, these pertain to the most important producing regions and countries around the world, with estimates for many benchmark years of the nineteenth century. However, some commodities that have been researched less widely in economic and environmental history, are not covered as extensively. For these, the geographical and chronological span is not as extensive. In every one of these cases it has been ensured that the data estimates represent regions that have historically been the most important centers of production.

Figure 2. Timeline of dissertation papers.



In Figure 2, the timeframe covered by each research paper is presented. The key period of the dissertation is the nineteenth century up until the First World War. The earlier period of industrialization, during the second half of the eighteenth century and mainly after c. 1780 is not covered in the thesis. As mentioned previously, this constitutes a limitation since some of these years that cover the period of the Industrial Revolution are left unexplored. This, however, is due to data constraints both on the part of trade statistics, but most importantly

on the part of land productivity estimates that limit the scope of the thesis to the nineteenth century onwards.<sup>1</sup> Official statistics and information from secondary literature becomes even scarcer before the 1800s. Future research that would extend the analysis further back in time would thus contribute valuable insights on the historical significance of natural resources and trade for industrialization.

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1 As regards Great Britain, the interested reader can find trade statistics which cover the period 1772–1807 in the work of Elizabeth Boody Schumpeter (1960). However, until 1892 the data pertain only to England and Wales, while Great Britain is covered from 1892 onwards.

# Results – Presentation of papers

## Paper 1: Trade and overcoming land constraints in British Industrialization – an empirical assessment

*Co-authored with Paul Warde and Astrid Kander*

The primary aim of the paper is to examine how the balance of land embodied in British trade developed during the intense period of nineteenth-century industrialization and provide new empirical evidence that we believe is lacking from the scholarly debate. The research question of the paper is: *What contributed more, in a strictly quantitative sense, to overcoming land constraints in Britain: domestic fossil energy or overseas land? How did this vary over time and what form did these land resources take?*

The starting point for the study is the association of the Industrial Revolution in Britain with the expansion of available “land” beyond the limited surface area of the island to *vertical* (coal) and *horizontal* (colonial) “frontiers” that hugely augmented available resources. The paper draws heavily on the scholarly debate initiated by Pomeranz’s (2000) seminal work *The Great Divergence*, which analyzes the divergent pattern of economic development that was observed between Western Europe and East Asia in the early phases of industrialization and which materialized during the nineteenth century. With a special focus on Britain, Pomeranz’s main proposition has been that, besides coal, an additional crucial contribution to industrialization came from horizontal expansion and specifically land imports from the periphery and the colonies. This was estimated to amount to approximately 25 to 30 million acres, at least up until the 1830s. This is a significant figure when compared to Great Britain’s total surface area of approximately 59 million acres.

The study thus implied an ecological exploitation of the periphery by Western Europe and particularly Britain through the use of the peripheral region’s land resources. However, studies thus far have mainly focused either on a few commodities or one trade activity. The empirical evidence is thus meager concerning the exact extent of horizontal and vertical land expansion during British industrialization. No all-encompassing assessment of the land embodied in British trade (both imports and exports) had been carried out before this study. Our paper contributes by providing such accounts, considering all the key products that have a significant bearing on land and coal.

The paper performs a quantitative analysis by employing British official trade statistics from the nineteenth and early twentieth centuries, from the *House of Commons Parliamentary Papers*, while also using nineteenth-century primary sources and secondary material to calculate the land embodied in land- and coal-based commodities. For the construction of land embodied in trade accounts, a variant of the ecological footprint methodology is used, as described in the methodology section. Instead of relying on only a few estimates derived from a few products, we account for the lion's share of traded commodities and provide ranges of possible values.

On a broader level, our results clearly demonstrate that the role of Britain throughout the nineteenth century was not that which is commonly portrayed in world system studies: of a core appropriating one-way flows of land and resources from abroad. The relationship that we observe is more multifaceted. During the early decades of the nineteenth century it is found that horizontal expansion was relatively more important as Britain was a net importer of land embodied in trade. However, from the 1850s onwards, the relative importance of vertical frontier expansion comes to the fore. Coal acted as an important land saver in the sense that it substituted for large quantities of wood that would otherwise be needed. For most of the nineteenth century Britain was a net-exporter of large quantities of “ghost” land in the form of manufactured products that embodied coal. Consequently, our understanding of these flows as part of a *system* is revised, with our empirical evidence supporting the claim that Britain was the “workshop of the world”. Our results also suggest that we should revise our understanding of the relative importance of particular commodities that have been stressed in previous historiography. Our results suggest that cotton, sugar and timber, which have so far been regarded as the main contributors to horizontal land expansion, actually contributed less than other commodities and their cumulative contribution was substantially lower than that of vertical frontier expansion in coal.

The textile industry again comes to the fore but in a rather different way. Based on our methodological choices, discussed in detail in the paper, potash and wool stand out as the most land-intensive commodities for horizontal land expansion and both commodities constituted important inputs for the textile industry in Britain. Despite finding that in relative terms vertical expansion was more important than the horizontal frontier, our results do not negate the importance of imported goods and “ghost acres”. In the earlier decades of the nineteenth century Britain was a net appropriator of significant quantities of natural resources and land from abroad while in absolute terms the throughput

of land to the British economy continued to increase dramatically until the end of the nineteenth century. This leads the way to more questions, concerning the role of colonialism in this contribution and the relative significance of different labor regimes established overseas. These constitute the starting point and objective of the second essay in the thesis and thus are examined and analyzed in detail there.

## **Paper 2: The White Man's relief – The ecological foundations of British trade in the nineteenth Century**

This paper constitutes a detailed study on the horizontal frontier expansion of Britain during the period of nineteenth-century industrialization and assesses the relative contribution of various trading partners in this process. It is an attempt to empirically examine and assess the role of colonialism in British industrialization within the context of horizontal frontier expansion, and juxtaposes this with the contribution of land relief that came from other parts of the world. The research question of the paper is: *Did colonies contribute significantly to horizontal expansion and abolishing Britain's land constraints?*

Horizontal frontier expansion overseas was essential to Britain's growth during the nineteenth century, but the existing debate in economic historiography has been rather inconclusive regarding the role and relative significance of the various trading partners and commodities in this process. Arguments from previous studies have varied significantly, ranging from Paul Bairoch, who regarded the role of colonialism and its contribution to the development of the "Western world" as a "myth", to Kenneth Pomeranz and Joseph Inikori who highlighted its central role in Europe's distinct development after the eighteenth century (Bairoch 1993; Pomeranz 2000; Inikori 2002). Additionally, the historical debate has not clearly distinguished the role of colonialism from that of "free trade" during the nineteenth century and especially during its second half in fostering industrial transformation. In many cases, colonialism has been regarded as a "paradox" on the basis that it could not have provided substantial advantages. Instead, the progressive integration of international markets for factors of production has been regarded as the foundation of trade relations in the nineteenth century.

In this study, I attempt to empirically assess the contribution of colonialism by providing a systematic account of the geography of horizontal land expansion throughout the nineteenth century, focusing on ten major imports: butter, cheese, wheat, coffee, cotton, wool, indigo, potash, tallow and wood. The paper

performs a quantitative analysis by employing British official trade statistics from the nineteenth century, and specifically the *Ledgers of Imports Under Countries – CUST 4*, kept in the British National Archives. A methodology in line with that described in the method section above is employed in this paper in order to estimate land embodied in trade, while specific methodological choices are discussed in more detail in the paper.

The results of the study complement previous research that was based mainly on the use of price values, by shifting the point of focus from the economy as such to the restricting ecological circumstance that governed Britain throughout the late eighteenth and nineteenth centuries.

It is found that the role of colonies was far from insignificant and the findings do not support any previous claims that have regarded their contribution as a “myth” or as an unsubstantiated process. Colonial trade did matter for Britain in relative terms. Nevertheless, what is interesting is that the colonies that contributed the most to this process of territorial expansion through trade were not the extractive slave-based colonies, but rather the European settlements in British North America and Australia. The findings suggest that Britain diversified its position from other slave-based European empires not only by utilizing settlement colonies as outlet markets but also as sources of raw materials that made important contributions to its domestic land-labor ratios. This evidence allows for a more refined interpretation of the role of colonialism, beyond the simplistic dichotomy based on rich versus poor or developed and underdeveloped regions. Trade in land-intensive imports of wood, wood products and wool acted as the main contributor to colonial land expansion, with their relative importance alternating between the first and second halves of the century. The more labor-intensive colonies contributed relatively less to alleviating land constraints, although they retained their relative importance in making imperial trade a valuable economic activity.

The findings also allow for some tentative arguments regarding the role of colonialism in partly determining the historical link between factor prices and factor endowments, which was broken in the nineteenth century through trade. The potential of the more land-intensive commodities to be produced in non-colonial, possibly European, territory actually raises interesting questions regarding the real contribution of colonial institutions in consolidating Britain’s industrialization. It could be hypothesized that the reason why other land-rich non-colonies did not export such land-intensive goods was because an additional advantage was provided by colonialism. In fact, large shares of both potash and wool were provided from European regions such as the Baltics



and Germany, Spain and Portugal in the early part of the nineteenth century. Consequently, there could have been additional comparative advantages from colonialism that rendered imports from what would later become the “Neo-Europes” a preferable alternative. These commodities, although contributing to “secondary” capital-intensive industries, were significant for the industrial system since they provided the ecological conditions that fostered the industrial specialization that took place in the nineteenth century. Colonialism could therefore have continued to provide advantages additional to those of factor endowments. However, any further argument on the relative importance of decreasing transport costs and common culture on one hand and the presence of colonialism on the other would be highly speculative. This constitutes a hypothesis which can only be analyzed exhaustively in future research by testing whether factor endowments were by themselves enough and is not something that is fully investigated here.

Furthermore, this new perspective on the relative importance of particular commodities sheds new light on the relationship between land availability and capital formation. Previous research has attributed the subsequent distinct development of European offshoots such as Canada and Australia to either institutional factors (Acemoglu et al. 2001) or to distinct trade patterns and geography i.e. the “staples thesis” (Innis 1930; Findlay and Lundahl 2017). The empirical evidence in this paper restores to this discussion potential explanations rooted in the latter.

### **Paper 3: Britain’s historical ecological footprint – an account of nineteenth-century industrial consumption**

This paper shifts the focus from trade as such and examines the British socio-economic system’s interplay with the environment as a whole. The aim is to analyze the dynamics of a system in transition. It is a methodological attempt to provide an all-encompassing ecological footprint analysis of the British socio-economic system that i) demonstrates the extent to which the first industrial society utilized its frontier capacity relative to its domestic organic and inorganic resources and, more importantly, ii) assesses the potential sustainability of a transition to the first industrial era. In this respect, the study attempts to bridge the gap between ecological economics and economic history. The research questions of the paper are *What was the UK’s historical ecological footprint during the period 1832–1907? How did the globalization process of the nineteenth century affect its (un)sustainability?*

To my knowledge no other study has attempted to historicize the ecological footprint methodology that far back in time. Such an attempt, using the first industrial country as a case study, provides valuable empirical evidence that can also be contrasted with results on the ecological footprint of late industrializers, such as twentieth-century Austria and Italy. The paper performs a quantitative ecological footprint analysis by employing empirical evidence from secondary literature. It also builds on the land embodied in trade accounts constructed in Paper 1 of the thesis. A variant of the ecological footprint methodology is used, as developed in contemporary ecological footprint literature by (Erb 2004). This, along with the limitations of the ecological footprint as an indicator, is discussed in more detail in the paper.

The results of the study suggest that the socio-economic system's consumption was highly unsustainable throughout the nineteenth century. In ecological terms it was a system in "overshoot", since its consumption exceeded by a wide margin its regenerative capacity. This should probably come as no surprise given the central role of coal and the fact that virtually all of the domestic arable land in the UK was in use. More importantly, however, a rather different picture is portrayed when looking at the relationship between globalization and sustainability. In contrast with previous claims that regard industrialization and globalization as processes associated with an ever-increasing independence from the national boundaries, the evidence at hand suggests otherwise. The major ecological footprint component i.e. coal, was sourced domestically. Furthermore, in sustainability terms, the empirical evidence presented here suggests that the British socio-economic system was becoming increasingly unsustainable, not necessarily because globalization allowed it to draw an ever-increasing share of resources from abroad, but due to its internal dynamics. In fact, most of the physical throughput responsible for environmentally detrimental economic activities was concentrated domestically rather than being imported. The results suggest that the system's consumption was exceeding its regenerative capacity already from the 1830s. An interesting question then is to specify when the socio-economic system made the switch, i.e. when did its consumption patterns exceed its regenerative capacity. The empirical evidence of this paper does not allow for the investigation of this question but future research that would stretch further back in time could provide valuable insights as to the timing of the transition and the role of industrial transformation in this process.

When the results are compared with modern ecological footprint estimates for other countries during the twentieth century it is possible to provide some tentative arguments regarding the relationship between economic develop-

ment and the growth trajectories of ecological footprints. It is observed that the situations of Austria and Italy in the late twentieth century are comparable with that of Britain almost a century earlier (in terms of biocapacity and ecological footprint per capita). This signals that the consumption patterns of late industrializers may still outpace any technological improvements and spill-over effects through trade transfers, and possibly reflects a catch-up process among late industrializers. Despite having diversified their energy mix towards more efficient energy carriers and thus decreasing energy intensities (Kander et al. 2017) with economic development, their ecological footprint was still at comparably high levels. Part of the explanation rests, of course, on the inherent limitations of the ecological footprint as an indicator to effectively accommodate technical change. In this sense, this bleak relationship between economic development and environmental pressure may not actually be that pessimistic. In fact, despite being an intriguing proposition, more detailed research is needed to identify drivers of this pattern. To some extent, however, this comparative perspective can raise awareness about the relationship between economic development and sustainability.

#### **Paper 4: African agricultural productivity and the transatlantic slave trade: evidence from Senegambia in the nineteenth century**

*Co-authored with Klas Rönnbäck*

In the fourth paper, the role of agricultural capacity in early modern African agriculture is analyzed in a comparative perspective. The role of agriculture has been central not only in contemporary Africa's long-term economic development, but also historically since the early modern period. Many scholars have attempted to analyze the historical productivity of the agricultural sector in Africa and most seem to have believed that the prospects facing African farmers historically were generally quite bleak. For a long time, African agriculture was understood as relatively static and suffering from very low productivity. Furthermore, previous research in economic history has asserted that the low agricultural productivity in Western Africa might also have had a very important implication for Africa's external slave trade. The rationale behind this argument was that it was more productive, and by extension more profitable, for Europeans to exploit slave labor in the western Atlantic rather than in Africa. This paper provides empirical evidence for these debates by examining the particular case of Senegambia. The research questions of this paper are: *Was agricultural productivity in Senegambia lower than that in the plantation complex*

*in the Americas? What were its implications for the region's capacity to produce an agricultural surplus and for the transatlantic slave trade?*

Although the discussion has been going on between scholars of African economic history for quite some time it has been surprisingly devoid of empirical support. In this paper, we study the historical productivity of agriculture in Senegambia, in the early nineteenth century and juxtapose that with comparable productivity estimates found primarily in the Americas. Previous research has suggested that Senegambia might have been among the most productive regions on the African continent and for this reason we believe it constitutes a critical case for study. We focus on five key crops: cotton, indigo, rice and maize/millet, and analyze estimates for both land and labor productivity.

For this paper, we have used primary quantitative data from archival material for the two African regions. In the case of Senegal, data were obtained from the French National Archives where information was provided at plantation level on the cultivation of cotton, indigo, millet and maize in the colony, for benchmark years in the 1820s and 1840s. In the case of Gambia, data from the British National Archives was used, and specifically a Report of the Commissioner of Inquiry on the Western Coast of Africa. For comparable estimates from the Americas and elsewhere, the data compiled in Paper 5 of this thesis is used.

Our results suggest that for all the crops we studied, both land and labor productivities were significantly lower in Senegambia than in the Americas and all other parts of the world for which we have comparable data. This refers to the average productivity for the region, since some Senegambian plantations demonstrated comparatively higher productivities than the average found elsewhere. Productivity in the Americas was at least twice as high as that we find in Senegambia. This applies to both land and labour productivity, decreasing the possibility of measurement errors. We are therefore inclined to lend support to claims that stress the role of a historically low African agricultural productivity as a crucial factor for various socio-economic outcomes. The low agricultural productivity could have further inhibited socio-economic development by limiting the agricultural surplus available to supply other economic activities and sectors. It might also have provided a rationale for the external slave trade, as many scholars previously have argued. It should be noted, however, that the empirical evidence at our disposal does not allow us to completely rule out the theoretical possibility that agricultural productivity might have been higher before the external slave trade began. Our estimates do however show that agricultural productivity in Senegambia in the early nineteenth century was

low, not only when compared to contemporary figures from the Americas, but also to the productivity of American agriculture at a much earlier date.

**Paper 5: The ecological footprint of early-modern commodities – Coefficients of land use per unit of product**

This paper constitutes the empirical basis for the studies conducted in this thesis. The aim of the paper is to contribute a data base of historical footprint estimates for more than 80 commodities that were highly traded throughout the nineteenth century. Additionally, the empirical evidence in this paper has a global reach, presenting the land productivities of various countries and regions. This work does not aim to answer any analytical or explanatory research question. Instead it is exploratory in character, and the main question is *how much land was required to produce highly traded early modern commodities?* To answer this question, the paper establishes coefficients for the amount of land that would have been required to produce these products. Various sources have been reviewed for the compilation of the data base, and the most important ones are briefly reviewed in the Data section above and critically discussed in detail in the paper.

In addition to its direct relevance for this thesis, the ambition is that the data provided here will also constitute an empirical basis for other researchers examining the importance of ghost acreages and ecological footprints historically, as well as the role of natural resources and land use in a long-term perspective. The data can be of relevance for research projects in the fields of environmental history, economic history, agricultural history and history of technology, but also historical studies that focus on particular commodities.

# Concluding discussion

The aim of the current thesis has been to assess the importance of natural capital and specifically that of land during the period of intense industrialization in Europe, to a large extent focusing on Britain. Although each essay of this thesis deals with specific research questions and engages with particular debates that are discussed in more detail under each paper, some overarching concluding remarks can be noted.

In brief, the first paper studied the question of *what contributed more, in a strictly quantitative sense, to overcoming land constraints in Britain – domestic fossil energy or overseas land? How did this vary over time and what form did these land resources take?* Such estimates, which give a sense of magnitude, are provided for the first time in this thesis. It is shown that the contribution of vertical expansion was far larger than that of horizontal expansion and in this sense contributed significantly to overcoming land constraints and fostering economic development throughout the nineteenth century. Indicatively, towards the early twentieth century, the land embodied in net imports amounted to approximately two to three times the total land area of Britain, while land embodied in net exports made up four to six times that area. Both served to ensure the effective functioning of what was at that time the world's largest industrial workshop and provided the ecological means by which it was sustained. Industrialism would have been unimaginable without this contribution. In reality, the relative magnitude of vertical expansion did not necessarily mean that horizontal expansion was unimportant. The second paper looks more closely at the contribution of horizontal expansion and tries to assess whether the colonial contribution was significant in abolishing Britain's land constraints and in enabling the industrial specialization that occurred in the nineteenth century. It is found that the land embodied in trade from British colonial and formerly colonial territory represented the lion's share of horizontal expansion that occurred in overseas territories. The commodity sources that contributed more, however, to this process of territorial expansion and economic development through trade were not the extractive slave-based colonies, but rather the European settlements in British North America and Australia. Although no causal relationship is established, it is hinted that colonialism could have also contributed to the consolidation of nineteenth-century industrial specialization. The results of the study provide circumstantial evidence that colonialism could have continued to provide advantages additional to

those from factor endowments. Further, the third paper looks at the British socio-economic system as a whole and the sustainability aspects of horizontal and vertical frontier expansion by juxtaposing them with the total domestic availability of natural resources. The main questions asked are what was the UK's historical ecological footprint during the period 1832–1907? and how did the globalization process of the nineteenth century affect its (un)sustainability? In line with most expectations, it was confirmed that the economic development that was based on the new industrial socio-economic system was particularly unsustainable. Furthermore, it has been demonstrated that in environmental terms, the industrial socio-economic system represented a system in overshoot whose consumption patterns placed a level of pressure on the environment that other European late industrializers would not reach until approximately 100 years later, in the mid-twentieth century. The socio-economic system was becoming increasingly unsustainable, not necessarily because globalization allowed it to draw an ever-increasing share of resources from abroad, but due to its internal dynamics. In fact, most of the physical throughput responsible for environmentally detrimental economic activities was concentrated domestically rather than being imported. This suggests that the relationship between globalization, industrialization and sustainable development is more dynamic and multifaceted than some research may assume. Finally, in the fourth paper, it is demonstrated that land continued to play a determining role in industrialization and economic development, not only directly as an important production factor for growth, but also indirectly, possibly determining the development of other historic economic activities and influencing the development of other production factors such as labor inputs. This was done by investigating whether agricultural productivity in Senegambia was lower than that in the plantation complex in the Americas and what implications this may have had for the region's capacity to produce an agricultural surplus and for the transatlantic slave trade. It has been found that land productivity differences between Africa and the Americas could have served as a motivation for the transatlantic slave trade, an economic activity directly linked with and of major importance to British industrialization and economic development.

To return to the overarching research question of the thesis, it can be concluded that the role of land remained central to industrialization throughout the nineteenth century. Its importance increased and was expressed as a rebound effect from industrialization, whereby industrial specialization in Britain drove expansion and the search for land elsewhere, specifically in the formation of an Empire. In fact, it can be argued that, for Britain, short-term bottlenecks to

growth could be overcome temporarily through technological change, while domestic resource endowments based on coal actually provided a comparatively larger land relief than that obtained through trade. However, in the long term a rebound effect mechanism triggered an ever-growing pressure on and consequently demand for land. To satisfy this, significant contributions would have to come from abroad. Although it can be debated to what extent and whether Britain was operating within a Malthusian context, no previous study has demonstrated comprehensively the extent of land relief that came through trade and how this compared to the land relief that came from domestic resources.

In this sense, the essays in this thesis allow us to re-evaluate the role of geography and natural resources, restoring them to a central position as proximate explanations for industrialization and the debate of the *Great Divergence*.

In more detail, the results presented in this thesis also call for a reconsideration of the commodities that have historically been regarded as most critical for the first Industrial revolution, at least in ecological terms. The central role played by potash and wool in relieving the land constraints has been underlined by the empirical evidence in the essays of this thesis. Until today, historiography has emphasized the importance of labor-intensive products over land-intensive products, and this is why certain commodities have been the center of attention in economic historiography while others, such as those stressed here, have not. However, the commonly asserted implication that labor-intensive commodities were more important for Britain may be part of the story. The evidence presented here allows for a refined interpretation of the role of colonialism, beyond commonly used dichotomies of rich versus poor or developed and underdeveloped regions. The most commonly considered labor-intensive commodities of the eighteenth and nineteenth century imperial trade, such as coffee, indigo, cotton, sugar and tobacco, were more geographically constrained than other land-intensive commodities such as wood and animal products. Some land-intensive commodities, such as wood products, potash and wool, had on the other hand already been produced in Europe and the Baltics since the seventeenth century. Thus, the geographical shift in British imports of these commodities during the nineteenth century, towards relatively more land-abundant colonial regions of European settlement frontiers, could have been important for nineteenth-century economic development. In fact, as is demonstrated in the papers, the land relief that was provided by these relatively less significant products, in value terms, was necessary for alleviating Britain's land constraints and enabling the industrial specialization that occurred in the nineteenth century.



## Suggestions for future research

The basic methodological steps outlined in this thesis could easily be applied to other geographical contexts and time periods. In particular, future research that would focus on land footprint accounts of trade for other European industrializers, could demonstrate the extent to which industrialization in these regions was associated with similar or diverging patterns of vertical and horizontal expansion. More importantly, a limitation of this dissertation has been the exclusion of technological change from the empirical analysis. Although some tentative estimates on the land relief that came with technological change are provided, these are very limited in scope and an all-encompassing analysis is missing. Future research that extends the analysis in this direction would provide very valuable insights as to the relative importance of all three factors that assisted in abolishing the land constraints during the industrial era, and would thus further refine the debate on the relative importance of domestic versus external forces at play. Additionally, it would be interesting to extend the research in time in order to cover the early modern period as well as the twentieth century. This would allow examination of how the role of land embodied in trade may have changed depending on the rate of industrial expansion, including the period after the introduction of ground-breaking technological innovations that truly revolutionized land productivity, such as the Haber-Bosch process. In environmental terms, it could also allow one to examine when the British industrial socio-economic system became unsustainable. Applications of historical ecological footprint studies in other countries could also shed more light on the relationship between economic development, industrialization and their bearing on natural resources and land. Finally, by expanding on the evidence of land productivities for various products and regions that has been collected in this thesis, future research could examine in a consistent and all-encompassing way the rather ambitious but central question of how widespread “progress” really was in nineteenth-century agriculture.

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# Svensk sammanfattning

Denna avhandling är en undersökning av industriell expansion och handel ur ett miljöhistoriskt perspektiv, där produktionsfaktorn land är den viktigaste analytiska kategorin. Produktionsfaktorn lands roll har historiskt förståtts på olika sätt. Den historiska övergången från jordbruksekonomi till industriell ekonomi i Västeuropa i slutet av 1700-talet och början av 1800-talet markerar en brytpunkt i vår förståelse av land och dess betydelse i det socioekonomiska systemet. I den här avhandlingen undersöks denna övergång empiriskt genom fyra forskningsartiklar som fokuserar på vilken roll landareal spelade för industrialisering, handel och hållbarhet under perioden mellan 1800-talets början och första världskriget.

Syftet med denna avhandling är att undersöka de materiella omständigheter som underbyggde industrialiseringen. Särskilt fokus ligger på den roll som produktionsfaktorn land hade för ekonomisk utveckling under hela 1800-talet. Under 1800-talet förändrades ekonomins funktion, eller det som andra forskare har identifierat som "metabolism" i det socioekonomiska systemet. Denna förändring uppstod genom omställningar i samspelet uppnåddes genom förändringar i samspelet och den relativa betydelsen av två grundläggande resurser: kol och land. I den här avhandlingen ligger det bredare fokuset på den relativa rollen för dessa två resurser. Denna period präglades starkt av industrialisering, vilket också markerade övergången till den postmalthusianska eran, där ekonomisk tillväxt främst förklarades av tekniska framsteg och produktivetsförbättringar. Produktionsfaktorn land kom gradvis att spela en allt mindre roll genom förändringar inom huvudsakligen tre områden: teknologiska förändringar inom jordbruket, förändringar i energibehovet (vertikal expansion), och handelsexpansion och kolonisering av nya okarterade territorier (horisontell expansion). Denna avhandling undersöker den relativa betydelsen av de senare två sätten att avhjälpa det hinder som en begränsad jordareal utgjorde. Den övergripande forskningsfrågan för hela avhandlingen är följande: *Vilken roll har naturresurser, och i synnerhet land, spelat för den ekonomiska utvecklingen under den första industrialiseringen?*

Varje forskningsartikel i denna avhandling utgör ett steg mot detta övergripande mål. Som helhet är avhandlingen också ett försök att överbrygga klyftan mellan överlappande akademiska diskussioner inom ekologisk ekonomi och ekonomisk historia.

Forskningsartiklarna i denna studie bidrar på två sätt till de vetenskapliga debatterna inom ekonomisk historia om 1800-talets industrialisering. Först och främst genom att kvantitativt bedöma den ökande betydelsen av och förändrade rollen för produktionsfaktorn land under 1800-talets intensiva industrialisering. Detta uppnås med en analys av landets relativa bidrag till industrialiseringen genom import och export av varor som krävde landareal för att kunna produceras, samt med ett indirekt bidrag till incitamenten för andra historiskt avgörande handelsaktiviteter, som slavhandeln. En sekundär, men lika viktig, ambition är att uppmärksamma läsaren på den tidiga industrialiseringens miljöpåverkan, och därmed historisera dagens forskning om förhållandet mellan ökad konsumtion och begränsad resurskapacitet.

Denna avhandling fungerar som ett komplement till forskning som redan har gjorts utifrån varors och produktionsfaktorerers priser, genom att använda ekologiska indikatorer. Detta kan öka vår förståelse för den relativa betydelsen av ekonomiska och ekologiska indikatorer i ekonomisk historia. Dessutom kan undersökningen av ekonomiska processer som kolonialism ur ett annat ekologiskt perspektiv vara användbar för att underbygga en materialistisk motivering till deras historiska förekomst och utveckling. Mer specifikt används två distinkta metoder i forskningsartiklarna i denna avhandling för att genomföra den empiriska analysen. I de tre första forskningsartiklarna används en variant av de metoder som har utvecklats inom ramen för begreppen ”spökarealer” och ”ekologiska fotavtryck”. I den fjärde forskningsartikel forskningsrapporten används en enkel jämförande analysmetod som huvudsakligen bygger på beskrivande statistik.

En mängd data har använts i denna avhandling. Ett avgörande empiriskt bidrag från denna avhandling är forskningsartikel 5, som beskriver den huvudsakliga databas som ligger till grund för samtliga forskningsartiklar som ingår i avhandlingen. I artikel 5 presenteras historiska data om uppskattningar av markavkastning och direkta ekologiska fotavtryck för mer än 80 tidigmoderna varor som man handlade med över hela världen. Forskningsartikeln 5 fokuserar på produkter som var av betydelse för handeln från och till Storbritannien under denna period. Förutom data som sammanställts i forskningsartikeln 5 har primära arkivmaterial erhållits från två arkiv, ett i Frankrike (Archives Nationales d’Outre-mer) och ett annat i Storbritannien (The National Archives).

Syftet med den första forskningsartikel är att undersöka hur handelsbalansen i brittisk handel, mätt i form av landareal, utvecklades under 1800-talets intensiva industrialisering. Forskningsartikeln är samförfattat med professor Astrid Kander och dr Paul Warde. Forskningsartikelns forskningsfråga är följande:

*Vad bidrog mest, i kvantitativ mening, till att övervinna landareals-begränsningar i Storbritannien – inhemsk fossilenergi eller utländska landarealer? Hur varierade detta över tid och vilken form tog de här resurserna?*

Utgångspunkten för studien är hur den industriella revolutionen i Storbritannien förenades med en utvidgning av tillgängliga landarealer, utöver den begränsade ytan på ön, till vertikala (kol) och horisontella (koloniala) områden, som innebar en enorm ökning av tillgängliga resurser. Ingen allomfattande beräkning av den landareal som innefattades i brittisk handel (både för import och export) hade genomförts före denna undersökning. Vårt forskningsartikkel bidrar med att tillhandahålla sådana beräkningar för första gången.

På en bredare nivå visar våra resultat tydligt att Storbritanniens roll under hela 1800-talet inte motsvarar den som vanligtvis visas i världssystemstudier: envägsflöden av land och resurser från periferin till centrum i världsekonomin. Relationen som vi observerar är mer mångfasetterad. Vi har förvisso konstaterat att horisontell expansion var viktig under de tidiga årtiondena av 1800-talet, eftersom Storbritannien var en nettoimportör av landareal som förkroppsligades i importen. Men från och med 1850-talet ökade istället den relativa betydelsen av vertikal expansion. Kol fungerade som ett viktigt substitut för landresurser i den meningen att det ersatte stora mängder trä som annars skulle behövas. Under större delen av 1800-talet var Storbritannien nettoexportör av en omfattande ”spökareal” genom produktion som förkroppsligade kol. Våra resultat tyder också på att vi bör revidera vår förståelse av den relativa betydelsen av särskilda varor som har uppmärksammas i tidigare historiografi. Resultaten tyder på att bomull, socker och timmer, vilka hittills har ansetts bidra mest till horisontell expansion, faktiskt bidrog relativt sett mindre än somliga andra råvaror, och deras kumulativa bidrag var väsentligt lägre än det från vertikal expansion i form av kolanvändning.

Textilindustrins roll var fortfarande central, men på ett ganska annorlunda sätt. Baserat på våra metodologiska val, som diskuteras i detalj i forskningsartikeln, utmärkte sig pottaska och ull som de mest krävande råvarorna för horisontell landexpansion. Båda råvarorna utgjorde viktiga insatsvaror för textilindustrin i Storbritannien. Trots att det var relativt viktigt för textilindustrin att expandera sitt resursutnyttjande vertikalt, i form av ökad kolanvändning, var den horisontella expansionen fortfarande viktig. Våra resultat utesluter inte betydelsen av importerade varor. Under de tidiga årtiondena av 1800-talet konsumerade Storbritannien betydande mängder naturresurser – och därmed landarealer förkroppsligade i dessa – från utlandet. I absoluta termer fortsatte landets bidrag till den brittiska ekonomin att öka dramatiskt fram till slutet

av 1800-talet. Detta banar väg för vidare frågor om kolonialismens roll och den relativa betydelsen av olika arbetsordningar som etablerades utomlands.

Dessa frågor utgör utgångspunkten och målet för den andra forskningsartikeln i avhandlingen. Detta artikel utgör en detaljerad studie om Storbritanniens horisontella expansion under 1800-talets industrialisering, och analyserar de olika handelspartnerns relativa bidrag i denna process. Det är ett försök att empiriskt skatta kolonialismens betydelse för den brittiska industrialiseringen inom ramen för en horisontell expansion och sammanfoga det med lättnaden från produktionsfaktor land som kom från andra delar av världen. Forskningsartikelns forskningsfråga är följande: *Har kolonier bidragit väsentligt till horisontell expansion och till att avskaffa Storbritanniens landareals-begränsningar?*

Den rådande debatten i ekonomisk historia har inte gjort tillräckligt tydlig skillnad mellan den relativa betydelsen av de olika handelspartnerna och råvarorna under brittisk industrialisering. Dessutom har den historiska debatten inte skiljt tydligt mellan kolonialismens roll och ”frihandeln”, när det gäller att främja industriell omvandling under 1800-talet. Kolonialismen har i många fall betraktats som en ”paradox”, på grund av att den inte har ansetts kunna ge väsentliga fördelar för kolonialmakten. Resultaten av denna studie kompletterar tidigare forskning som huvudsakligen har baserats på användningen av monetära värderingar av naturresurser. Denna studie flyttar fokus från den monetära ekonomin till de begränsande ekologiska omständigheter som styrde Storbritannien under slutet av 1700-talet och början av 1800-talet.

Studiens resultat visar att koloniernas roll var långt ifrån obetydlig. Resultaten visar också att den historiska koppling mellan faktorpriser och faktortillgångar som bröts på 1800-talet genom utrikeshandel, delvis kunde ha bestämts av kolonialismen. Det är emellertid intressant att de kolonier som bidrog mest i denna process av territoriell expansion genom handel, inte var de extraerande slavbaserade kolonierna, utan snarare de europeiska bosättningarna i brittiska Nordamerika och Australien. Resultaten tyder på att Storbritannien diversifierade sin ställning från andra slavbaserade europeiska imperier, inte bara genom att utnyttja bosättningskolonier som försäljningsmarknader utan även som råvarukällor. Detta utgjorde ett viktigt bidrag till deras förhållanden mellan land och arbete. Dessa resultat möjliggör en mer komplex tolkning av kolonialismens roll, bortom den förenklade dikotomi baserad på rika gentemot fattiga, eller utvecklade gentemot underutvecklade regioner. Handel med landkrävande import av trä, träprodukter och ull fungerade som den främsta drivkraften bakom kolonial landexpansion. Den relativt mer arbetsintensiva

produktionen i andra, tropiska, kolonier bidrog inte i lika hög grad till att lindra Storbritanniens landareals-begränsningar, även om den hade stor betydelse för att göra kolonialhandeln till en värdefull ekonomisk aktivitet.

Potentialen hos de mer landintensiva råvaror som producerades i icke-koloniala, europeiska territorier väcker ytterligare intressanta frågor om koloniala institutioners faktiska bidrag för att befästa Storbritanniens industrialisering. Anledningen till att andra icke-kolonier med stora landarealer inte exporterade de landintensiva varorna i större utsträckning var förmodligen att kolonialismen som sådan utgjorde en ytterligare fördel för produktionen i och importen från kolonierna. Faktum är att stora andelar av både pottaska och ull tillhandahölls från europeiska regioner som Baltikum och Spanien i början av 1800-talet. Följaktligen kan ytterligare komparativa fördelar från kolonialismen som institution ha gjort import från brittiska bosättarkolonier till det föredragna alternativet. Dessa varor var, även om de bidrog till ”sekundära” kapitalintensiva industrier, viktiga för det industriella systemet.

Ännu mer, detta nya perspektiv på den relativa betydelsen av vissa varor ger ännu fler upplysningar om förhållandet mellan produktionsfaktor land och kapital. Tidigare forskning har förklarat den framgångsrika utvecklingen av tidigare europeiska bosättarkolonier, som Kanada och Australien, med antingen institutionella faktorer eller med deras handelsmönster och geografi, dvs. *staples-thesis*. De empiriska bevisen i denna forskningsartikel bidrar till denna diskussion med empiri som stöder den senare förklaringsmodellen.

Den tredje forskningsartikel skiftar fokus från handeln som sådan och undersöker det brittiska socioekonomiska systemets samspel med miljön som helhet. Det är ett metodiskt försök att göra en övergripande analys av det brittiska socioekonomiska systemets ekologiska fotavtryck som skulle i) visa hur mycket det första industriella samhället utnyttjade sin kapacitet i förhållande till sina inhemska organiska och oorganiska resurser, och ännu viktigare, ii) bedöma den brittiska ekonomins hållbarhet under övergången till den första industriella tiden. I detta avseende försöker studien att överbrygga klyftan mellan ekologisk ekonomi och ekonomisk historia. Forskningsfrågorna i forskningsartikel är följande: *Vad har Storbritanniens historiska ekologiska fotavtryck varit under perioden 1832–1907? Hur påverkade globaliseringsprocessen från 1800-talet dess (o)hållbarhet?*

Resultaten av studien tyder på att det socioekonomiska systemets konsumtion var mycket ohållbar under hela 1800-talet. I ekologiska termer var det ett system i *overshoot*, eftersom förbrukningen översteg dess regenerativa kapacitet med stor marginal. Detta borde antagligen inte komma som någon överraskning, med

tanke på kolets centrala roll och det faktum att praktiskt taget all inhemsk mark i Storbritannien var i bruk. Ännu viktigare är dock att resultaten ger en annan bild än vad man hade kunnat förvänta sig efter att ha läst tidigare forskning, när man tittar på förhållandet mellan globalisering och hållbarhet. I motsats till tidigare påståenden där industrialisering och globalisering betraktas som processer förknippade med ett ständigt ökande oberoende från de nationella territorierna, antyder den empiri som presenteras här motsatsen. Den viktigaste komponenten i Storbritanniens ekologiska fotavtryck, dvs. kol, utvanns på hemmamarknaden. Ur ett hållbarhetsperspektiv tyder det empiriska bevis som presenteras här vidare på att det brittiska socioekonomiska systemet blev alltmer ohållbart, inte nödvändigtvis för att globaliseringen gjorde det möjligt att hämta en allt större andel resurser från utlandet, utan på grund av sin interna dynamik. Faktum är att det mesta av den fysiska genomströmning som miljökadlig ekonomisk verksamhet förlitar sig på koncentrerades på inhemsk utvinning av naturresurser, snarare än på importerade dito.

När man jämför dessa resultat med resultaten från beräkningar i ekologiska fotavtrycksstudier från andra länder under det tjugonde århundradet är det möjligt att dra några hypotetiska slutsatser om förhållandet mellan ekonomisk utveckling och ekologiska fotavtryckstillväxtmönster. Österrikes och Italiens ekologiska fotavtryck var under slutet av 1900-talet jämförbara med det i Storbritannien nästan ett sekel tidigare (när det gäller biokapacitet och ekologiskt fotavtryck per capita). Detta indikerar att konsumtionsmönstren hos länder som industrialiserades sent fortfarande kan motverka tekniska förbättringar och fördelningseffekter genom överföringar av varor. Trots att deras energimix har diversifierats mot effektivare energibärare och att energinivåerna därigenom minskar i takt med ekonomisk utveckling, var deras ekologiska fotavtryck fortfarande på jämförelsevis höga nivåer. En del av förklaringen ligger självklart i det ekologiska fotavtryckets inneboende begränsning som en indikator på en effektiv anpassning till tekniska förändringar. I detta avseende behöver detta till synes dystra förhållande mellan ekonomisk utveckling och miljöbelastning möjligen inte vara så pessimistiskt. Men även om det är en intressant hypotes, krävs mer detaljerad forskning för att identifiera drivkrafterna bakom detta mönster. I viss utsträckning kan detta jämförande perspektiv dock öka medvetenheten om förhållandet mellan ekonomisk utveckling och hållbarhet.

I den fjärde forskningsartikeln analyseras kapaciteten i det tidigmoderna afrikanska jordbruket ur komparativt perspektiv. Forskningsartikeln är samförfattat med docent Klas Rönnbäck. Jordbrukets roll har varit central, inte

bara för det moderna Afrikas långsiktiga ekonomiska utveckling, utan också historiskt, sedan den tidigmoderna perioden. Många forskare har försökt att analysera historisk produktivitet inom jordbrukssektorn i Afrika och de flesta verkar ha dragit slutsatsen att utsikterna för afrikanska bönder historiskt sett var ganska dystert. Under lång tid sågs det afrikanska jordbruket som relativt statiskt, och som karaktäriserat av mycket låg produktivitet. Vidare har tidigare forskning i ekonomisk historia hävdats att den låga jordbruksproduktiviteten i västra Afrika också kan ha haft en mycket stor inverkan på Afrikas externa slavhandel. Bakgrunden till detta argument är att det har påståtts vara mer produktivt och i förlängning därmed mer lönsamt för européer att utnyttja slavarbete i Amerika än i Afrika. Detta dokument bidrar med empiriska bevis till dessa debatter genom att undersöka det särskilda fallet i Senegambia. Forskningsfrågan i denna forskningsartikel är följande: *Var jordbruksproduktiviteten i Senegambia lägre än i plantageekonomin i Amerika? Vad blev konsekvenserna för regionens kapacitet att producera ett jordbruksöverskott och för den transatlantiska slavhandeln?*

Våra resultat tyder på att både land- och arbetsproduktiviteten för samtliga grödor vi studerade var betydligt lägre i Senegambia än den var i Amerika och alla andra delar av världen för vilka vi har jämförbara data. Vissa senegambiska plantager visade relativt hög produktivitet, och kunde då ibland nå upp till de genomsnittliga produktivitetsnivåerna på andra ställen i världen. Produktiviteten i Amerika har dock i genomsnitt varit minst dubbelt så hög som den vi finner i Senegambia, både när det gäller land- och arbetsproduktivitet, vilket minskar möjligheten att skillnaderna enbart kan förklaras som mätfel. Resultaten ger därmed stöd till påståenden som framhåller en historiskt låg afrikansk jordbruksproduktivitet som en avgörande faktor för olika socioekonomiska resultat. Den låga jordbruksproduktiviteten kan ha hindrat ytterligare socioekonomisk utveckling genom att begränsa det jordbruksöverskott som fanns tillgängligt för andra ekonomiska aktiviteter och sektorer. Detta förhållande kan också ha gett drivkraft åt den externa slavhandeln, vilket många forskare tidigare har hävdats. Det bör dock noteras att de empiriska bevis som vi har till vårt förfogande inte tillåter oss att helt utesluta den teoretiska möjligheten att jordbruksproduktiviteten kan ha varit högre innan den externa slavhandeln började. Våra uppskattningar visar dock att jordbruksproduktiviteten i Senegambia i början av 1800-talet var låg, inte bara i jämförelse med samtida data från Amerika, utan också i jämförelse med produktiviteten i det amerikanska jordbruket vid mycket tidigare tid.



För att återgå till den övergripande forskningsfrågan i avhandlingen kan man dra slutsatsen att produktionsfaktorn land fortsatte att ha en central roll för industrialiseringsprocessen under hela 1800-talet. Dess betydelse ökade i takt med att industrialiseringen tog fart, varigenom industriell specialisering i Storbritannien drev på landexpansionen utomlands, och därmed bidrog till utvecklingen av Brittiska imperiet. Faktum är att man kan argumentera för att Storbritanniens flaskhalsar för tillväxt hade kunnat övervinnas tillfälligt med teknisk förändring, med ett inhemskt resursutnyttjande baserat på kol, där man faktiskt frigjorde större landarealer än de som uppnåddes genom handel. På lång sikt utlöste en motsatt mekanism ett allt större tryck på, och följaktligen efterfrågan på, land. För att det skulle kunna ske skulle betydande bidrag behöva komma från utlandet, och den största andelen kom från kolonier. Ingen tidigare studie har visat omfattningen av den förkroppsligade landareal som kom till Storbritannien genom handel och hur den kunde jämföras med landarealer som kom från inhemska resurser. Avhandlingens resultat har därtill visat att det industriella socioekonomiska systemet representerade ett system vars konsumtionsmönster överskred dess ekologiska ramar, och blev alltmer ohållbart under hela det studerade seklet. Produktionsfaktorn land fortsatte också att spela en deterministisk roll för industrialisering och ekonomisk utveckling indirekt. Det gjorde det genom att påverka utvecklingen av andra ekonomiska aktiviteter som slavhandeln.

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*Development constrained* is set in the historical context of industrial transformation and economic development of the nineteenth century. Through a series of four research essays it examines the changing role of natural resources, and specifically that of land, for economic development during the era of the first industrialization. This was a period during which economic growth began to be explained primarily as the result of technological progress and productivity improvements. Much previous research has therefore assumed that the role of land consequently became less important, not least via technological change in agriculture. This thesis in contrast explores how land continued to be of key importance for economic development, but that land constraints could be abolished through changes in the energy regime through the use of coal (vertical expansion), combined with trade expansion and the colonization of new uncharted territories (horizontal expansion). This thesis examines the relative significance of the latter two pathways for relieving land constraints, for giving rise to particular trade activities and for explaining the long-term sustainability of the industrial socio-economic system that emerged in the nineteenth century.

The quantitative analysis of a data set compiled in this work and of data from other primary sources provides the empirical basis of the work. The first essay examines how the balance of land embodied in British trade developed during this period and provides for the first time all-encompassing accounts of land embodied in trade. The second essay examines the contribution of colonies and colonialism in abolishing Britain's land constraints. The third essay provides a sustainability assessment of Britain's socio-economic system using the ecological footprint methodology. The fourth essay performs a comparative analysis of agricultural productivity in Senegambia in relation to that found in the plantation complex in the Americas, and examines its implications for the region's capacity to produce an agricultural surplus and for the transatlantic slave trade.

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