The rise of industrial capitalism. What happens next?

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Abstract

This paper seeks to contribute to understanding the English Industrial Revolution and the rise of industrial capitalism by applying basic economic principles to the data and historical descriptions available over more than a millennium.

After using data and theory to characterize the rise of industrial capitalism in England starting in the early–modern period the paper examines the economically important Sung, Ming, and Qing eras in China to see if "sprouts of capitalism" existed. Finding evidence that they did then evokes an explanation of the failure of Chinese living standards to continue rising as England's did after the English Industrial Revolution. The evidence that explains the Chinese "failure" lies again in economic principles—China simply did not have strong

enough incentives given relative prices to motivate the required invention, innovation, and entrepreneurial investments.

Finally and briefly the conclusions allow us to speculate on the future of industrial capitalism.

1 Introduction

This paper attempts to contribute to answering the question of "why capitalism" primarily in the context of the Industrial Revolution meaning the English Industrial Revolution (EIR). The specific form of capitalism the paper investigates is industrial capitalism. The approach is that capitalism is an institution representing a mode of production, a social sytstem, or an economic system. The task then is to explain why and how that institution arose.

The paper's primary motivation is to examine history to see if roots of capitalism are found in proto–industrial economies. English history is examined. But the histories of Sung China and later dynasties are also mined for any evidence of embryonic capitalism. If found across comparative economies the implication is that capitalism's roots may have been shared across those economies. Once more than one instance of proto–industrial capitalism is found then finding what is common among those economies should yield clues about underlying roots of capitalism.

And if shared causes are found that can be explained in the context of the rise of industrial capitalism then another interesting question can be asked: if the underlying roots are changing then how will the institution itself be affected?

The intuition behind asking the main question is that applying basic economic principles may yield interesting outcomes. The most basic economic principles are those of the laws of supply

and demand. Those principles will be tested in this paper to see if they can add to the answer sought.

1.1 Definitions

Since the objects of study are in wide use definitions are in order. Immanuel Wallerstein attempts the definition this way: "Historical capitalism, is, thus, that concrete, time–bounded, space–bounded integrated locus of productive activities within which the endless accumulation of capital has been the the objective or 'law' that has governed or prevailed in fundamental economic activity." (Wallerstein, 1995, p. 18). While not specifically defining industrial capitalism Wallerstein's definition should encompass it.

A modern mainstream economics textbook would define capitalism in some manner close to this from Merriam-Webster: "an economic system characterized by private or corporate ownership of capital goods, by investments that are determined by private decision, and by prices, production, and the distribution of goods that are determined mainly by competition in a free market," with the essentials parts of the definition being private ownership and free market.

In his writings Karl Marx seldom uses the word "capitalism" directly but often uses "capitalist mode of production." One interpretation of his term includes these attributes: private ownership of the means of production used to produce commodities for exchange, exploitation of wage labor, increasing value by appropriating surplus value beyond subsistence from wage labor, and class struggle between the bourgeoisie (owners of capital) and the proletariat (owners of labor power) over dividing value between wages and power. (Archive, Definition of capital).

Marxists (meaning followers of Karl Marx's work in some sense) define capital as an accumulation of money that is then used in the circuit of capital (M–C–M') to purchase a commodity

in order to sell it at a profit.

For this paper's purpose it will be useful to examine the idea of physical capital such as mines, roads, canals, transportation systems, and machines that are used in the circuit of capital; this definition of capital as physical is a characteristic important to the EIR. This contrasts with a purer Marxist definition such as merchant capital which can be thought of as money invested in commodities purchased from someone else in order to pursue the circuit of capital.

1.2 English transition to industrial capitalism

Historians commonly discuss the rise of capitalism in terms of the transition from a feudal system to a capitalistic system and often describe it in terms of struggle and conflict among different classes of society. This can involve discussing an economy's structural change from primarily agrarian to primarily industrial.

Karl Marx's main written work was largely modeled on England (Marx and Mandel, 1992) and thus the EIR. Other scholars have built on his great contribution to continue to describe the transition from feudalism to capitalism in western Europe. Maurice Dobb and Paul Sweezy in the 1950s engaged in a debate—the "transition debate"—that delineates the two main threads of Marxist thought (Sweezy and Dobb, 1950). Paul Sweezy attacks Dobb's theory that the decline of western European feudalism was due to the overexploitation of labor by the feudal ruling class. Feudalism is characterized by production for use through local markets rather than production for exchange including long-distance markets. Sweezy identifies several sources of instability in the feudal society including lords competing (warring) for land and vassals and the growth of population that is pushed from the manors and become brigands or mercenaries (Sweezy and Dobb, 1950, p. 136). Yet Sweezy does not explain how an otherwise such stable system as

feudalism had proven to be could spark the kind of social revolution that causes a transition of social systems; this is the kind of change that is essentially Dobb's theory of the transition—an endogenous conflict between classes eventually causing the transition.

Rather Sweezy sees the growth of long–distance trade in commodities produced explicitly for market or exchange value as the fundamental cause of the transition. His favored cause for this exogenous factor is Henri Pirenne's explanation—the eleventh-century re-opening of Mediterranean shipping between the western ports and the tenth-century development by Scandinavians of commercial routes from the North Sea and the Baltic via Russia to the Black Sea (Pirenne, 1936) (Sweezy and Dobb, 1950, p. 143).

Many historians agree that European feudalism's demise was succeeded by an era of proto-industrialism (characterized by home production for market or exchange value) before industrial capitalism dominated. While in historical time these processes were likely arrayed along a continuum focusing on the key elements of each era helps in understanding what the important changes were. Paul Sweezy describes the transition mechanism as composed of four elements.

First, the rise of long-distance trade causes an increase in production for exchange or market; this system that featured specialization and division of labor was more economically efficient than the manor–based production–for–use system it was competing with and eventually this new exchange system dominated the older system. Second, the existence of exchange value as an ever more important economic fact changes the producer's attitude allowing them to visualize accumulating riches in the form of money or claims to money and this change led to the desire for accumulating wealth as an end in itself. Third, the remaining feudal ruling class develops ever more of a taste for conspicuous—often luxury—consumption. Fourth, these changes were accompanied by the rise of the towns as centers of the exchange economy that attracted the

former manorial vassals. Urbanization was underway as a major trend (Sweezy and Dobb, 1950, p. 143–144)).

Sweezy agrees with Dobb (and Marx) on the historical time frame of the transition events. This chronology has western European fedualism entering a period of acute crisis in the fourteenth century. The fifteenth and sixteenth centuries were characterized by "pre-capitalist commodity prodution" (Sweezy and Dobb, 1950, p. 150) that laid the groundwork for the rise of capitalism in the second half of the sixteenth century. A non–Marxist term might be proto–capitalism.

A different group of scholars writes about the transition period with a different poin-of–view and one that is important as a prototype for the rise of industrial capitalism. E. M. Carus–Wilson writes of a thirteenth century industrial revolution centered on the important English wool textile industry (Carus-Wilson, 1941). Additional contributors to this literature include Lynn White (White, 1970), Jean Gimpel (Gimpel, 1992), and Debeir et al. (Debeir, 1991) but Carus–Wilson tells the story in a most compelling manner.

Carus–Wilson relates the story of how fulling—one of the four key steps in the process of woolen-cloth making—was transformed in the thirteenth century from a manual (or importantly foot–based) process of beating the cloth in water to improve its finished characteristics. In a two-step invention mechanical fulling evolves from the old method of fulling–by–foot. First, the two feet are replaced by two wooden hammers alternatively raised and dropped on the cloth in the fulling trough by the action of a revolving drum. Second, a series of these hammers was attached by their drums to a water–wheel spindle for power. Water–power replaced human or muscle–power and several—perhaps tens—of human fullers were replaced by one person managing the whole process and now called a fulling mill (Carus-Wilson, 1941, p. 43).

Reviewing what happened in the thirteenth century, foot fulling gives way to mechanical fulling, human labor is displaced by water power, the industry is centralized at the mill rather than in homes, the new system depends "as never before" on capital equipment, and the system is passing out of guild system control. The investments are largely in the country around water sources on property owned by the church or landlords who are usually a member of royalty. The royal investments include those by King Henry III who owned a fulling mill at Elcot (Carus-Wilson, 1941, p. 50–51).

It is not difficult to visualize replacing water–power with steam–power when steam engine technology matures in the eighteenth century; the fundamental groundwork is already laid. Economists must ask what are the incentives to make this dramatic productivity–enhancing innovation? Two come to mind: one, a larger scale operation is required than is achievable by muscle power—an increase in aggregate demand could explain this; two, wages paid to fullers are sufficiently high that substitution of muscle–power by water–power promises sufficiently large economic returns (profit) that the large development effort and investment is worthwhile.

There is an extremely important related chain of events triggered by the great productivity gains in woolen manufacturing that were partly translated into lower costs and prices. This encouraged converting land to enclosed sheep ranches—a momentous event that we call the "enclosure movement." Note that is implies economically an increase in demand for woolen cloth driven by increased population, lower prices, or both.

Later this paper explores the idea that an even more fundamental cause of the transition to industrial capitalism is the general rise in population levels driving increases in aggregate demand for many commodities including woolen cloth. This factor is woven throughout the transition debate and Sweezy explicitly refers to but does not develop the idea. Under this theory the

long–distance trading activities and trade route expansion that certainly happened are important proximate events but not the ultimate cause of the transition.

This demographic transition theory is sometimes referred to as demographic determinism and is explicitly rejected by Robert Brenner in a less–explicitly Marxist essay contained in The Brenner Debate (Aston and Philpin, 1985). Brenner favors the class–struggle explanation for the rise of capitalism; arrayed against his argument are contributions in the volume by M. M. Postan and John Hatcher (Postan and Hatcher, 1978), Emmanuel Le Roy Ladurie (Ladurie, 1966), and Guy Bois (Bois, 1984). This group sees population changes as important in the transition away from feudalism.

John Nef's impressive two-volume The Rise of the British Coal Industry (1932) discusses in depth the rise of industrial capitalism without explicitly invoking Marxist ideas. He however does not avoid discussing class–related conflicts including the judicially–supported concentration of mineral rights in the hands of a few owners (Nef, 1932, v.1, p. 286) and the conflicts caused by the cleavage between capital and labor in the coal mines and coal trade (Nef, 1932, v.1, pp. 411–429).

Importantly for this paper and discussed in more depth later Nef explicitly attributes the rise of industrial capitalism to the rise of the British coal industry. This claim becomes an important piece of the argument in this paper—that industrial capitalism likely arose primarily from fundamental economic changes no matter what other events were active at the same time.

The french historian Paul Mantoux writes extensively about the EIR and its connection to the rise of industrial capitalism in The Industrial Revolution in the Eighteenth Century (Mantoux, 1961). Like Nef, Mantoux writes of the conflicts between capital and labor and the rise of industrial capitalism as an outcome of the EIR in a manner that is not explicitly Marxist yet is rich in the materialism that Marx exposes. Mantoux thus is also an important contributor to the ideas in

this paper.

1.3 Evidence of a Chinese transition to industrial capitalism

Is there evidence of an early Chinese transition to either proto–capitalism or industrial capitalism? This paper investigates three Chinese historical periods—the Northern Sung dynasty (960–1126 CE), the Ming dynasty (1368–1644 CE), and the Qing dynasty (1644–1911 CE)—for such evidence.

What kinds of evidence would be interesting? Several come to mind—first, evidence of wage–labor at least in some basic industries—Marx would look for alienated workers who primarily reproduced by selling their labor power to another; second, evidence of integrated labor and commodity markets one sign being correlated wage rates for the same type of work across some logical geography; third, evidence of capital investment of a scale that is remarkably different than before motivated by some identifiable economic incentive.

Sinologist Robert Hartwell provides significant evidence of wage–labor in one important Sung Chinese industry–the iron and steel industry. Sung iron production is remarkable in its industrial scale—producing more iron than Europe up until the late eighteenth century in centralized industrial areas with large capital investments—and marked by its use of wage–labor (Hartwell, 1962, 1966, 1967, 1982).

Japanese Sinologist Yoshinobu Shiba prodvides a detailed look at the structure of several key industries during the Sung dynasty (Shiba, 1970).

Robert Allen provides data on Chinese labor markets during the Qing dynasty (Allen et al., 2011). This will provide the basis for finding whether China had developed integrated labor markets. Kenneth Pomeranz provides additional evidence of wage–labor and market integration

(Pomeranz, 2001).

Xu Dixin and Wu Chengming provide a very detailed Marxist–structured analysis of Chinese capitalism during the Ming and Qing dynasties. They provide evidence of wage–labor and other capitalist signature attributes as they evolved through these more than 300 years (Xu and Wu, 2000).

John Hobson provides evidence of Chinese water–wheel powered production requiring substantial capital investment (Hobson, 2004). This is one of capitalism's signatures—significant investment in mechanical devices to either scale up or replace labor inputs.

2 English industrial capitalism

Karl Marx used the EIR and the related rise of industrial capitalism as a primary source for his monumental work Capital: A Critique of Political Economy. England was the first economic system to widely industrialize with masses of wage–laborers confined in centralized mechanized factories tending machines that produced commodities at greater scale and lower cost than ever in history. The momentous changes in living standards, culture, institutions, and entire social systems put the world on a course that it still travels.

Understanding the rise of industrial capitalism—the underlying reasons for its existence and dominance of economic systems—may lead us to an understanding of its possible futures. Economists are first trained to think about markets—a fundamental component of economic systems—as a way of explaining how economic systems work. They learn that demand and supply are the rules—even laws—that govern how markets function. And they learn that demand for inputs to the production process is a *derived* demand depending on the demand for the commodity it helps produce and its own cost and productivity. While much of the history written about the EIR

talks mainly of the supply–side—the inventions, innovations, and the capital needed to build and commercialize them—it may be fruitful to first examine the demand side for capital.

This paper explores how using the idea of the derived demand for capital helps explain the rise of industrial capitalism. Many analyses of capitalism focus on the idea that capitalists simply want to accumulate capital for personal gain. There is almost surely some truth in this but this cannot on its own explain why capital and capitalism have come to dominate the world's economies. First we will investigate how the demand for capital arises. For the most part this will be an investigation of productive—physical—capital.

2.1 A first look at data

It is possible to think about aggregate demand for produced commodities and services as having two components—a subsistence component and a living–standards component. The subsistence component is essentially a function of population levels. The living-standards component is demand above subsistence. Total aggregate demand is the sum of both.

For most of economic history population levels have been the sole determinant of levels of aggregate demand; most of the world lived at subsistence most of the time. That began to change around the time frame of the EIR when living standards began their long march upward. That trend still continues to this day. But in order to understand where the basic aggregate demand comes from that the Industrial Revolution met and therefore where demand for capital comes from we should first examine population levels through time.

2.1.1 Sources and methods

The primary source for population data is the database started by Angus Maddison (Maddison, 2007) as supplemented by United Nations data (Nations). The main analytic tools are graphs of population levels and transformations of that data to clarify trends.

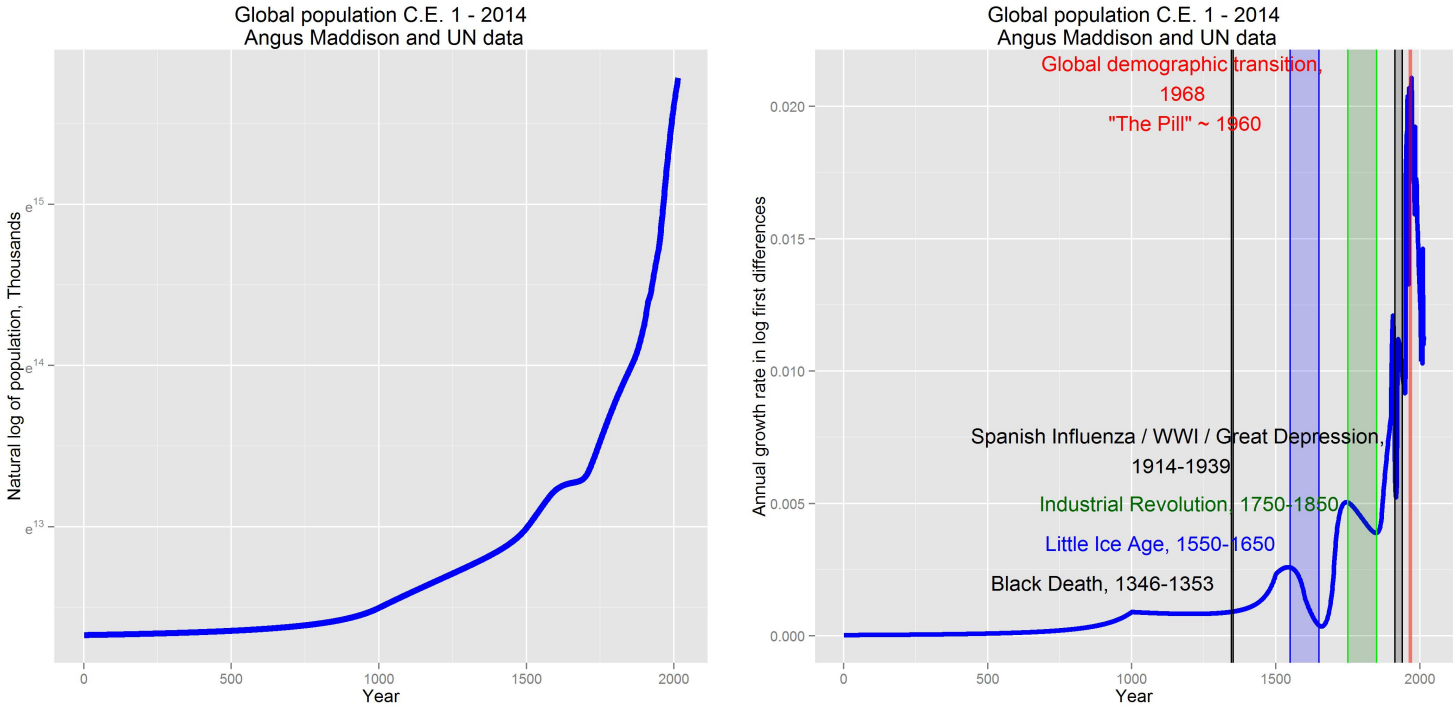
2.1.2 Global population trends

The left panel of figure 1 displays the log of population levels since year one. This is smoothly increasing super–exponential growth with some barely visible wiggles. This population growth dynamic and its ever–increasing aggregate demand drove the supply–side of the global economy into creating the EIR and thus created industrial capitalism due to the self–accumulating nature of the investments that were required.

The right panel is in log differences of annual population levels since the year 1 CE and thus shows approximate annual growth rates. Note that the growth rate peaked in 1971 at 2.2 percent, has declined to about 1 percent now, and appears poised to head lower. If population growth was the underlying cause of industrial capitalism then we must question the implications of its plummeting growth rate. A later section will address that possibility.

One can clearly see the gobal population liftoff in the late middle ages followed by accelerating growth during the early modern period and "going exponential" during the EIR. England's population growth follows this pattern providing expanding aggregate demand in its domestic market. Population growth globally accounts for aggregate–demand expansion that caused a commercial and trading expansion. This was first exploited in the Dutch Republic then England as that country began to dominate world trade. Most of this growth can be characterized as subsistence with the great gains in living standards awaiting the second–phase EIR in the nineteenth

Figure 1: Angus Maddison and UN: log and log differences of global population



century. As aggregate demand grows the supply–side must respond but in the still Malthusian pre–EIR world living standards increased slowly at best until the late eighteenth century. Nevertheless there is significant and increasing total aggregate demand growth.

There are many approaches to understanding the great event that is the EIR from purely institutional to purely economics–driven. The next sections relate several stories of the The English Industrial Revolution and the rise of industrial capitalism.

2.2 Jan de Vries from Early Modern Capitalism—a survey

Jan de Vries writing in a chapter in Maarten Prak's edited volume Early Modern Capitalism—Economic and social change in Europe, 1400–1800 clearly defines the great debates among the various disciplines and schools who continue to attempt to explain the English Industrial Revolution.

de Vries' chapter "Economic growth before and after the Industrial Revolution—a modest proposal" explains the contours of the debates and in the end argues for a broad historical approach rather than one dominated by a particular school of thought (de Vries, 2001).

2.2.1 Different modeling schools produce an ahistorical approach

de Vries opens by analyzing the problems in past and current approaches: "Coherent accounts of historical economic growth are difficult to achieve only in part because of the venerable jurisdictional boundaries that have for so long governed the training of professional historians" (de Vries, 2001, p. 177). This allows for potentially different stories among eighteenth century (early modern) and nineteenth century (late modern) histories.

"One might suppose that what historians tear asunder with their conventions of periodization, economists would stitch together with the healing balm of theory" (de Vries, 2001, p. 177). However before the neo-classical era economists applied classical models with some binding constraint usually land whether the modeler followed Smith, Malthus, or Ricardo in details. Later neo-classical modelers assumed constant returns to scale, substitutability at all margins, and technologies freely available to all, and thus told a story abstracting from time and space—no history and no geography. And thus he introduces his case for a more integrative approach to fix the rifts in both historical and economic story–telling.

de Vries reviews the commonly–held neoclassical model's "bookends" of the EIR, meaning the neo-Malthusian model that precedes it, and the Kuznetsian model of modern economic growth that follows it as a unitary growth model with a single long term trend; de Vries accepts the revisionist criticisms from many including Mokyr (Mokyr, 1992), Jones (Jones, 1988, p. 26), and Crafts (Crafts and Harley, 1992). The revisionists claim the EIR covered a longer period and

had a slower rate of growth than Kuznets' version. de Vries does not fully dismiss the bookends but instead appeals to the complexity of the event and says that we must revise those models. de Vries dismisses as un–historical and un–empirical the neoclassical "Solow" convergence models.

de Vries sketches the post–Industrial Revolution contours of modern economic growth using the empirical work of Simon Kuznets, Phyllis Deane and W. A. Cole, and Angus Maddison. He supports and explains the empirics with the neoclassical growth theory represented by Robert Solow's work that highlights the role of technology. These works describe a higher growth structural break from the prior rate of economic growth and is supported by a growth theory that demands technological change for its growth engine.

2.2.2 The neo–Malthusian model—pre–industrial growth

Next, de Vries outlines the pre-Industrial Revolution neo-Malthusian models. He cites a large number of contributors including François Simiand, Wilhelm Abel, Ferdnand Braudel, Michael Postan, E. H. Phelps Brown and Sheila Hopkins, B. H. Slicher van Bath, Emmanuel Le Roy Ladurie, and the team of E. A. Wrigley and R. S. Schofield. The consistent essence of this model is that movement in populations, fuelled by sexual relations, is the dominant economic relationship and is always constrained by a more–or–less fixed supply of land to feed the population and an agricultural technology at its frontier (de Vries, 2001, p. 181).

Surveying the extended era of pre-industrial growth de Vries summarizes that given the "revised view of British macroeconomic performance during the Industrial Revolution…" (less than earlier estimates) "…would appear to required that significant pre–industrial growth took place in the long run" (de Vries, 2001, pp. 188–189). He cites contributing factors to this secular growth as including institutional development, urbanization, demographic control mechanisms,

market expansion, agriculture, industrial organization, and technology. These are all important proximate events; this paper investigates if one can be identified as a primary or ultimate cause.

2.2.3 Wrigley's neo–Malthusian world

E. A. Wrigley models the Malthusian world which he describes in People, Cities and Wealth. The main components of the Wrigley model include living standards (most often represented as gross domestic product per–capita), nuptiality (marriage) rates and ages, and fertility rates. In the neo-Malthusian world before about 1880 in England, there is a strong positive correlation between living standards and nuptiality rates and also a very strong positive correlation between nuptiality rates (and age at first marriage) and fertility rates. In this world as living standards fluctuate upward due typically to exogenous factors such as better weather and crops more women marry at a younger age and therefore increasing fertility rates drive up population levels.

Wrigley's (and Scofield's) Wrigley (Wrigley, 1987, p. 237) major correlations for his neo-Malthusian model for England are summarized as follows:

Factor 1	Factor 2	Sign of correlation
Population increase	Food prices increase	Positive
Food price increase	Real income decrease	Negative
Real income decrease	Nuptiality decrease	Positive
Nuptiality decrease	Fertility decrease	Positive
Fertility decrease	Population decrease	Positive

Thus rising population caused lower living standards and retarded fertility through the nuptiality mechanism. Wrigley claims a different mechanism for China's version of a neo-Malthusian model as in:

Factor 1	Factor 2	Sign of correlation
Population increase	Food prices increase	Positive
Food price increase	Real income decrease	Negative
Real income decrease	Mortality increase	Negative
Mortality increase	Population decrease	Negative

Wrigley summarizes the "Chinese" version of his model this way: "Here to balance the books nature audits with a red pencil" (Wrigley, 1987, p. 236). This neo-Malthusian variant was not the most pleasant of existences.

The fundamental importance of Wrigley's theories is that they fit the historical data that we know describes the millennia preceding the EIR in terms of population and living standards and suggest how radically these changed post–Revolution. The history is of increasing total final demand because of gradually rising population and occasionally rising living standards. But the rising final demand eventually ran into some constraint or set of constraints that caused living standards to fall.

Only in the late eighteenth century was this perpetual cycle interrupted allowing persistent simultaneous increases in both population and living standards. Total final demand started marching inexorably upward and the supply revolution that was the EIR was able to continually match the population's rising desires and incomes for the first time in history.

2.2.4 From two models to one

de Vries approaches the great question of how to explain the miracle of the EIR by quoting from David Landes (Mokyr, 1992): "In a polemic directed against revisionists of the Industrial Revolution, David Landes excoriates economists in general and Cliometricians in particular for being 'passionate seekers after the One Cause, the prime mover.' He (Landes) observes that these methodologically sophisticated economists forget that everything is substitutable and hence nothing is indispensable,... and praises the approach of 'multiple causation'."

de Vries further comments that "Landes fails to acknowledge that the search of the One Cause of the Industrial Revolution arises from the need to explain the lifting of the great constraint that defines the neo-Malthusian model" and then invokes Wrigley as a champion of the 'essentialist' (primary cause) approach (de Vries, 2001, pp. 189)(Prak 2001:189)

He concludes by describing a gradualist time line and then makes the case for a centrist approach basically ignoring Wrigley's core essentialist message in Continuity, Chance and Change (Wrigley, 1988). This paper investigates the Wrigley approach.

2.3 Nicholas Kaldor

Kaldor attempts to explain the large regional differences in development rates and comments on the essentialist version of history. He verges on declaring economics as the primary or ultimate cause (Kaldor, 1970, p. 339).

> ...industrial production requires a great deal of capital—both in terms of plant and machinery, and of human skills, resulting from education—but in explaining such differences in 'capital endowment' it is difficult to separate cause from effect. It is as sensible—or perhaps more sensible—to say that capital accumulation results

> from economic development as that it is a cause of development. ... Accumulation is largely financed out of business profits; the growth in demand in turn is largely responsible for providing both the inducements to invest capital in industry and also the means of financing it.

The rest of this paper explores strengthening the essentialist message of the cause of the EIR which then leads directly to explaining the rise of industrial capitalism. It develops a very basic theory of the EIR which applies also to China and perhaps to other pre–modern industrialization attempts such as the Dutch Republic during the sixteenth and seventeenth centuries.

2.4 Industrial revolutions

The first paper in this dissertation moves toward a theory of industrial revolutions centered on the EIR. It claims and demonstrate empirically that the EIR was essentially an energy revolution in the strong sense that without the energy revolution there would not have been an event which has come to be called the EIR. The core elements of this theory are in the Technical Appendix, section 6.

There was an up-welling of populations and thus total incomes during the Middle Ages; this is temporally related to the Medieval Warming Epoch which increased (likely globally) agricultural yields and influenced institutions and culture. Increased goods and services demand led to increased production in heat–consuming industries such as smelting, metal working, salt making, dyeing, and brewing. Heat–consuming industries used mainly wood (sometimes as charcoal) as their energy source. The rising wood demand deforested neighborhoods, regions, and countries. Wood prices rose dramatically for example in sixteenth–century England. This also affected household uses of wood for heating and cooking.

Producers and households naturally sought alternative energy sources. In England and China that source was coal. Using coal for heating was not an easy technological transition for many reasons; the full transition was on the order of centuries. In the Dutch Republic the energy source was peat. The Dutch ran out of peat supplies and their industrialization attempt stalled.

In pre–modern eras the path to an industrial revolution was the transition from an inherently limited heat energy source—trees—to an essentially unlimited source—coal. Both England and China did this and further research should show that other areas in addition to the Dutch Republic did as well. But this is only the first step on the path.

The main leap to a complete industrial revolution was learning to apply the new highly–scalable energy source to steam–powered devices to replace human and animal power. This invention unleashed the enormous productivity gains and scale that are the hallmarks and legacy of the EIR.

High wages in England provided sufficient incentive for inventors and entrepreneurs to invent and commercialize steam–power and this added momentum to the rise of industrial capitalism.

2.5 The rise of the demand for capital and its supply—the path to industrial capitalism

This section develops the derived–demand–for–capital story that causes the rise of industrial capitalism in England.

2.5.1 Transition from wood to coal for heating in England

In the "real economy" story of the previous section there are clues that explain how the demand for capital arose that when paired with the capital supply story will present a picture of the

economic foundations of industrial capitalism.

John Nef plays an important role in telling this story. Nef's 1932 two–volume work titled The Rise of the British Coal Industry is a little–cited work in recent scholarship but is as definitive a work as one could hope for on a most important event of the EIR (Nef, 1932).

In Volume I Nef lays out the case for the development of capitalism as a result of the level of investment needed in the nascent coal industry. Nef dates the start to the mid–sixteenth century along with the rise of using coal as a heating fuel. He discusses that the division of labor in the mining and transportation of coal was great calling a mine or colliery "a Jack of all Trades shop" (Nef, 1932, p. 348). Most of this labor was wage–labor from workers who depended entirely on these wages for their living and that is a signature feature of capitalism. Quoting Nef as he captures the state of capitalism across the continent as well as in England:

> "There was no other British industry of equal importance which had advanced so far on the road to modern capitalism. This observations leads naturally to the question : How far does the expansion of the coal industry in Great Britain at an earlier period than in any other part of the western world account for the fact that the new capitalistic order, which, before the reign of Elizabeth, had found more fruitful soil in Italy, Flanders, and southern Germany than in England, should have obtained, during the seventeenth and early eighteenth centuries, a tighter hold on the economic life of England than on that of any continental country? How far, in other words, is the growth of modern capitalism as the dominant form of economic organization related to the rise of the coal industry?" (Nef, 1932, p. 349).

He then develops the case for the large demand for capital in the first phase of the EIR—the transition from wood to coal for industrial and domestic heating. He relates the large costs of

exploratory drilling, deep structural requirements (up to 36 fathoms), and drainage requirements, sums far beyond the resources of a few workers to supply on their own. He relates many cases of individual investments (capital supply), and concludes the section on the capital requirements of coal mining by saying "For the first time in western Europe, in connection with an industry employing a considerable portion of a country's population, large capitals had become the rule" (Nef, 1932, p. 380).

These events begin in the sixteenth century and grow dramatically in the seventeenth and eighteenth centuries and thus precede the dating many other estimates claim for such a beginning for the EIR. Nef further elaborates on the even higher capital requirements for transporting mined coal; the early mines were in north east England, far from London and other consumption centers. This required capital investment in boats, wharves, warehouses, wagons, and roadways.

Are we yet at what we might recognize as industrial capitalism? No, but we have in the investment required for coal mining an engine of demand for capital that leads inexorably to nineteenth century institutions.

The capital supply required came mainly from wealthy merchants and nobility. Thus the story of the rise of merchant capitalism that had relatively low capital demand and high capital accumulation (supply) is important. Eric Mielants in his The Origins of Capitalism and the 'Rise of the West' makes the strong case for a rise in merchant capitalism among the western European city–states between 1000 and 1500 CE (Mielants, 2007). This becomes an important capital accumulation source to supply the capital investment required by the EIR.

This first phase of the EIR has given us two critical pieces of infrastructure: the technologies and physical infrastructure for the mining, transportation, and consumption of coal for industrial and domestic heating applications; and a financial institution—merchant capitalism—capable of

supplying the comparatively large capital needs of the physical infrastructure.

2.5.2 Transition from muscle–power to steam–power in England

The second phase of an industrial revolution is the transition from muscle–power both human and other animals to mineral (coal) power. This is exemplified during the EIR by the increasing substitution of steam–power for muscle–power for both commodity production and transportation. This promotes a great increase in labor productivity and—given distribution—living standards. A key invention is of course the steam engine. By contrast China knew of steam engines by at least the seventeenth century they did not apply them to practical applications until the nineteenth century (Wang, 2009, pp. 31–54).

However in England this was not the case. After making the wood–to–coal heating transition England made the muscle–to–machine power transition by increasingly taking advantage of the enormous energy and power supply scalability of coal–fired steam engines.

The English had strong economic incentives to apply machine technology as a substitute for high–wage English labor throughout much of the early–modern era. This argument extends the work of Robert Allen The British Industrial Revolution in Global Perspective (Allen, 2009) who covers this transition as well. The Chinese had little such incentive—wages are thought to be low during the relevant historical periods.

This application of economic incentives is sufficient to explain why England completed their industrial revolution and China did not. Section 3 discusses Chinese economic transitions in greater detail.

As England proceeds on the path toward the EIR the demand for capital increases. Capital is now required for building the new steam engines, steam–powered factories, and the steam–

powered land– and water–transportation systems. So we have an energy source revolution causing the derived demand for capital to increase dramatically. By this stage in English history (eighteenth century and later) more formal financial systems were increasingly participating in creating credit to supply the inventors and entrepreneurs with needed capital.

The muscle–power–to–steam–power transition story is masterfully told by French historian Paul Mantoux in The Industrial Revolution in the Eighteenth Century (Mantoux, 1961). Mantoux published this in the original French in 1907; the first English translation was 1928. Mantoux is another great historian who is under–cited by contemporary economic historians to their detriment. T. S. Ashton in the preface to the 1961 edition says:

> " . . . in both its architecture and detail this volume is by far the best introduction to the subject in any language. It is, moreover, a permanent work of reference. . . . It is astonishingly fresh. And not a few of the findings of modern writers that one had thought of as new are now seen to have been anticipated by M. Mantoux. His book is one of a few works on economic history that can justly be spoken of as classics" (Mantoux, 1961, p. 23).

Mantoux draws a clear distinction between "manufacture" and the "factory system." Manufacture is to him the centralization and division of labor; the factory system expands upon that by using machine power instead of labor power. Woven throughout is the role of first the merchant capitalists and then the great landowners in this centralization of labor and its mechanization including the transportation infrastructure required for the associated expansion of exchange (trade). Mantoux covers in great detail the ways this evolution of production affected the "whole economic system and consequently the whole social system, which is controlled by the growth and distribution of wealth" (Mantoux, 1961, p. 25).

Among the industries Mantoux cites is the woollen industry during the Renaissance starting in the the fourteenth century and the seventeenth and eighteenth centuries. Specifically he relates "the existence of capitalist undertakings, particularly in the woollen industry, and the beginning of the sixteenth century and even in the fifteenth and fourteenth" (Mantoux, 1961, p. 33). He also describes these capitalist roots: "Instead of being mere merchants, buying cloth from the weavers and selling it in markets or at fairs, they [rich cloth merchants in the north and west of England] set up workshops which they supervised themselves. They were manufacturers in the modern sense" (Mantoux, 1961, p. 33).

This story seems to be clear evidence of early roots of English industrial capitalism. One must next ask why would these merchants travel this path and what were the expectations of the future of their business that motivated them? While Mantoux does not directly address the growth of demand that surely must be behind the merchants activities he talks about a proxy for that.

That proxy is commercial expansion starting before and continuing during the early modern period. One can ask why would such a commercial expansion arise? Was it *sui generis*? Almost certainly the cause here was the increase in populations in at least the countries comprising the trading world including England and its export targets. As an illustration of continually–rising population levels refer again to Figure 1.

Mantoux further analyzes land redistribution in England and focuses on the enclosure movement. This episode is fascinating and important in that it freed agricultural labor to urbanize and provide the labor source for the EIR and as a by–product raised agricultural productivity. The story of the thirteenth–century water–powered mechanization of the woolen–industries' fulling process is reviewed in the introduction. See this description 1.2.

Mantoux traces the beginnings of replacing labor with machinery in the textile industry and

the role of capitalist undertakings resulting in the rise of the factory system. He discusses the technologies such as the knitting frame and the silk throwing mill and their inventors in detail. This includes a fascinating narrative on the transition from tools to machines that changed the nature of labor described as essentially a skill transfer from man to machine; this initially uses wind and water power but enables the application of steam–power when that becomes technically and cost feasible (Mantoux, 1961, pp. 189–191).

Not all important inventions were developed in England. Mantoux relates the story of John Lombe pirating Italian silk–throwing technology and using it to build a very large (five hundred feet long and five or six stories high) Derwent factory that was centrally powered by a water wheel. This was in about 1718 and illustrates his three key points: the skill transfer from men to machine, the power transfer from men or animals to something much more scalable, and the demand for capital to realize this achievement. John's brother Thomas supplied that capital; the capital source is likely from Thomas' merchant activities. The factory employed about three hundred workers (Mantoux, 1961, p. 191).

This clearly was the prototype for the future of the factory system in cotton and woollen textiles and thus heralded the course of the EIR over the following 150 years. The more famous inventors and entrepreneurs such as John Kay (fly shuttle), John Wyatt (cotton spinning machine), William Hargreave (spinning jenny), and Richard Arkwright (water frame) built on this successful factory template, created the EIR, and greatly increased the demand for capital.

The factory system was a fertile ground for the application of steam–power; this loosed the constraints of finding a suitable water–power location or unreliable wind power source and thus began the essentially uninterrupted productivity rise leading to ever–increasing per–capita living standards. This also led to the revolution in land transportation represented by the railroads and

the maritime transport revolution of the steam ship. And all of these events led to a great increase in the demand for capital.

While actual aggregate capital stock data is sparse for the era, a simple illustration will show the growth–rate leverage capital had as growing population demands drove aggregate output.

An article by Jeffrey G. Williamson, "Why Was British Growth So Slow During the Industrial Revolution?", provides a survey of capital growth rates and, importantly, estimates through time of the Capital/Output ratio. Williamson draws on work by Phyllis Deane, Floud and McCloskey, and Simon Kuznets. The data is partially reproduced (Williamson, 1984) as table 1:

Table 1: British capital productivity. Source: Jeffrey Williamson (Williamson, 1984, p.702)

Period	Capital's productivity Y/K	Calculated K/Y
1761–1820	0.36	2.78
1791–1820	0.38	2.63
1821–1860	0.53	1.89

Before 1820 for every additional British pound of aggregate output more than 2.6 British pounds worth of capital stock was required. During this period gross domestic product estimates went exponential in Britain. Note that while growth rates of GDP and capital will be the same the capital growth rate adds to an ever larger base such that capital accumulation is increased at the multiplied rate.

It does not appear from either Nef or Mantoux that capital supply was a real constraint with investment flowing from wealthy merchant capitalists, wealthy landowners (often nobility), and eventually a banking system. Instead capital appears to have been called forth by capital demanded to keep up with aggregate demand growth and the technical productivity factors summarized by the K/Y ratios in the table.

Thus we have a straightforward supply and demand economic story for the rise of industrial

capitalism. This was facilitated by the fact that capital stock is consumed only over many units of output thus the relative mathematical ease of building large capital accumulations during the nineteenth century.

2.6 The primary roles of capital in the EIR

Tangible capital has two primary roles in the EIR:

The first is the infrastructure investment required to extract and transport coal as a scalable energy source used initially to substitute for ever more expensive wood–supplied Joules in heat–using applications. Increasing demand caused deforestation causing rising wood prices. Compared to using wood as the primary heat source, English coal supplies were distant, deep, wet, but ultimately cheaper than wood. As John Nef documents (Nef, 1932) the investment required for successful coal extraction and distribution was large and historically unprecedented.

The second is to replace muscle–supplied power inputs to the production process with steam–powered mechanical devices. The energy input is largely from coal during this revolution so the tangible capital assets use coal energy inputs to provide power in the form of rotating or reciprocating motion through the mechanical application of steam—the steam engine.

There is an important class of mechanical devices—gears and levers—that amplify muscle power by allowing increased muscle power input for a given output allowing low-intensity muscle power to leverage up their power inputs to accomplish higher–intensity tasks. Note that this requires added muscle Joule inputs for a given amount of output recognizing the energy input constraint that humans have fixed potential power output per unit of time; the important EIR capital devices allow essentially unconstrained energy inputs per unit of time. The purely mechanical muscle assists are not the important technologies in the second phase industrial revolution.

There were non–coal non–muscle power inputs to manufacturing through much of recent history. These were either water– or wind–powered rotary and reciprocating machines and were precursors to steam–powered machines. In recent scholarship Örjan Wikander claims "Today, we may state with confidence that the breakthrough of the water–powered mill did not take place ... in the early middle ages, but rather ... in the first century A.D., or perhaps even slightly earlier." The water wheel was known and used during the late Roman republic or the early empire (as cited in (Temin, 2012, p. 224). The Arkwright water frame was an EIR water–powered mechanical cotton spinning device but the true energy revolution was fulfilled when the essentially unconstrained scale of steam power was applied through such devices to manufacturing processes.

Note that in the theory of industrial revolutions (formalized here 3) capital is always labor substituting since the Joules of energy that are production inputs are either muscle or fossil inputs but not both. Tangible capital applies additional fossil Joules to industrial processes. Rather than the normal economic analysis of labor substitution this frameworks suggests that the economic analysis of capital inputs may be better understood as how much energy input can be added to any process. Of course both organic and inorganic energy input sources for a production process can be mixed and it is this frequent case that causes the "complements" versus "substitutes" economic conversation.

To crystallize the increase in scale the energy revolution represented in choosing among energy input sources, Fred Cottrell who wrote Energy and Society in the mid–twentieth century: Cottrell sharply contrasts low–intensity and high–intensity energy regimes and societies. Low intensity "converters" include human and animal power using plant–based input sources, and water– and wind–mills (Cottrell, 1955).

The first high–intensity converter in Cottrell's history is the sailing ship that provides at least an order of magnitude increase in energy surplus over low–intensity converters, and dramatically changed the economics and institutions of the world's economies.

Cottrell recognizes that the most disruptive high–intensity converter was the steam engine—the signal technology of the EIR. The steam engine disrupted the economic systems and their social systems and institutions, a legacy of turmoil that continues to this day.

3 Evidence of Chinese industrial capitalism

With the case made above that industrial capitalism is a more–or–less expected outcome of an energy–driven industrial revolution, a series of interesting questions regarding historical China can be asked. The questions are designed first, to detect if there were enough economic incentives in historical China to foment at least the beginnings of industrial capitalism, and second are there other markers of capitalism and industrial capitalism that would support a positive answer to the question. If there is sufficient evidence then we can think about possible generalizations of the rise of industrial capitalism across otherwise disparate economies.

The main questions we would like to answer about China during the three eras we have some data on are:

- What is the aggregate demand posture of China during the Sung, Ming, and Qing dynasties? This is primarily an investigation of population level changes.
- What are the price levels and dynamics of energy inputs?
- What are the price levels and dynamics of labor inputs?
- What is the evidence of non–muscle–power energy sources?

– Is there evidence of large–scale centralized commodity production in any industry?

– What is the invention evidence relevant to a possible industrial revolution?

– Is there evidence of the building of a factory system?

– What is the evidence about wage labor?

– What is the evidence about integrated markets including labor?

3.1 A look at the data–sources and interpretation

This section will investigate available evidence organized by the three eras—Sung, Ming, and Qing.

3.1.1 Sung dynasty: 760–1279 CE

Determining what is happening to aggregate demand is important to help understand the economic incentives inventors and entrepreneurs might face to overcome supply–side constraints if demand is increasing. In the three eras under investigation, much of aggregate demand is population–growth driven as the evidence indicates mean living–standards are at low levels and likely close to subsistence—except in the Sung era as explained below.

Robert Hartwell presents population estimates for China for the years 742, 1014, and 1064 CE. This span covers the period leading up to the start of the Sung dynasty in 960 CE and the first hundred years or so of that dynasty. This gives at least some idea of population dynamics (Hartwell, 1966). The data are summarized in Table 2.

These population growth rates are very low and probably could not have by themselves provided much aggregate–demand–based economic incentives to entrepreneurs; if they are accurate

Table 2: Chinese population dynamics 742–1064 CE. *Source:* Robert Hartwell (Hartwell, 1966, p. 34 Table 1 footnote *b*)

Year	Population–million	Period growth rate–midpoint	Compound annual growth
742	52.5		
1014	55.0	0.047	0.0002
1064	62.5	0.128	0.0025
Total		0.175	0.0004

was there another dynamic in play? Hartwell claims that there was a large increase in living–standards during the era. Quoting,

> ”From about 750 to 1100, China experienced a series of economic changes roughly comparable to the subsequent patterns of European growth from the Crusades to the eve of the French Revolution. The spread in the use of money, development of new credit and fiscal institutions, increase in interregional and international trade, and colonization of hitherto marginal land which took place in the Occident during the half millennium preceding the Reformation was paralleled by an earlier era of progress in East Asia during the two- hundred-fifty years from the rebellion of An Lu-shan (755) to the treaty of Shan-yüan 1004)” (Hartwell, 1966, p. 29).

Hartwell further presents evidence of significant increases in the real money supply and in the output of several industrial enterprises including alum making, salt processing, quicksilver and cinnebar production, shipbuilding, papermaking, and printing. He concludes that the best explanation is an increase in real per–capita income (and consumption).

His most “astonishing” estimate was the scale of production in the extraction and refining of metallic ores including iron, copper, lead, and tin. In all these cases he claims the scale of operation and absolute level of output were greater than any other national economy until the late

eighteenth century. The iron output in the northern Sung increased six–fold between 806 and 1078 CE. In 1078 that meant per–capita iron consumption of 3.1 pounds, roughly comparable to Europe's 3.5–4.3 pounds per–capita in 1700. Some northern Sung market areas had per–capita consumption of at least 7.0 pounds. These estimates suggest strong and growing industrial scale and output and support the idea that living–standards must have been increasing (Hartwell, 1966, p. 31–33).

Iron relative price dynamics indicate that there must have been significant innovations and investment in those innovations between 997 and 1080 CE since the price ratio of iron to rice dropped from 632:100 to 177:100 (Hartwell, 1966, p. 33). Examples of Chinese productivity–enhancing innovation include the use of water–wheel powered bellows in smelting operations as early as 31 CE and in Sung China and the eleventh–century substitution of coke for charcoal as wood became scarce. This prefigures the same dynamics starting in sixteenth–century England although Alexander Darby did not discover coke use in England until the early eighteenth century. Sung China also prefigured England with major technical advances in silk production (Hobson, 2004, p. 53).

The uses for iron output included armaments produced in government–owned armories and private Kaifeng manufacturers producing for market. The iron demand market appears well–integrated based on records of transportation costs for iron that vary by distance from the production site as one would expect in an integrated market (Hartwell, 1966, p. 37).

There is an increasing contrast in the scale of the large iron–works surrounding Kaifeng and the many traditional small smelting operations that co–existed and were likely spread throughout China. Mining and smelting in the large operations are "full–time occupations of wage laborers employed by ironmasters who owned the ore deposits and smelting plant and who provided

the requisite operation capital. ... By the last quarter of the eleventh century , over 3,600 full–time, free, wage–earning workers were engaged ... at the thirty–six complex and costly mining and metallurgical establishments." (Hartwell, 1966, p. 45). Wealthy families funded these large operations; at some point they likely made the transition from wealthy landed gentry to industrialists—industrial capitalists—to meet the swelling demand for iron output.

Yoshinoba Shiba writes of many wage–paying occupations in the Sung dynasty that arose along with the growth of urban areas. His examples beyond agriculture include smithies, water–mills, threshing yards, rice–cake shops, oil shops, tea plantations, orchards, fish–rearing pools, building, transport and communications, and the handling of cargo (Shiba, 1970, p. 209).

These stories expose two hallmarks of capitalism—wage labor and capital–intensive profit–oriented production for exchange. Hartwell draws many comparisons between the Sung and eighteenth–century England in these respects—capitalism seems to have common seeds across space and time.

The controversy of whether the economic successes of the Sung era spread across China in later eras continues. One group claims a decline in living standards after the Sung period of intensive growth. Another claims that the Sung successes did indeed spread but modern economic growth stalled (Tim Wright, 2007, p. 406). Mark Elvin's "high level equilibrium trap" describes this second view (Elvin, 1973, p. 285). Are there possible economic hints about what happened?

Recall that Hartwell's data shows very low population growth during the Sung era. Refer to Table 2. If output is growing ahead of population growth rates it is likely that wages must be increasing. Using the theory of industrial revolutions logic this would account for productivity–enhancing investments during the Sung—substituting cheap non–muscle power for expensive labor power. Refer to Appendix 3. In the next section we will see that population growth exploded

in later eras but productivity and wages likely stagnated and even decreased. This is a clue then as to why Sung China's incipient industrial revolution stalled—not enough expensive labor pressure to drive productivity innovation and investment.

3.1.2 Ming dynasty: 1368–1644 CE and Qing dynasty: 1644–1911 CE

Xu Dixin and Wu Chengming edited a major work of Chinese history: Chinese Capitalism, 1522–1840; this was translated to English in 2000. Notably the work was commissioned by Premier Zhou Enlai to produce a history of Chinese capitalism as China was exiting the Mao era of experimentation. The translation of its original title is "The Sprouts of Chinese Capitalism" (Xu and Wu, 2000, p. ix). Its methodology is rigorously Marxist—seeking evidence of capitalist relations of production in various sectors. Evidence includes commercial capital investing for profit; integration of markets across regions, the nation, and internationally; industrial capitalism with large producers emerging either from small producers or investments by commercial capital; and a propertyless full–time wage labor force employed by capitalists (Xu and Wu, 2000, p. xv).

The analysis is meticulous. Within the boundaries of the scholarly debate over the course of the early–modern Chinese economy, this work is "situated at the cautious end of this spectrum" but mostly rejects the idea of a major decline in overall living standards. This contrasts with the conclusion of Chris Bramall and Peter Nolan in the introduction that surveys recent scholarship.

Their view is that "It is now abundantly clear that there was a long, sustained phase of economic development interrupted only in the mid–seventeenth century (Xu and Wu, 2000, p. xxiii). In coming to this conclusion they cite Mark Elvin (Elvin, 1973), W. T. Rowe (Rowe, 1986), and Li Bozhong (Li, 1986). Li in particular takes a more positive view on the advance of embryonic capitalism in the early modern period. In fact his approach of focusing on the most advanced

economic areas including the lower Yangzi region—the same comparison that Kenneth Pomeranz and other "California School" historians make (Xu and Wu, 2000, p. xxvii).

In his conclusion Fang Xing summarizes the findings on embryonic capitalism. First, there clearly was embryonic capitalism that paved the way for the modern capitalism since the new industries are founded on old industries that incorporated elements of capitalism. Among these elements are creating social conditions for employment of labor by capitalists—there is a ready supply of skilled workers available for hire for example in the tea and textile industries suggesting elements of a market for labor; long–distance trade exists in the products of Ming and Qing industries where capitalist relations appear; and early capitalist elements in several industries provide a physcial and capital base for modern industry—these include calendering, tobacco processing, printing and book production, and shipping (Xu and Wu, 2000, pp. 424–427).

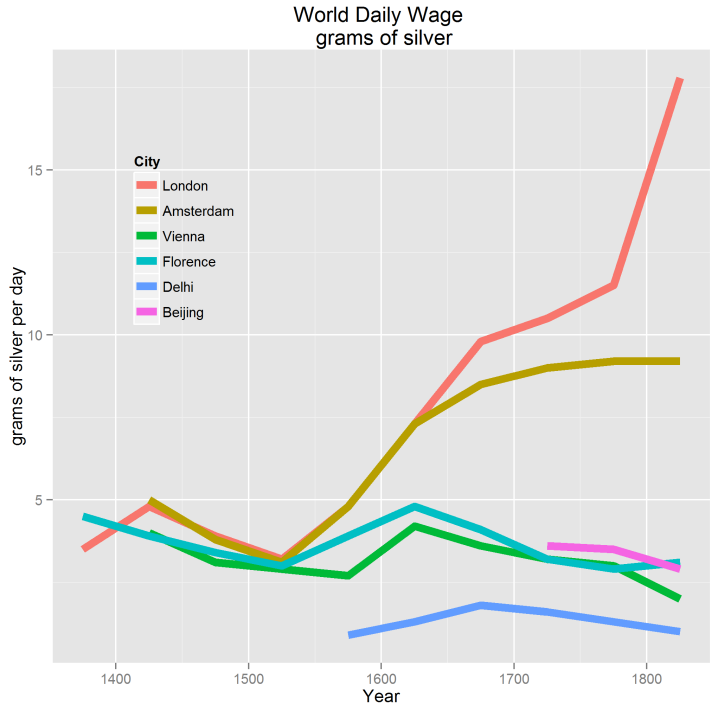
These are markers of capitalism—labor markets populated by wage–laborers, integrated long–distance markets, and innovation and investment in physical capital. But for more evidence that can provide hints about why pre–modern China did not participate in the level of growth after 1800 that England did we can turn to Robert Allen.

First, Allen provides data indicating that integrated Chinese labor markets existed at the beginning of the nineteenth century. This is presented as a table of daily nominal wages for the same occupations and skill levels across many prefectures (Allen et al., 2007, p. 46). One can see essentially the same level wages, an indicator of an integrated labor market.

Kenneth Poemeranz comes to similar conclusions finding that the use of labor in China around the eighteenth century conformed to principles of a market economy (wage labor and market integration) at least as well as in Europe (Pomeranz, 2001, p. 70). While these are revisionist scholars, they do provide convincing evidence of wage–labor markets in China.

But it is the level of the wages that provides a major clue on the apparent very slow upward trend in early modern Chinese growth. Figure 2 shows that real wages in Beijing were low by world standards and declining.

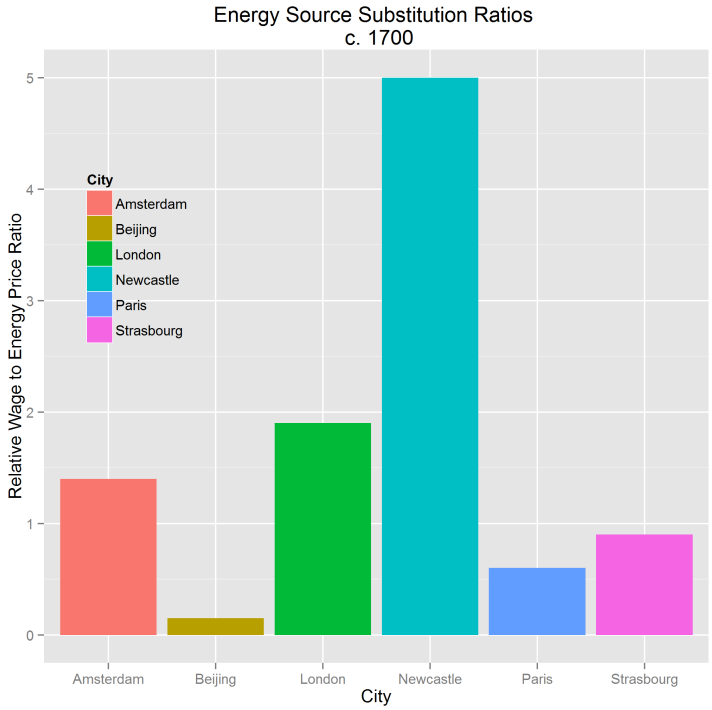
Figure 2: World wages, 1375–1825 CE. *Source:* Allen (Allen, 2009)



When combined with relatively high energy costs in China and presented in Figure 3 note that the ratio of real wages–to–energy costs was very low in China especially compared to England.

In the terms of the theory presented in Appendix 6 Chinese inventors had very low economic incentives to invent, innovate, and commercialize productivity–increasing investments as long as wages were so low compared to the energy costs that were needed to power them.

Figure 3: Real wage–to–energy price ratios
Source: Robert Allen (Allen, 2009)



4 Conclusion

This paper presents evidence that the rise of industrial capitalism can be explained by basic economic principles: demand and supply; profit–seeking by entrepreneurs; and input substitution in production based on relative input prices.

Demand as an economic principle dominates the story. The seldom interrupted rise in global population since 1 CE is mirrored in national population growth rates in England and China. Even in millennia characterized by subsistence–level–living standards this provides increasing potential market size that often pushes against perpetual supply constraints—the Malthusian story. One of this paper's claims is that the supply constraints are often energy inputs—either too expensive or simply not enough to supply the required scale.

Secondly demand enters the story in another important way. As inventors and profit–seeking entrepreneurs invest to remove the supply constraints they naturally accumulate capital. Since capital is essentially non–rival meaning it is not consumed in the production process it will—even with a strict assumption of constant capital–to–output ratios—accumulate rapidly in the face of population–growth–driven demand increases. Viewing economic history through this lens suggests that—given population increases and supply constraints—the rise of capitalism in its most productively–efficient form of industrial capitalism—is inevitable.

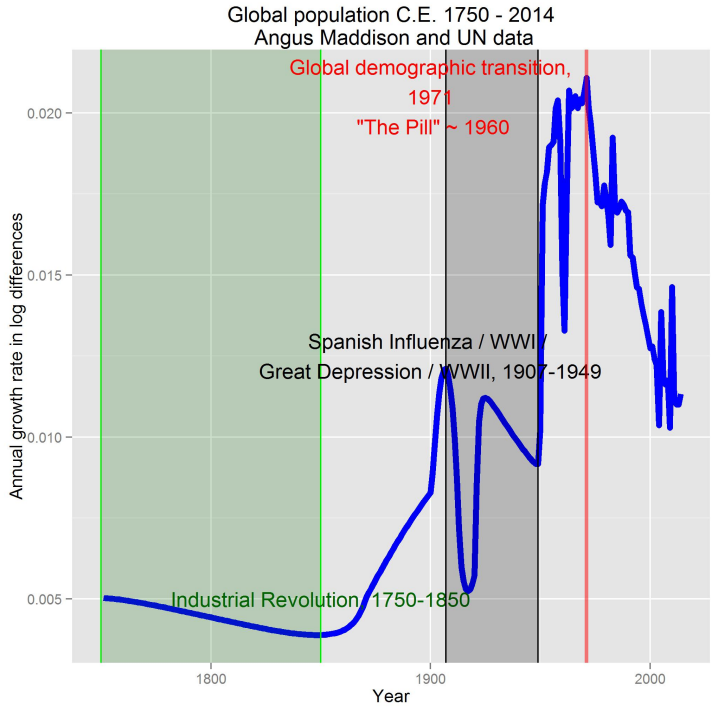
Breaking supply constraints is not a trivial exercise—it took the English several centuries of invention and innovation. To explain the willingness and persistence of inventors, innovators, and entrepreneurs to make the necessary time and treasure investments requires an explanation of incentives. When the price of non–muscle–energy inputs drops sufficiently relative to the price of muscle–energy inputs economic incentives come into play to justify the difficult work of inventing and commercializing the labor–substituting technologies of the English Industrial

Revolution. And a probably inevitable outcome given the levels of physical capital required is industrial capitalism.

China over many centuries longer than England and Europe displayed "sprouts of capitalism." As in England these were driven partly by the investments required for China to overcome deforestation–driven–energy–supply constraints in the first millennium in the face of increasing population and aggregate demand. In a strong contrast with England, equally–capable Chinese inventors, innovators, and profit–seeking entrepreneurs face relatively high energy costs and low wages. And while China likely continues to slowly grow in living standards through the second millennium, once cumulative English advances began to pay off in the early nineteenth century China simply does not have enough gathering momentum to prevent the "Great Divergence" that we call the English Industrial Revolution and the rise of industrial capitalism.

Given an understanding of the rise of industrial capitalism as an institutional phenomenon primarily caused by a centuries–long population–driven increase in aggregate demand, what happens next? Referring to Figure 4 we note that since about 1970 the growth rate of global GDP has been moderating and it appears possible it will approach zero sometime in the middle of the twenty–first century. When that happens the aggregate–demand engine that drove industrial capitalism will start grinding to a halt. It is unknown if that will be enough to damage the institution, but for the first time since the dawning of the age of industrial capitalism its fundamental driver will start to disappear.

Figure 4: Angus Maddison and UN: log differences of global population



5 Appendix - Imperial Chinese Dynasties

Table 3: Chinese Imperial Dynasties

Empire	Historical Era
Qin Dynasty	221–206 BC
Han Dynasty	202 BC–AD 220
Wei and Jin Period	AD 265–420
Wu Hu Period	AD 304–439
Southern and Northern Dynasties	AD 420–589
Sui Dynasty	AD 589–618
Tang Dynasty	AD 618–907
Five Dynasties and Ten Kingdoms	AD 907–960
Sung, Liao, Jin, and Western Xia Dynasties	AD 960–1234
Yuan Dynasty	AD 1271–1368
Ming Dynasty	AD 1368–1644
Qing Dynasty	AD 1644–1911

6 Technical Appendix

6.1 Importance of energy for growth and development

Table 4: Energy/GDP correlations – the case for energy revolutions

Period	Pearson Correlation Coefficient: energy and GDP
England 1300-1873	0.998
World 1980-2008	0.993

6.2 Cross-country history of energy consumption

Table 5: Per-Capita Primary Energy Consumption, annual Tonnes of Oil Equivalent. *Source:* Angus Maddison, [a]de Zeeuw, [b]US DOE EIA

Year	England	China	Netherlands	India
1650[a]			0.63	
1820	0.61			
1840[a]			0.33	
1870	2.21			
1970[a]			8.07	0.33
1973		0.48		
1998[b]	6.56	1.18		
2008[b]	5.99	2.56	9.86	

6.3 Theory of industrial revolutions

With the price spread between coal and wood used for such an essential economic input as energy for heating moving dramatically in coal's favor the basic economic mechanism of input–price substitution should work. It does explain the transition. To formalize this we can write:

$$\frac{\text{Marginal Product}_{\text{wood Joule}}}{\text{Price}_{\text{wood Joule}}} \ll \frac{\text{Marginal Product}_{\text{coal Joule}}}{\text{Price}_{\text{coal Joule}}}, \tag{1}$$

or if one prefers a non-neoclassical writing:

$$\frac{\text{Average Product}_{\text{wood Joule}}}{\text{Price}_{\text{wood Joule}}} \ll \frac{\text{Average Product}_{\text{coal Joule}}}{\text{Price}_{\text{coal Joule}}}. \tag{2}$$

Either writing leads to the same theoretical conclusion: assuming no qualitative difference in the two inputs in terms of work being done (a Joule is a Joule) with the data showing the right–hand–side coal ratio being significantly greater than the wood ratio we would expect entrepreneurs to substitute away from wood to coal. This is the first phase of an industrial revolution.

Equation 3 is a variation on production theory that will be familiar to those who remember

their Econ 101. A major topic of mainstream production theory is how entrepreneurs maximize profits given the derived demand curves of the various input choices.

$$\frac{\text{Average Product}_{\text{labor Joule}}}{\text{Price}_{\text{labor Joule}}} \ll \frac{\text{Average Product}_{\text{steam Joule}}}{\text{Price}_{\text{steam Joule}}} \tag{3}$$

Instead of using different substitutable inputs such as labor and capital we apply the theory to the different sources of energy since that is essentially the only non–substitutable input as in you must have Joules from whatever source to do any economic transformation. If we take the numerators in Equation 3 to be equal abstracting again from the difficulties in invention that were eventually solved then because of the much lower price of English coal–Joules than wages for labor–Joules the relentless (in the face of rising wages) pressure will be for the inventors to invent and the entrepreneurs to commercialize steam–power thus creating the machine age and completing the EIR.

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