

Economic development with unlimited supplies of energy:

causes and consequences of industrial revolutions *

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1 General introduction

This dissertation contains two related papers and this introduction. The common themes they explore are the unresolved questions surrounding the English Industrial Revolution (EIR). The questions include what happened, why did “it” happen first in England, why did it happen then in history, and what are the consequences? The story is a history of economic growth from a specific

*In the spirit of Sir William Arthur Lewis

point of view—energy consumption for an economy; the framework can be used to illuminate our economic present and possible economic futures.

Economic and other historians have been grappling with these puzzles for a long time; their answers fall along a continuum from New Institutional Economics (some mix of institutions and perhaps culture) to almost pure chance. Institutional explanations are at least a plurality; this work makes the case that these explanations are not sufficient in the sense of not being primarily causal or sufficiently explanatory in the EIR's history. The work further explores that at least the major institutional changes are endogenous to the revolutionary economic changes.

The major claim is that the EIR was primarily an energy consumption revolution, the English having had the correct economic incentives and historical path to learn how to use steam power to replace muscle power. The contribution is the attempt to apply economic principles to the data and history and measure their explanatory power.

The work identifies two energy revolutions explaining the EIR. The first, converting from wood to coal for industrial and domestic heating purposes, probably happened several times in history at other places in addition to England. In addition to this first-phase energy revolution in England, Paper one documents an added noteworthy instance, that of the iron and steel industry in Sung China (960–1126 CE). The second revolution, converting from muscle power to steam power happened first in England before engulfing the world.

To support the claims the work employs several methods including empirical analyses, microeconomic theory, macroeconomic theory, and descriptive narratives from many sources. The general method is to apply basic economic principles to the available data and narratives.

Among the insights the work proposes a hypothesis of industrial revolutions that can be tested beyond the cases included in this work. This work uses basic microeconomics, macroeconomics,

and relevant empirical data (as the data permit) to test the cases of China and England.

To support the revolutionary growth on the supply side, the work makes the case that there was sufficient consumer demand to drive the efforts of the entrepreneurs and inventors.

Once the theoretical framework for industrial revolutions is explored then the work turns to the question of how did these momentous economic events affect the growth of industrial capitalism since it is one of the more important institutions that is associated with the EIR.

2 Paper one – “Energy and institutions: What really happened in the English Industrial Revolution? What did not happen in China?”

This paper is the core of the project to understand the link between economic growth and energy. By analysing two very long series—English gross domestic product and English energy consumption—with statistical tests the paper demonstrates that there is essentially no difference between these series. The original methodological strategy was to perform a cointegration analysis to test this hypothesis. But, presented with the graphical evidence and very high correlation coefficient it was judged unnecessary to present those results in this paper.

This evidence suggests that at least a plurality of economic and other historians who attribute the EIR to one or more aspects of culture or institutions might additionally consider this very physical energy–growth channel as an important cause. The institutional and cultural changes were certainly large, but the paper questions if they would have happened without the great surge in output, incomes, and wealth that can only be explained by learning to consume a virtually unconstrained amount of energy in the production process. So that is the paper’s major claim;

the paper then explores both macroeconomic and microeconomic theories to support the case.

After developing the English data and descriptive history the paper then suggests that after accounting for a background of increasing aggregate demand it is useful to apply basic microeconomic principles to explain what would cause inventors, innovators, and entrepreneurs to invest in overcoming the great technical difficulties required to remove the supply-side constraint on growth in living standards before the EIR.

This same framework is then applied to the case of Sung China that experienced a period of economic growth including living standards that is remarkable in history. Some historians go so far as to call this episode an industrial revolution. The paper develops partial support for that position.

The introduction for paper one is structured as a literature review and has several sections. The first section reviews the data and descriptive sources used to analyze English energy and macroeconomic performance over the period 1300 to 1873 CE. Included are some who place the energy story very high in the list of possible explanations of the EIR. W. Fred Cottrell in particular takes a very thermodynamic-economic approach in his discussion of the transition to “high-intensity energy converters” from “low-intensity energy converters” as the primary mechanism causing the EIR. Kenneth Pomeranz believes it is English geographical luck that accounts for a large part of the causation of the EIR. Robert Allen takes a similar approach.

The second introductory section reviews the institutional literature. This is the major alternative explanation to the more physical explanations from the sources discussed in section one. The sources include Douglass North, David Landes, Jack Goldstone, Max Weber, and Daron Acemoglu.

The third introductory section reviews the literature on Chinese energy data focusing on the

period of significant economic growth that occurred during the Sung dynasty. The sources include Robert Hartwell, William McNeil, Mark Elvin, and Robert Allen.

The fourth introductory section reviews Chinese institutions. This discussion is mainly about the Ming dynasty although Robert Hartwell discusses Sung dynasty institutions. The sources include Kenneth Pomeranz, R. Bin Wong, and Peer Vries.

The fifth introductory section reviews the literature of Chinese science and invention. This becomes important when attempting to understand some arguments that China had an insufficient tradition of invention and innovation to develop the technologies required to produce an industrial revolution. These sources claim China had a very rich tradition of innovation and invention probably sufficient to accomplish an industrial revolution. The authors include Joseph Needham and John Hobson.

The sixth introductory section reviews economic growth theory. The sources include Roy Harrod, Evsey Domar, Robert Solow, Trevor Swan, Paul Romer, and Robert Ayers.

Section two develops and analyzes English data, econometrics, and economics. The topics covered include discussions of the sources and methods for the data, an analysis of modern economic growth, a discussion of energy revolutions, formal econometric analyses, and the economic analyses.

In this section the paper applies structural change econometric methods to the data series and deduces four energy–GDP eras covering the historical period. Each has different aggregate demand and supply characteristics. Here is a brief summary of each:

The important conclusion is that until 1750 with brief exceptions economic growth for a growing population was largely constrained by a lack of energy supplies. The structural change analysis show that this constraint started lifting in about 1600 and then accelerated in the mid–

Table 1: Energy/GDP eras

Era	AD/AS regime
1300 – 1500	European Marriage Pattern, Black Death, wages/family income increasing
1500 – 1600	Positive demand shock, high wages
1600 – 1750	Energy supply constraint
1750 – 1873	Positive supply shock, large income effect, “virtuous” macro feedback cycle

eighteenth century. Using this data the paper claims that the energy revolution that became the EIR started 150 years earlier than the common starting point many historians claim. The story is consistent with a Malthusian story of temporary growth spurts in population that were eventually constrained by supply (in this story energy supply). Paper two discusses the Malthusian constraint and its removal.

Section three develops and analyzes Chinese data and institutions. The topics include discussions of the sources and methods for the data, a discussion of regional and global population and gross domestic product dynamics, and a discussion comparing Chinese and English institutions.

Section four develops the beginnings of a theoretical framework of industrial revolutions.

Section five concludes.

3 Paper two — “The rise of industrial capitalism. What happens next?”

Paper two analyzes the rise of industrial capitalism and its links with industrial revolutions. This is done both for England and China. England is normally thought of as the birthplace of industrial capitalism; the paper attempts to identify traces of embryonic capitalism in the Chinese economic

history starting with the Sung dynasty (960–1126 CE). If there are common institutional elements that can be linked to industrial revolutions then it will improve our understanding of the how both industrial revolutions and industrial capitalism happen.

The introduction for paper two is structured as a literature review. Topics include some definitions and then reviews of the sources for the English transition to industrial capitalism, and sources for discussion of a Chinese transition to industrial capitalism.

Section two is a discussion of the rise of English industrial capitalism. Topics include a discussion of the data including sources and methods, an analysis of global population trends, a discussion of Jan de Vries' survey of early modern capitalism to help understand common approaches to explaining the event, a review of industrial revolutions and how they give rise to demand for the large capital investments of support the two English energy revolutions that were fundamental to the EIR. Then the section closes with a discussion of the two primary roles that capital played in the EIR.

Section three is a discussion of evidence for shoots of (embryonic) Chinese industrial capitalism including data and a discussion of the three eras for which we have evidence—the Sung, Ming, and Qing dynasties.

Section four concludes.