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Economic Revolution:
Song China & England

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Abstract: I claim that China during the Song Dynasty (960 – 1279 AD) (Song China hereafter) experienced the onset of an Economic Revolution, preceding England's by nearly a millennium. The concept of Economic Revolution is defined to include two types – one Premodern (non-science based) with a low growth rate of per capita product and one Modern (science-based) with a high growth rate of per capita product. It is argued that the Song China vs. England comparison is more relevant than other comparisons with England. Using both the Song China and England episodes, I introduce a new definition of the "onset of an Economic Revolution" that identifies preliminary social changes. I call this the Embryonic stage and contend that it causes firm formation, household changes and an increase in the pace of technological innovation. I argue the Embryonic stage more clearly identifies and dates the onset of an Economic Revolution. This has important implications for theories of its cause.

* See page 2.

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1. Introduction

Arguably, the most important question in all of the social sciences is: "What caused the onset of Economic Revolution?" Over the past several centuries human societies have undergone a transformation unimaginable to their predecessors. Almost every aspect of daily life has been influenced in some way. Scholars have struggled to understand and explain this major turning point in human history. No consensus has yet emerged and social scientists are not in agreement as to the important features of this social process.[1] Without clear identification of its fundamental features, discovery of its cause seems unlikely. This study aims to tackle this part of the problem – namely to more clearly identify some of the fundamental features of the onset of Economic Revolution with the purpose of identifying its cause.

England's Economic Revolution involved accelerated change in many aspects of society, transcending the artificial boundaries of narrowly defined economic dimensions. These include the role of religion in society, the culture of entertainment and women's rights to name a few. Yet the economic aspects seem fundamental to these changes, even if we do not fully understand their relationships to the non-economic aspects. In order to make this problem manageable, economic aspects will be emphasized. I will begin with the quantitative economic aspects.[2] This starting point may seem overly restrictive to some but I would suggest withholding judgment at this point, since this analysis will take us deep into qualitative territory and explore aspects that border non-economic features.[3]

From a quantitative economic perspective, there is somewhat of a consensus that the distinctive features of economic growth are sustained increases in the growth rates of both per capita product and population.[4] These features serve as the starting point of Simon Kuznets' quantitative analysis of long-run economic growth. In a major study of 14 countries over the 1750 – 1950 period, Kuznets identified a set of quantitative regularities and used these features to define what he called "modern

[1] A detailed introduction to this vast literature is far beyond what can be presented here. For an excellent introductory review of the concept of the Industrial Revolution as well as of various views on the topic see Mokyr (1999), pp. 1 – 28.

[2] This approach falls into one of the four schools of thought on the Industrial Revolution that Joel Mokyr calls the "Macroeconomic School" – see Mokyr (1999), pp. 6 – 8.

[3] For instance, the process of "modernization," as studied by sociologists includes urbanization, which will play a central role in some qualitative analysis here – see Kuznets (1973), p. 168.

[4] This is true at least at the national aggregate level. Most notably, Simon Kuznets emphasizes these two quantitative features – see Kuznets (1973), p. 1. The unification of the classical and modern theories of production comes to mind as a recent example of the importance of these quantitative features. See, for example, Hansen and Prescott (2002) and Lucas (2002), Ch. 5. Recently, quantitative growth economists have also begun to analyze the factors leading to the drop in fertility, which is a central component of this transition – see for instance Doepke (2004) and Fernandez-Villaverde (2001).

economic growth."[5] Sustained increases in the growth rates of both per capita product and population played a prominent role in Kuznets' definition of "modern economic growth", but he went beyond them to include structural changes. In this study, the term Economic Revolution is related to Simon Kuznets' definition of "modern economic growth". I do not mean to imply that this definition is superior to all others; it is but one of many. Kuznets' definition of "modern economic growth" is well established and contributed in no small part to his 1971 Nobel Prize.[6] The goal of this study is to produce a new definition for the "*onset* of Economic Revolution." By my definition, *onset* occurs in a country without contact with another country experiencing Economic Revolution. This is in contrast to the *spread* of Economic Revolution which does involve such contact. I argue that comparisons between onset cases are more relevant than onset vs. spread cases. One contribution of this research is to modify Kuznets' definition to more clearly identify the early characteristics of the onset of Economic Revolution, which I call the Embryonic Stage. I suggest that judgments regarding the appropriateness of definitions focus on the resulting definition of the "*onset* of Economic Revolution" produced here rather than the initial reliance on Kuznets' "modern economic growth."

A brief comment here regarding my use of the term "Economic Revolution" as opposed to the traditional term "Industrial Revolution" will be helpful.[7] I shall discuss the terms "Economic" and "Revolution" in turn. When one considers the case of China during the Song Dynasty (960 – 1279) (Song China hereafter) it becomes apparent that the role of heavy industry, unlike the case of England (1750 – 1850), did not play as important a role. This is not to say that the iron industry did not undergo unprecedented changes in Song China – iron output per capita tripled in the 11th century, innovations in iron production took place and the Chinese made the switch to coal and even coke as fuel sources. Nonetheless, the influence of these developments, which were largely concentrated in northeast China, were naturally limited in a country with a population of 100 million people spread out over one million square miles. Closely associated with industry, in the case of England (1750 – 1850), were mechanized factories. Although some mechanized factory production appeared in Song China it did not take root as it did in England (1750 – 1850). The analysis in this study focuses on the comparison between England (1750 – 1850) and Song China. These observations indicate that dramatic growth in the iron industry and widespread

[5] See Kuznets (1966), p. 1. Note of the original 16 countries, Kuznets only performs comparative analysis on 14 countries. The reasons for excluding two countries will be discussed in what follows.

[6] Kuznets' 1971 Nobel Prize citation reads: … awarded to Simon Kuznets "*for his empirically founded interpretation of economic growth which has led to new and deepened insight into the economic and social structure and process of development*."

[7] Thomas S. Ashton has traditionally dated the "Industrial Revolution" to the period 1760 – 1830. See Ashton (1948).

mechanized factory production are *particular* to the case of England (1750 – 1850) and *not common* features of the onset of economic growth, or increases in the growth rates of both per capita product and population. We are only interested in identifying commonalities in onset cases. An objective, logical analysis compels one to reduce the importance of industry (especially iron) and mechanized factory production in determining common features of the onset cases, despite the current dominant view to the contrary. Jan de Vries and Ad Van der Woude have forcefully argued that the Netherlands experienced modern economic growth before England during the 16th and 17th centuries. It is now very well established that widespread factory-based industry did not appear in the Netherlands until the late 19th century.[8] To the extent that the Netherlands presents an additional case of the onset of Economic Revolution, industry and mechanized factory production are further minimized in a disciplined comparative analysis of onset cases. Despite the traditionally established view of the prominent role of industry and its associated mechanized factory production in economic growth, the facts contradict this view ***in onset cases*** and therefore the prominence of industrial and mechanized factory production will be overturned as scholars begin to carefully analyze onset cases, at least in my view. The history of science shows that in the long run objective scientific analysis overturns popular views based on limited data. A lack of knowledge of Song China is no defense of the traditional view. A richer understanding of the onset of Economic Revolution must integrate a working knowledge of Song China and its relation to England's case. No sound theory of the onset of Economic Revolution can ignore a three century episode of a fifth of humanity – period. The Song China episode, and likely that of the Netherlands, clearly require us to de-emphasize of the role of heavy industry and mechanized factory production in the onset of Economic Revolution. For these reasons, I shift the emphasis away from industry and towards economic aspects by my use of the term "Economic".

It is important to note that this view does not deny that in the case of both England (1750 – 1850) and Song China, that there were unprecedented and widespread changes in the organization of production and a shift in production *toward* industry. Regarding the role of factory production in the case of England, Franklin Mendels and Maxine Berg have made a compelling case that many unprecedented, widespread changes in the organization of production in England took place in the 17th and 18th centuries, well before the appearance of factory production and developments in the cotton industry. Mendels indentified the process of proto-industrialization, which laid the foundation for subsequent industrialization – in

[8] See Vries and Woude (1997), pp. 711 – 12.

the case of England.[9] These changes emphasized by Mendels, Berg and others include the development of mass-produced goods, the appearance of rural industry, increased division of labor in production, the appearance of organizational managers and the regional concentration of industries.[10] The fact that we see similar unprecedented, widespread changes taking place in China during the late 8th through 10th centuries compels one to date the primordial beginnings of the onset of Economic Revolution *before* the dramatic developments in heavy industries, such as iron. In Berg's influential book, *The Age of Manufactures, 1700 - 1820*, she states: "This is also a book about the process of restructuring and transformation of production, a process which was spread over a longer period and a broader range of manufacture than once thought." She goes on to suggest, correctly so in my view, "that we look on the Industrial Revolution as a more complex, many-sided and long-term phenomenon than economic historians have recently assumed."[11] Indeed the shift toward specialized production and its associated changes in the organization of production are undeniably at work in both the cases of England (1750 – 1850) and Song China.

Regarding the term "Revolution", due to contributions by Nicholas Crafts and others, we now know that England's growth in per capita product was much more gradual than previously thought. Walt Rostow's sudden "take-off" has effectively been discredited.[12] Yet the term "Revolution" can only be given meaning with reference to a time frame. If one considers several decades or even a century, the early stage of England's economic growth appears quite modest. I take a much longer time frame for reference – on the order of a millennium or two. From this perspective, per capita product of England appears as a sudden and dramatic increase.[13] For these reasons, I contend the term "Economic Revolution" more accurately describes the phenomenon we are studying, as opposed to the traditional term "Industrial Revolution".

The comparison between Song China and England (1750 – 1850) underscores two arguments put forth by a generation of scholars. First, a group of scholars including Maxine Berg, Eric L. Jones, Franklin Mendels and others have argued that the so-called "Industrial Revolution" does not owe its origins to technological

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[9] See Mendels (1972).

[10] See Berg (1994), pp. 7 – 9, 66 – 72; Szostak (1991), pp. 3 – 13. See also Berg (1991, 1999), and Berg et al. (1983); Jones (1968) and (2010), especially pp. 193 – 214; Kriedte et al. (1981); Mendels (1972), Vries and Woude (1997) and Westerfield (1968).

[11] See Berg (1994), pp. 7, 9.

[12] See Rostow (1971).

[13] I agree with Maxine Berg, who "challenges the attachment of older generations of economic historians to the years after 1780, to the factory and to the cotton industry." But she also "challenges the current and now orthodox preference for gradual and continuous change over the discontinuity associated with the Industrial Revolution. That discontinuity was less short and sharp than once thought, but it was nevertheless a transformation, and one in which changes in manufacturing played a prominent part." See Berg (1994), p. 8.

innovations in cotton, iron or coal but rather to unprecedented changes preceding these innovations.[14] Second, a group of economists point to the mounting evidence that England was not the first episode of economic growth – i.e. unprecedented increases in the growth rates of *both* per capita product and population. Other probable cases predating England's episode include the Netherlands, Song China and Tokugawa Japan. These scholars include Kent Deng, Jack Goldstone, Eric L. Jones, Morgan Kelly, Angus Maddison, Stephen L. Parente, Edward C. Prescott, and Jan de Vries among others.[15] I argue that both cases, Song China and England (1750 – 1850), were preceded by essentially the same changes, which I collectively call the Embryonic Stage, laying the foundation for subsequent Economic Revolution. This observation dramatically alters the landscape of debate on the origins of the *onset* of Economic Revolution through the power of comparison, at least in my view.

Kuznets' research in his 1966 book, *Modern Economic Growth*, serves as a point of departure for my analysis.[16] I expand Kuznets' comparative analysis of "modern economic growth" to include an additional economic episode, that of China during the Song Dynasty (960 – 1279 AD).[17] Kuznets strongly encouraged extensions of his comparative analysis and made specific suggestions, particularly with regard to

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[14] Berg (1991, 1994, 1999); Berg et al. (1983); Jones (1968, 2010); Jones (2000), pp. xxxiv – xxxv; Kriedte et al. (1981); Mendels (1972); Szostak (1991), pp. 3 – 13; and Vries and Woude (1997), as well as the much underappreciated work Westerfield (1968). The unprecedented changes preceding technical innovations in the cotton and iron industries include changes in the organization of production. Note that new organizations of production can be technically considered new "production technologies". I have in mind here other production technologies such as Hargreaves' spinning jenny, Arkwright's water frame, Darby's coke fueled blast furnaces, Watt's steam engine and other such production technologies – not new organizations of production with existing production technologies.

[15] See Deng (2013); Goldstone (2002); Jones (2000), pp. xxxv – xli, 35 – 8, 73 – 84, 149 – 67; Kelly (1997); Maddison (2007), Tables A1 and A7, pp. 376, 382; Parente and Prescott (2000), pp. 17 – 8; Vries (2001) and Vries and Woude (1997). It should be noted that even modern growth theorists have begun to study early episodes of economic growth. For instance Acemoglu and Zilibotti (1997) study the economic growth of 14th century Florence, 16th century Genoa and 18th century Amsterdam, Desmet and Parente (2012) consider English developments predating industrialization and in an extremely stimulating article Kelly (1997) considers the onset of economic growth in Song China. There are two important themes common to these three economic growth studies (i.e. Acemoglu and Zilibotti (1997), Desmet and Parente (2012) and Kelly (1997)). First, market expansion is a major driving force in increases in per capita product in their models. Second, growth does not occur because of technological externalities. Regarding England, previously there was a bias against addressing and integrating evidence that challenged the traditional view of England – see Lyons et al. (2008), pp. 279 – 82. The stage is now set for a detailed comparison between Song China and England (1750 – 1850) to firmly establish the traditional view that economic growth first occurred in England is untenable. It is extremely important emphasize that this fact does not diminish England's dominant impact on the world relative to previous cases. The unique impact of England's episode needs neither introduction nor defense. Yet this must not distract us from the goal of our research – to discover the *cause* of economic growth. Generations of scholars have focused only on England and have generated no consensus as to its cause. Comparisons with previous cases of economic growth offer a powerful opportunity to discover commonalities that will lead to the cause.

[16] See Kuznets (1966).

[17] Specifically, the analysis in Kuznets (1966), which compares the long-run economic growth of 14 countries, is expanded to include Song China – yet the focus here is on the England vs. Song China comparison.

premodern episodes which he called "indispensable for understanding much of the present". He stated that such extensions must be made even if the available evidence is of relatively low quality. My extension of Kuznets' comparative study to include Song China fits the type of extensions he invited.[18] The eminent world historian William H. McNeill encouraged the comparison between Song China and England with emphasis on non-traditional aspects, noting it is of "prime significance for world history."[19]

I conclude that Song China experienced "modern economic growth" as Kuznets defined the term. The addition of the Song China episode requires a reformulation of Kuznets' "modern economic growth" to include two types – one non-science based with a low growth rate of per capita product and one science based with a high growth rate of per capita product. I use this modification of Kuznets' modern economic growth to define Premodern Economic Revolution as non-science based economic growth, and Modern Economic Revolution as science based economic growth. Precise definitions will be presented later, but here economic growth means increases in the growth rates of both per capita product and population as well as structural shifts. Thus, I introduce two types of Economic Revolution: Premodern Economic Revolution and Modern Economic Revolution.

Finally, I argue the two episodes – Song China and England (1750 – 1850) – are both cases of Premodern Economic Revolutions, which differ from all post mid-19th century cases of Modern Economic Revolution, including England (1850 – 1950). I argue that Premodern and Modern Economic Revolutions have different causes, and thus the Song China and England (1750 – 1850) comparison is most relevant when the goal is to discover the cause. Comparisons of a social process are done in order to distinguish general from particular characteristics. Kuznets concluded that "common characteristics are interrelated because they stem from a common cause."[20] Based on this insight, I compare the Song China and England (1750 – 1850) cases with a focus on early commonalities. My comparison reveals four common phases which precede a Premodern Economic Revolution. I include these four phases in what I define as the Embryonic Stage: 1) urbanization and commercialization of the countryside, 2) improvements in the internal transportation network, 3) regional specialization, and 4) development of markets and supporting organizations such as those providing transportation of goods and related improvements in money and credit. I use my Embryonic Stage to produce a new definition of the "onset of Economic Revolution." I argue this new definition more clearly identifies and dates the onset of Economic Revolution and has important implications for theories of its cause.

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[18] See Kuznets (1966), pp. 23, 31 – 32.
[19] Personal correspondence, May 20, 2010.
[20] See Kuznets (1966), p. 501; and Kuznets (1971), p. 1.

A final comment is in order. Quantitative economists who emphasize the importance of the growth rate of aggregate per capita product tend not to fully appreciate a fact regarding the break from a nearly zero to considerably positive growth rate. As economic growth which is associated with increasing urbanization begins, the vast majority – roughly 90% – of a country's population lives in the countryside. Increases in the wealth of a few extremely large cities can not significantly increase national per capita product. For example, during the 1st century AD, Rome and Alexandria were the two largest cities in the Roman Empire with about 750,000 and 500,000 inhabitants respectively. Yet when compared to the total population of the Roman Empire, which was nearly 50 million, one gets a clear sense of the relative importance of the living standards of rural inhabitants in national per capita product. If we define the urban inhabitants to be those residing in towns of over 10,000 inhabitants we find that the urban population of the Roman Empire in the 1st century AD was less than 10% of the total population, which was similar to that of Western Europe around 1700.[21] Increasing the income of urban inhabitants, which include the majority of a country's officials and elite, will not generate national economic growth. These comments point to the importance of increasing the living standards of the vast population in the countryside. Robert E. Lucas, Jr. has pointed out, correctly so in my opinion, regarding increases in national living standards:

> "*For the first time in history, the living standards of masses of ordinary people have begun to undergo sustained growth. The novelty of the discovery that a human society has this potential for generating sustained improvement in the material aspects of the lives of all of its members, not just of a ruling elite, cannot be overstressed.*"[22]

My Embryonic Stage provides an identifiable mechanism by which we can see the rural masses being brought into the fold of economic growth. As small towns increase in number and develop commercial activities along with improvements in transportation systems and markets, the countryside begins to gear its economy towards specialized production and trade. As these networks of towns, transportation and markets extends throughout the entire *countryside*, national per capita product increases become possible and all classes of society are affected.

The remainder of the paper is organized as follows. Section 2 argues that Song China experienced "modern economic growth" as Kuznets defined the term. In Section 3, Kuznets' concept of modern economic growth is reformulated to include

[21] See Maddison (2007a), pp. 40 – 42.
[22] See Lucas (2002), p. 109.

two types – one premodern (non-science based) and one modern (science based). Section 4 argues that when one's goal is to discover the cause of the onset of Economic Revolution, a comparison between Song China and England is the most likely to make progress. Section 5, based on the Song China and England episodes, presents a new definition of the "onset of Economic Revolution". Section 6 presents a discussion, summary and conclusion.

2. Song China – Kuznets' Modern Economic Growth

In Section 3, I will introduce a definition of Economic Revolution that related to Kuznets' definition of "modern economic growth." China during the Song Dynasty (960 – 1279) (Song China hereafter) plays an important role in the development of my definition. As background information, I will introduce a discussion of Song China before presenting my arguments that Song China experienced "modern economic growth" as Simon Kuznets defined the term. Why this period of economic growth and technological innovation did not continue is not addressed in this study.[23] My focus

[23] Note that there are far more experts of the Song Dynasty in China and Japan than in the West, virtually all of them Marxists of some persuasion. Marxists in China and Japan are more concerned with the periodization system of Karl Marx and related issues. Japanese Marxists observed many decades ago that there does not exist sufficient evidence to produce national product estimates of reliable quality for making comparative tests for Song China – so they never tried in earnest (Aoki (2002), p. 128 and see pp. 127 – 36 for an excellent introduction to Japanese scholarship on Song China since the WWII – in English.). Regarding national product estimates for the Netherlands during the 17th and 18th centuries, Vries and Woude show a healthy determination to produce the best possible estimates combined with the recognition of the limits of the quality and quantity of quantitative evidence (Vries and Woude (1997), pp. 700 – 10). It is noteworthy that, under these circumstances, Vries and Woude appealed to other factors as "more promising general indicators of the overall performance of the economy" – in particular they considered the evidence for inter-city transportation (Vries and Woude (1997), pp. 708 – 10). Those interested in quantifying Song China's economic performance would be wise to learn from these two respected scholars when studying an economy from one thousand years ago. In fact, an excellent similar study of China's water transportation system of the 11th century has recently been produced by William Guanglin Liu – see Liu (2012) as well as his stimulating Ph.D. dissertation Liu (2005). These comments are not intended to say we should give up on producing quantitative estimates. Quite the contrary, we *must* do the best we can with the existing quantitative evidence. An excellent example of recent quantitative analysis for Song China has been produced by Kent Deng – see Deng (2013). But a healthy skepticism of the reliability of estimates for a millennium old economy is in order, as well as consideration of other available indirect indicators of economic performance. Given the relative motivation towards quantification by Western trained scholars, it is not surprising that most of the theories attempting to explain China's long-run economic and technological performance have come from scholars with links to the West, although some historians in China have proposed theories – see for example Ge (2002, 2004, 2008a, 2008b, 2010). Some scholars have proposed answers to the question of why Song China's growth did not continue. A non-exhaustive list is given here. Mark Elvin has proposed his well known "high-level equilibrium trap" as an answer to the question of why Song China's economic growth did not persist into the Ming-Qing period – see Elvin (1973), Part Three and especially pp. 203 – 215, 298 – 315, 318. Eric L. Jones suggests that the withdrawal of Song economic policies during the Ming-Qing period gave rise to organizations that allowed extensive but not intensive economic growth – see Jones (1990). Joel Mokyr argues that the state during the Song encouraged technological innovation and that a change in the

here will be the economic performance of Song China and its beginnings. Before presenting arguments in support of Song China's modern economic growth, it will be useful to provide some background on Song China scholarship, describe Song China's place in the world at that time and present Kuznets' definition of modern economic growth.

Song China Scholarship: Background

The view that Song China experienced fundamental economic and social changes is not new. Research which discovered and initially developed this observation came from Japan and remains largely unknown to many in the West. In the early 20th century in Japan, Naitō Konan (内藤湖南) challenged the then widely held view that the modern period in China began with the arrival of the Westerners and that prior to this China was generally changeless and stagnant. Naitō contended that the modern period in China began with the Song Dynasty (960 – 1279) and that fundamental changes took place in China during the Tang-Song transition.[24] His 1922 article, "A general view of the Tang and Song periods" became the starting point for ensuing debates in Japan about Song China.[25] Subsequent generations of Japanese scholars such as Hino Kaisaburō (日野開三郎), Katō Shigeshi (加藤繁), Miyazaki Ichisada (宮崎市定), Shiba Yoshinobu (斯波義信), Sogabe Shizuo (曽我部靜雄), Sudō Yoshiyuki (周藤吉之) and others spent a lifetime studying Song China.[26] With differences of opinion regarding details, a consensus emerged in Japan as to the important qualitative features of the Tang-Song transition.[27] The traditional view of a

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state's attitude towards technological innovation largely accounts for the lack of technological progress in the Ming-Qing period – see Mokyr (1990), Ch. 9, especially pp. 234 – 238. Stephen L. Parente and Edward C. Prescott conjecture that centralization of political power around the late-14th century lead to an increase in the ability of some groups to block technological innovation – see Parente and Prescott (2002), pp. 17 – 18, 135 – 138. Ronald A. Edwards argues that changes in political institutions around the late-14th century weakened commercial and industrial property rights – see Edwards (2005). Angus Maddison suggests that "mental attitudes" from 1500 onward prevented China from repeating the Song performance during the subsequent imperial period – see Maddison (2007b), pp. 27 – 29.

[24] China's Tang Dynasty (618 – 906) is referred to in what is commonly called the Tang-Song transition. This usage traditionally means the period after the Tang civil war (An-Shi Rebellion, 755 – 763) to the early Song Dynasty, i.e. roughly the period 750 – 1100.

[25] See Naitō (1922). Although this paper became very well known in Japan, this was not the first time these ideas were published – Naitō had published them eight years before in a previous publication. For an extensive treatment of Naitō and his influence in Japan see Fogel (1984).

[26] See Hino (1938a), (1938b), (1939a), (1939b) (1940a), (1940b), (1961), (1967); Katō (1952-1953); Miyazaki (1950), (1953), (1976), (1979); Shiba (1965), (1967), (1968), (1970a), (1970b), (1975), (1982), (1988) and Shiba and Yamane (1967); Sogabe (1958), (1965), (1974); and Sudō (1933), (1950), (1962), (1965), (1969). Note that Yabuuchi Kiyoshi (藪内清) has made numerous contributions to the history of Chinese science, including some significant contributions in Song China.

[27] Richard von Glahn describes two features of agreement among Japanese historians on the Tang-Song transition as follows: (1) the permanent eclipse of an aristocratic class by an autocratic

changeless and stagnant China prior to the arrival of the Westerners has been discarded by Japanese Sinologists.[28] Scholars of Song China have also largely come to a similar consensus in Greater China. Some important contributors on Song China here include Mingsheng Cheng (程民生), Liyan Liu (Nap-yin Lau, 柳立言), Ken-Yao Liang (梁庚堯), William Guanglin Liu (劉光臨), Qi Xia (漆俠) to name a few.[29]

This important literature from Japan and China began to influence Song China historiography in the West in earnest by the 1960s and by the 1970s the stagnation view of Song China had been largely overthrown in the West. Many Song China historians in the West have been influenced by this scholarship of Japan and China and made contributions of their own. Some important Song China contributors in the West include Bettine Birge, Patricia Buckley Ebrey, Mark Elvin, Jacques Gernet, Peter J. Golas, Robert M. Hartwell, Edward A. Kracke, Jr., James T.C. Liu, Winston W. Lo, Brian E. McKnight, Richard von Glahn, Donald B. Wagner and others.[30]

Regarding the consensus among historians on the fundamental changes in China during the Tang-Song transition, perhaps Denis Twitchett, the editor of the Cambridge History of China, stated it best. "It is common ground among all serious historians of China, whatever their political complexion, that the period from about 700 to 1000 was one of profound and radical social change, although interpretations placed upon this social change have been almost as various as the authors who have written about it. To some it marks the transition to a "modern" period of Chinese history; to others, the first stirrings of capitalism and urbanization; and to still others, the transition from a society based upon slavery to a stage of "feudalism.""[31]

Despite this fundamental change of view in historiography of Song China, even some notable comparative historians have missed the new found importance of Song

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imperial state; and (2) the growing importance of the market economy and commercial capital in the creation of wealth and the articulation of power in Chinese society. See von Glahn (2003), pp. 37 – 41.

[28] Whether one chooses to label these features "modern" has become moot. The fact that these major changes took place has become virtually universally accepted in Japan. See Miyakawa (1955), p. 552.

[29] See Cheng (1992), (1997), (2008); Liang (1984), (1997); Liu L. (1990), (1991), (1994), (2000), (2004a), (2004b), (2008a), (2008b) and Liu L. and Huang (2009); Liu G. (2005), (2008), (2009), (2012); Qi (1987 – 1988), (1999), (2001), Qi and Qiao (1994). See also Li (2009); Wang L. (2005).

[30] See Birge (1989), (2002), (2008); Ebrey (1981), (1984a), (1984b), (1986), (1991), (1993), (2008); Elvin (1973), (2004a), (2004b); Gernet (1970), (1995); Golas (1972), (1980), (1988), (1990), (1995), (2012) and Needham (1999); Hartwell (1962), (1963), (1966), (1967a), (1967b), (1982), (1989); Kracke (1953), (1975); Liu J. (1959), Liu and Golas (1969); Lo W. (1972), (1974a), (1974b), (1982), (1987); McKnight (1968), (1971), (1975), (1981), (1992) and Sung (1981); von Glahn (1987), (1996), (2003), (2004), (2010); Wagner (1978), (1979), (1985), (2001a), (2001b), (2001c) and Needham (2008). See also Lo J. (1955); Ma (1971); Smith and von Glahn (2003); Wang G. (1963), (2007); Worthy (1975), (1976). See also Haeger (1975); Ho (1956); Hymes and Schirokauer (1993); Rossabi (1983); Smith (1983); Twitchett (1965), (1966), (1968), (1970), (1973) and Twitchett and Smith (2009). Note that two historians of Chinese science in the West have made some very important contributions – Joseph Needham and Nathan Sivin. Although their work spans all of Chinese history, they have made numerous significant contributions to our understanding of Song China.

[31] See Twitchett (1973), p. 47.

China. For example, writing 25 years after the 1963 publication of his influential book *The Rise of the West*, William H. McNeill indicated that the central failure of this book was his ignorance of Song China and his failure to understand China's world primacy during this era.[32] Among social scientists and most notably economic historians and economists in the West the traditional view of economic stagnation in Song China remains strong.[33] Although the traditional view is widely held throughout academia in the West, the view that Song China experienced the onset of modern economic growth will eventually be the predominant one, in my opinion. Ignorance of data is no defense of a theory. Arguments not supported by data will not stand the test of time in the scientific community. As Western trained economic historians and economists begin to pore over China's economic performance during the Song Dynasty, I predict the traditional view will increasingly be seen as untenable and eventually rejected – just as similar views were rejected in Japan and China.

However, there are signs of change among those in the West who have examined the evidence of Song China. The economic historian Mark Elvin argues that Song China experienced economic revolutions in farming, water transport, money and credit, market structure and urbanization and science and technology. Elvin goes on to describe Song China as a "medieval economic revolution" and points out that it was accompanied by the invention of new techniques of production.[34] Eric L. Jones forcefully argues that England was not the first country in the world to experience economic growth. According to Jones, "As it happens, China under the Song, and probably under the preceding late Tang, dynasty underwent a transformation that included many 'industrial revolution' features. There was enormous monetization and industrialization, presupposing structural change on a scale usually associated with modern growth, and reflected in the swelling of Song cities."[35] More recently, some economic growth experts have come to acknowledge the economic growth of Song China, including Simon Kuznets, Angus Maddison, Stephen L. Parente and Edward C. Prescott.[36]

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[32] McNeill (1991), pp. *xviii – xx*. McNeill states that one major reason for this failure was a lack of literature in Western languages at the time. In particular, he points out work by Robert Hartwell, Yoshinobu Shiba and Mark Elvin as having been published after his book. However, to some extent McNeill revised his view subsequently in his chapter, "The Era of Chinese Prdoinance, 1000 – 1500," see McNeill (1982), pp. 24 – 62.

[33] Recently, there has been an increase in the number of economic historians of China. However, these scholars are almost all experts on the Ming and Qing dynasties, the last two dynasties of China's imperial period. There are extremely few experts of Song China among these younger economic historians of China, at least among those trained in the West. One important exception is Guanglin William Liu (劉光臨).

[34] Elvin (1973), Part Two and p. 203.

[35] See Jones (1988), pp. 35 – 36. Ian Morris argues suggestively of economic growth during Song China and clearly views Song China as more socially developed than the West at that time. See Morris (2010), pp. 376 – 83.

[36] Kuznets states that previous to the late 18th centuries "several" countries experienced increases in

Song China in the World

China is one of the major world civilizations. Like today, China during the Song Dynasty (960 – 1279) constituted about one fifth of the world's population. Song China was the center of the world in the Far East and had some, but limited, contact with Europe, the Arab world, India and other regions. Song China was host to the largest cities in the world with several of one million or more inhabitants.[37] During the Song Dynasty, China was the richest country in the Far East and one of the richest countries of world. At that time China was also the world's leader in science and technology.[38] In this context we can clearly see that Song China's growth experience was not a "growth miracle," where China caught up to the world leader in terms of income or technology.[39]

Extant data is insufficient in quality and quantity to provide us with a reliable picture of the international income disparities a millennium ago. Nonetheless, considering the data is important. One simply must keep in mind that data of this age provides rough estimates and that magnitudes should not to be taken too literally.

One way to compare across countries is to use the wage approach. Here, a country's average per capita wage can be estimated and a per capita subsistence wage

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both per capita product and population. According to Kuznets this is not the unique feature of recent economic growth. Rather the distinctive features of modern economic growth are the "extremely high" rates of increase. He does not specifically mention Song China (see Kuznets (1973), p. 1). The remaining scholars' estimates of Song China per capita GDP growth will be presented in what follows.

[37] See Modelski (2003), pp. 62 – 65. Note that the city of Baghdad appears to have had a larger population than cities in China early in the Song Dynasty. Yet the Chinese cities of Kaifeng, Hangzhou and Beijing all show indications of having one million or more residents – Hangzhou possibly reaching one and a half million.

[38] In my opinion, at the time of the onset of modern economic growth Britain was not the richest country of Western Europe and it enjoyed a smaller advantage in technology over its neighbors relative to Song China. In part, this view is based on arguments of Joel Mokyr. See Mokyr (2009), p. 99. Also see Maddison (2007), p. 382.

[39] This is not to say that other countries did not play a role. International competition among states was clearly at work during the Song Dynasty. Nonetheless, the technological innovativeness of Song China was not driven by an influx of new technologies from abroad or the migration of highly skilled workers or scientists from abroad. Some important technologies were adopted from abroad – early ripening Champa rice from Vietnam is one example. However, the net flow of technology was overwhelmingly from Song China to its neighbors. Paper, printing, gunpowder, tea, porcelain, Buddhist texts and classical Chinese written works, to name a few, all flowed to countries in contact with China where they influenced local ideas and production. Foreign travelers such as Marco Polo in their writings consistently and clearly indicated a high regard for the wealth, sophistication and technology of Song China's cities relative to other countries. There is little evidence of foreign technologies influencing the development of a considerable share of China's economy during this era, nor was demand from abroad a major stimulus in any but a few small sectors. Robert Hartwell estimates that around 1100 China's total trade as a share of GNP was about 1.7%. Here the Chinese largely imported spices and herbs and exported silks, tea, salt and manufactured products. See Hartwell (1989), pp. 453 – 54. The influence on China from foreign trade in terms of goods and ideas was minimal. Furthermore, there was no Chinese colonization or slavery to speak of during the Song Dynasty.

can be constructed. The ratio of the average per capita wage to the per capita subsistence wage provides an approximate measure of the average living standard relative to subsistence. This ratio can be compared across countries to provide an indicator of relative international wage disparities. Here, I use daily wage data from Cheng (2008) and take the average low skilled worker's daily wage to be 90 *wen*. Based on data for daily income support for prisoners, I take 16 *wen* as the daily subsistence wage for one person.[40] This data tells us that around the 12th century, the average low skilled worker in China earned a daily wage over 5 times the daily subsistence wage. Next, let us consider England on the eve of the Industrial Revolution. Here the English population is divided into six groups: landed classes, bourgeoisie, commercial, farmers, workers and the poor. Using data on the worker group Allen (2008) estimates that the average English worker earned an income slightly less than 3 times the subsistence income in the late 17th century.[41] This comparison suggests that the average Chinese low skilled worker's income was more than that of his English counterpart five centuries later. Some view English incomes as slowly growing over the period 1100 to 1700, while others view them as roughly constant. No serious argument has been made that they exhibited a long run decline during this period.[42] This reasoning suggests that in the 12th century the average Chinese low skilled wage was higher than that of England.

Another approach to international comparisons is the aggregate output approach. Data is insufficient to produce reliable GDP estimates for Song China and other countries of this era. Yet, based on various indicators, Angus Maddison has produced estimates for most countries' GDP per capita during the early second millennium. Maddison's estimates for GDP per capita for China and Europe are reported in Table 1 below.[43]

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[40] Using daily wage data on rural low skilled workers provided in Cheng (2008) during late Northern Song (960 – 1127) to mid Southern Song (1127 – 1279), I take 90 *wen* to be the average daily wage for a low skilled worker. Cheng reports that in 1143 the state paid 20 *wen* to support each prisoner at the capital city, Linan. He also reports that the state paid 15 *wen* to support prisoners throughout the country outside of the capital region, where prices were much lower. I take 16 *wen* as a national average daily subsistence wage based on these observations. See Cheng (2008), pp. 559 – 69.

[41] See Allen (2008), pp. 953 – 54; and Lindert and Williamson (1982). Workers are defined to include manufacturing and agricultural laborers, building craftsmen, miners, soldiers, sailors and domestic servants. In addition, the data are annual income figures and not daily wage data. Nonetheless, the comparison with a similar ratio from Song China gives us an idea of the relative wealth of the two countries. Note that the English figures are ultimately based on Gregory King's social table of England in 1688.

[42] The one major deviation to these long-run trends was the period after the arrival of the plague in the mid-13th century in England. During the following century English wages (and most likely incomes) increased considerably, thereafter wages returned to their long-run trend. See Clark (2007), pp. 41 – 42, Figure 3.1.

[43] See Maddison (2007b), Table 1.3, p. 29.

Maddison's Estimates of
Chinese and European
GDP per capita (1990 $)

	960 AD	*1300 AD*
China	450	600
Europe	422	576

Table 2.1

According to Maddison's estimates, China was richer than Europe throughout the Song Dynasty (960 – 1279). His estimates for the remaining countries of the world suggest that throughout the Song Dynasty China had a higher GDP per capita than other countries of the Far East, India and the remaining non-European countries.[44] International income disparities (in terms of per capita GDP) of this era were small relative to those currently observed. Within a major region, richer countries were perhaps twice as wealthy as poorer countries, while in some cases differences across major regions might have been a bit greater. Whether China during the Song Dynasty was *the* world's richest country or not is not important. It was by all accounts clearly the richest country of the Far East and *one* of the richest countries in the world. Song China's growth in per capita GDP can not be reasonably characterized as an economic "growth miracle", where China closed the gap with a much richer country that was in contact with her. A similar situation existed regarding science and technology.

[44] See Maddison (2007a), Table A.7, p. 382. Two caveats must be made regarding Maddison's estimates (and similar estimates by others). First, during the later part of the Song Dynasty (i.e. around the 12th and 13th centuries), it is possible that the northern Italian city-states – then independent political countries – had a higher GDP per capita than that of China. Regarding modern economic growth, if we follow Kuznets' view that the unit of study is the state, one should compare an Italian city-state of this era with China. Modern economic growth, as Kuznets observed it, included sweeping structural changes such as a shift in product and resources employed away from agriculture toward nonagricultural activities. It also included sweeping changes in the distribution of the population between the countryside and the city – the process of urbanization. These phenomena seem to preclude a city-state, which lacks a substantial and populated rural area characterized by these processes. With respect to Kuznets' modern economic growth, the wisdom of comparing a city to a country with a vast landmass and substantial rural population is fragile. City-state economic miracles of the late-20th century, such as Singapore, are certainly episodes of economic growth. But they remain largely outside of Kuznets' framework. Indeed, the countries Kuznets considered all had considerable landmasses and rural populations. Better to give such city-states a distinct classification, which lies beyond the scope of this study. The same can be said about a collection of city-states in a comparison with China. Nonetheless, in the 13th century at least one Italian from Venice – Marco Polo – was impressed with China's cities relative to those of his homeland. Recently, important research in political economy on the late medieval Italian city-states has been produced by Avner Greif – see Greif (1998). Second, the Abbasid Caliphate of Baghdad may have also had a higher GDP per capita in the early Song Dynasty during the waning of the Abbasid empire. See Jones (1988), pp. 66 – 67; and Maddison (2007a), p. 382.

In the centuries preceding and during the Song Dynasty, China was the world leader in science and technology.[45] Joel Mokyr, Joseph Needham and Nathan Sivin, all eminent historians of science and technology, hold this view.[46] Needham contends that during this period the flow of inventions across Eurasia was mostly from China to the West.[47]

During the Song Dynasty Chinese mathematics and astronomy achieved their peak in China's imperial era. While some have suggested that the Chinese lacked the ability to derive logical proofs or geometrically analyze problems prior to the introduction of these techniques by the West, recent research has decisively disproven this view. It is now known that in the 3rd century AD, Chinese mathematicians had derived a proof of the volume of a pyramid and produced a geometric proof of the Pythagorean Theorem. It is a notable achievement that the concept of limit or infinitesimals was used to solve some of these mathematical problems. By the end of the 5th century, a proof of the volume of a sphere had been produced using a concept equivalent to Cavalieri's Principle.[48] Even before the Song Dynasty, Chinese

[45] This claim does not imply that China led the world in every field. Indeed there were examples of another country with a more advanced theory or technique. Nonetheless, we can still make an overall assessment.

[46] Notable historians of science and technology agree that during the period 500 – 1300, China was the world leader in science and technology. Joel Mokyr views China as being the world's technological leader for many centuries, until it was surpassed by the West around 1400. See Mokyr (1990), pp. 31, 40, 44, 209 and 229. Joseph Needham argues that in science and technology China was, with the exception of ancient Greece, much in advance of Europe between the first century BC and 1500 AD. According to Needham, China was *more* efficient than the European West in applying knowledge of Nature to useful purposes during this period. See Needham (1969), pp. ii, 16, 190; and Needham (1981), pp. 3, 11. Based on Needham's work, Mark Elvin views China as "often superior, and only rarely inferior" to western Europe until around 1600 in the fields of mathematics, science and technology. See his introduction to Needham's final volume of *Science and Civilisation in China*, Needham (2004a), p. xxiv. Nathan Sivin argues that China was technologically superior to the West between 500 and 1400. See Sivin (1982), pp. 46 – 47. David S. Landes makes a similar argument. See Landes (2006), pp. 5, 6, 16

[47] See Needham (1969), pp. 15 – 16. See also Mokyr (1990), pp. 31, 40 and 44.

[48] Historians of mathematics and science agree that the commentaries on *The Nine Chapters on the Mathematical Art* (九章算術, Jiu Zhang Suan Shu) contain proofs of mathematical results. This a book completed around the late 1st century AD that lists problems and algorithms to find their solution – without explanation. In subsequent centuries Chinese mathematicians and astronomers produced commentaries that explained and proved the solutions in this book. In the 3rd century AD, Liu Hui (劉徽) produced a major commentary that contained a proof of the volume of a pyramid, a geometric proof of the Pythagorean Theorem as well as other proofs. In the preface to his commentary Liu Hui explained that his methodology was to explain the principles with words and illustrate the argument with diagrams. Liu Hui was the first Chinese mathematician to use the concept of limit to prove a mathematical solution. Although Liu Hui failed to find the solution for the volume of a sphere, Zu Chongzhi (祖沖之) and his son Zu Gengzhi (祖暅之) – also known as Zu Geng (祖暅) – continued his work and by the late 5th century had successfully completed the proof of the volume of a sphere using a principle equivalent to Cavalieri's Principle, named after the Italian mathematician Bonaventura Cavalieri (1598 – 1647). These two also built on Liu Hui's algorithm for calculating pi and produced an approximation of 355/113, which is accurate up to seven decimal places. This was then the world's most accurate estimate for pi and would not be bettered for nine centuries. For more on *The Nine Chapters on the Mathematical Art* and its commentaries see Guo (1995), introduction, pp. 35 – 39 and 112 – 114; Li and Du (1987), pp. 33 – 59; Martzloff (1997), pp. 7 – 8, 13 – 15 and 127 – 136; Qian

mathematicians had clearly shown the capability of producing important logical and geometric results on their own.

China's four great mathematicians of the late Song Dynasty had no equal at that time. China led the world in the solutions to equations. The Chinese discovered an algorithm that solved equations up to the 10th degree. In the 13th century the "Chinese Remainder Theorem" (中國剩餘定理) was solved and its method of solution was completely described. This problem was not independently solved in Europe until the 18th century with the work of Euler and Gauss. Chinese mathematicians proved a more sophisticated version of Newton's interpolation formula, which was used to calculate planetary motions. The so-called "Pascal's Triangle" from 17th century Europe was discovered in China before 1300. The 13th century also witnessed notable developments in China in the field of mathematical series.[49]

Chinese depiction of "Pascal's Theorem" from the 13th century

(1964), pp. 32 – 33; and Shen et al. (1999). For Liu Hui's proof of the volume of a pyramid, geometric proof of the Pythagorean Theorem, methodology and use of limit concept see Guo (1995), pp. 135 – 136; Guo (2010), pp. 178 - 184, 226, 238 – 263, 271 – 297; Li and Du (1987), pp. 65 – 80; Qian (1963), p. 92 and Wagner (1979), (1985). For the contributions of Zu Chongzhi and Zu Gengzhi see Guo (1995), introduction; Guo (2010), pp. 191 – 194, 246 – 247 and 263 – 71; Li and Du (1987), pp. 80 – 87; Martzloff (1997), pp. 14 – 15; Qian (1963), pp. 152 – 168; Qian (1964), pp. 83 – 90; Wagner (1978); Yabuuchi (1963), pp. 115 – 120.

[49] Qin Jiushao (秦九韶), Li Ye (李冶), Yang Hui (楊輝) and Zhu Shijie (朱世傑) all made outstanding contributions to mathematics around the later part of the Song Dynasty. See Libbrecht (1973), pp. 2, 17 – 21; Needham (1969), pp. 16 – 17; Needham (1981), p. 10; and Qu (1996), pp. 15 – 24, 75 – 6, 80, 84, 90 – 1, 255 and 261. For Chinese interpolation formulas see Guo (2010), pp. 300 – 317 and He (2004). However, astronomical predictions of China in the 13th century did not reach the accuracy of those of Ptolemy a millennium before. See Sivin (1982), p. 47. For Figure 1 see Guo (2010), p. 424.

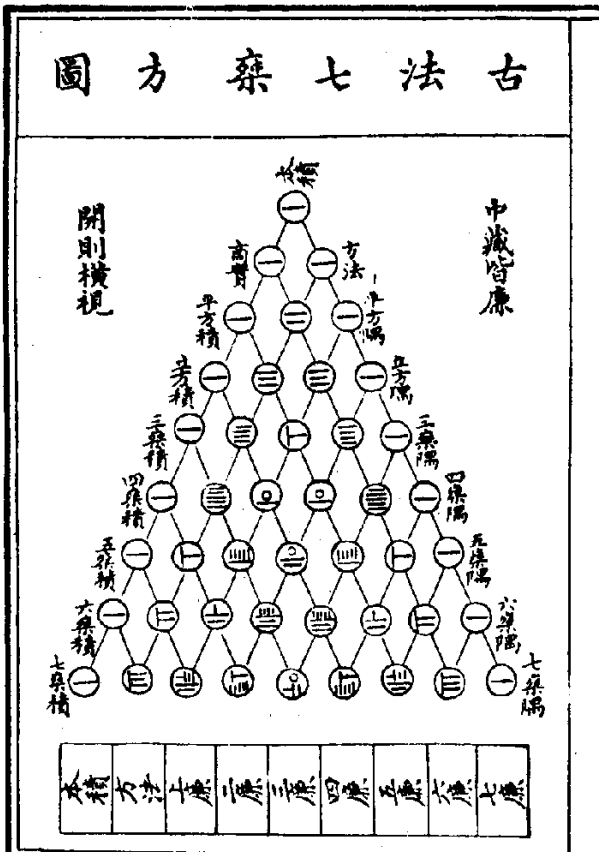

Figure 1

During the Song Dynasty, China was at the forefront of knowledge in many fields of science including acoustics, magnetism, optics, geography and cartography. In engineering, especially hydraulic and civil engineering, China was at the world's technological frontier. In the 11th century they produced a very accurate mechanical clock, powered by water, which also served as an astronomical measuring device.[50]

Drawing of Su Song's water powered mechanical clock/observatory (1088)

[50] Note that the West was relatively advanced in mechanics and dynamics. See Needham (1969), pp. 17 – 20; Needham (1981), pp. 10 – 12, 15 – 22.

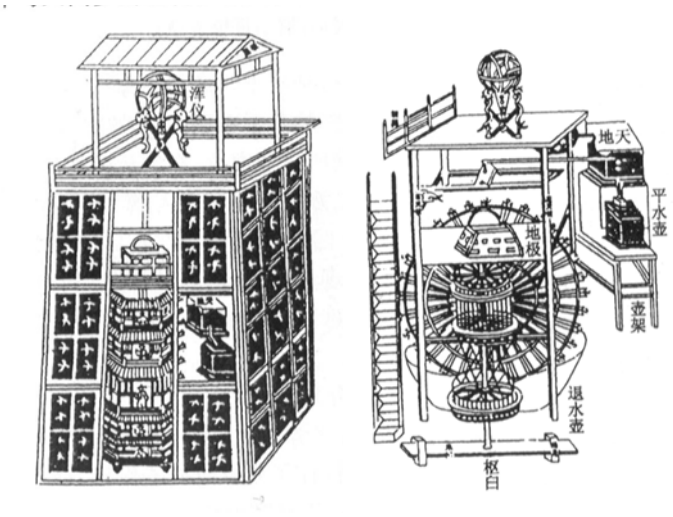

Figure 2

During the Song Dynasty, China led the world in the level of industrial production technology. During this time, China was the world leader in textile technology. The Industrial Revolution in England began in the cotton industry in the mid-18th century. The introduction of James Hargreaves' spinning jenny and Richard Arkwright's application of water power ushered in mass production of cotton. However, by the 13th century China had already been using treadle-operated multiple-spindle spinning wheels and cotton gins. In addition, water power had been applied to big ramie spinning wheels, which had 32 spindles. China was technologically far ahead of Europe in the cotton industry during this time.[51]

In shipbuilding technology China was far ahead of the West by the 11th century. Water-tight compartments had been a common part of bulkhead construction in China since at least the 2nd century AD. By designing the body of a ship so that it had multiple independent water-tight compartments, leaks were limited to flooding one compartment of the ship and spared the ship from sinking. By the 11th century China had devised the balanced rudder, which made steering the ship easier and more efficient. These two important shipping technologies did not appear in the West until the late 18th century.[52] In addition, by the 3rd century AD Chinese ships had multiple masts and mat-and-batten sails, which increased their efficiency in capturing the force of the wind. By 1500, these technologies had still not appeared in the West.[53] The

[51] See Chao (1977), pp. 16 – 18, 56 – 59, 67, 68; Needham (1988), pp. 190 – 98, 215 – 36. In silk-reeling Song China was also technologically superior to pre-19th century Europe – see Needham (1988), p. 428.

[52] See Needham (1971), pp. 420 – 22, 695, 697. It has been noted that Leonardo da Vinci proposed ships to be built with two sides to reduce the danger of flooding. This idea never seems to have been put into practice. Four centuries earlier the Chinese had designed transverse compartments which are superior to a double hulled craft, which is an approximation of da Vinci's idea. See Needham (1971), p. 420.

[53] See Needham (1971), pp. 696 – 697.

Chinese magnetic compass needs no introduction but it should be noted that it was first used around the 10th century, leading its use in the West by several centuries.[54]

Porcelain appeared in northern China around the early 7th century, preceding its appearance in southern China by about three centuries. During the Song Dynasty the considerable expansion of ceramic production throughout China led to an increase in exports of ceramics. Despite the attempts of other countries to imitate Chinese ceramics, including porcelains, China's ceramic production technology remained the most advanced in the world throughout the Song Dynasty and for many centuries thereafter.[55]

Paper was first produced in China in the 2nd century BC, possibly earlier.[56] The period from the 3rd to the 10th century witnessed important improvements in the use of raw materials and paper production techniques in China. These included methods to prevent ink from excessively bleeding on the paper, paper preservation and protection from insects.[57] In the Song Dynasty, bamboo came to be used as a raw material for paper, replacing hemp and rattan. After some production problems involving bamboo were solved in the 12th century, paper quality improved. This coupled with its low cost made the introduction of bamboo paper an important innovation.[58] It is widely held that Chinese paper produced from the 12th to 14th centuries is generally of better quality than that of previous periods.[59] Currently, the broad consensus is that paper production technology spread from China throughout the world. However, it was only after paper was well developed as a writing material in China around the 2nd century

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[54] See Needham (1971), pp. 562 – 563.

[55] Korea was the first imitator to successfully produce white porcelain around the 9th century. By the 15th century, ceramic technology in Vietnam and Thailand matched that of China. Porcelain was not produced in Japan until the 17th century. From the 9th to the 11th centuries Egypt, Iran, Iraq and Syria all unsuccessfully attempted to reproduce Chinese ceramics – most notably porcelain. Although these Middle Eastern attempts failed, they nonetheless stimulated local innovation in new ceramic production techniques. In the English speaking world the fact that the word "porcelain" is often synonymously used with the term "china," is testament to the influence of Chinese porcelain. The Arabic word for porcelain, "faghfuri", also means "China." By the 16th century Turkey had also attempted to imitate Chinese ceramics. Not until the early 18th century did European production of porcelain began in Saxony. See Needham (2004b), pp. 29, 146 – 147, 214, 281, 709 – 710, 732 – 736, and 739.

[56] Archaeological evidence decisively proves that paper with written Chinese characters and maps existed in the 2nd century BC. See Pan (1998), pp. 49 – 57; Tsien (2004), pp. 145 – 147; Wang (2006), pp. 39 – 83. Furthermore, the Chinese word for paper, "*zhi* (紙)," has been discovered on bamboo tablets dated to 217 BC as well as on a wooden statue dated to the 3rd century BC. These discoveries suggest that although physical proof is lacking, paper well may have existed in China in the 3rd century BC. See Tsien (2004), pp. 147 – 148. In 105 AD, Cai Lun (蔡倫), who is the "traditional" founder of paper, made important *improvements* to paper production. Previously cloth and fishing nets had been used to make paper. Cai Lun discovered that certain abundant, low cost, fresh plants could be used as raw materials in paper production. His significant contribution was therefore not the discovery of paper, but the shift in raw materials used from rags to plants. See Pan (1998), pp. 83 – 88; Tsien (2004), pp. 148 – 150.

[57] See Needham (1985), pp. 42 – 43, 73 – 84; Pan (1998), pp. 103 – 106, 113, 121 – 134; Wang (2006), pp. 141 – 148.

[58] See Needham (1985), pp. 59 – 61; Shiba (1968), pp. 245 – 249; Wang (2006), pp. 261 – 164.

[59] See Pan (1998), pp. 202 – 204.

AD that it began its very slow worldwide dissemination. This gave China a major technological head start in paper production.[60]

Paper production in Korea began around the 6th century and in Japan about a century later. The Arab world began paper production in the middle of the 8th century. India began paper production around the 11th or 12th century. Paper production spread from the Arab world to Europe arriving in the 12th century. Not until the 16th century did it appear in America. In short, it took over one and a half millennia for paper production to spread from China to the rest of the world.[61]

The quality of China's paper was superior to that of other countries. The Koreans largely imported Chinese paper production technology in the 6th century, while in the 7th century Japanese paper was of lesser quality than that of contemporary China. As late as the 17th century Jesuits visiting China reported that the quality of Chinese paper was not bettered by that of anywhere else in the world.[62]

In summary, China had a head start in paper production with its appearance around the 2nd century BC. Over the following several centuries, improvements were made to paper. Around the 2nd century AD Chinese paper production techniques began to spread to other countries. While Chinese paper technology slowly spread abroad, the 3rd century to the 10th century in China witnessed many important improvements in paper technology and production techniques. During the Song Dynasty and the several centuries leading up to it, China's was the world leader in paper production technology. A similar situation existed for printing technology.

Woodblock printing appeared in China around the early 8th century.[63] In the mid-11th century, moveable type printing was discovered in China by an engraver, Bi Sheng (畢昇).[64] Multi-colored woodblock printing appeared around the early 12th

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[60] See Needham (1985), pp. 1 – 3, 296, 303, 319.

[61] A general pattern is evident in the spread of paper and paper production. There was a lag of one or two centuries between the first importations of paper from abroad and local production. See Needham (1985), pp. 1 – 3, 296, 303, 319 – 320, 331, 357; Pan (1998), pp. 577 – 588; Wang (2006), pp. 390 – 393.

[62] See Needham (1985), pp. 294 – 295, 320, 331.

[63] The earliest extant printed material known is a scroll dated to the period 704 – 751. This scroll was discovered in Korea in 1966, but was very likely produced in China. See Needham (1986), pp. 149 – 151, 322. There is also indirect evidence that suggests that printing began in China in the 7th century, but the foundation for such claims is less secure than that supporting an 8th century beginning. See Needham (1985), pp. 146 – 149. A strong argument has been made that during the reign of Empress Wu Zetian (武則天) (684 – 704) conditions and incentives were strongly conducive to the introduction of woodblock printing in the Tang court. See Pan (1998), pp. 342 – 346. It should be noted that the basic concept of using a collection of objects with reverse-carved Chinese characters to imprint a passage on non-paper material has a tradition that extends over two millennia before the Song Dynasty. Many extant bronze vessels from the Shang Dynasty (商朝 ca. 1500 – 1100 BC) clearly attest to this.

[64] See Needham (1985), pp. 201 – 203; Pan (1998), pp. 303 – 308; Pan (2001), p. 17. It should be noted that moveable type printing in Chinese has a particular characteristic. Its use is only economical for very large one-time printing runs. For smaller and repeated printing runs, woodblock printing was superior. The fact that moveable type printing appeared for the first time in the mid-11th century suggests that there was a change in the nature of demand. From about 700 to 1000 woodblock printing

century.[65] Its applications included the printing of emphasized text, book illustrations and paper money. It was during the Song Dynasty that Chinese printing became fully developed. This was China's golden age of book printing. Subsequent dynasties emulated books printed in the Song Dynasty.[66] Unlike paper, it appears likely that printing was independently discovered in the West, and in other countries.[67]

Initially, Chinese printing spread regionally within the Far East. In Japan, printing first appeared around the late 8th century, but of poor quality. The first known printings of complete books in Japan appeared around the 10th century. In Korea, printing began around the 11th century.[68] Printing appeared in Persia around the late 13th century and in Europe around the late 14th century. Not until the mid-15th century, when Johann Gutenberg's moveable type printing was invented, did printing have a notable impact in Europe.[69]

During the Song Dynasty and several centuries preceding it, China led the world in paper and printing technology. In the case of the West, China's technological superiority was particularly pronounced. China led the West in paper production by

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served the needs of the imperial court (the largest organized consumer) for printed books. The appearance of moveable type printing was likely induced by an increase in short term demand. If demand for printed books began to penetrate into social classes beyond officials and the wealthy, this could stimulate such an increase in demand for books. One can point out that China's population during the Song Dynasty roughly doubled, but the discovery of moveable type printing has been dated to around 1040. At this time China's population had only increased by a third to a half. Doubtless there had been large fluctuations in the imperial court's demand for new printings over the three previous centuries. A doubling or tripling of previous levels of new printings was probably not a rare event during these three centuries. It therefore seems unlikely that population growth caused the demand increase that led to the moveable type innovation. In my view, the main cause for the increased demand of printed books was the appearance of new consumers who were outside of the previous privileged groups.

[65] See Needham (1985), pp. 277 – 280. In China multi-colored printing of decorations on silk was known by the 2nd century AD. See Whitfield and Farrer (1990), pp. 111 – 112.

[66] See Needham (1985), pp. 1 – 3, 159 – 172; Pan (1998), pp. 202 – 204, 365 – 369; Zhang (1994), pp. 26 – 27, 34 – 37.

[67] The issue of the nature of the development of printing throughout the world remains a controversial topic. Some scholars argue that, similar to paper, printing technology spread throughout the world from China, where it first appeared. The evidence presented for this claim is far less convincing than that supporting the spread of paper. In defense of this view it should be noted that before the appearance of printing in Europe in the late-14th century, printed materials from China had already arrived – e.g. playing cards. Connections between China and the West, most notably during the Mongol unification of much of Eurasia, clearly existed and there were similarities in Western printing to that of the Chinese. See Needham (1985), pp. 3, 303 – 319. In my judgment, the technical differences in printing methods between China and the West outweigh the circumstantial evidence suggesting transmission. This is not to deny that there was some *influence* from China in the appearance of printing in the West. However, I see the innovation of Western printing as largely indigenous.

[68] See Needham (1985), pp. 150, 322 – 327, 336 – 338.

[69] Single sheet prints of illustrations together with text were produced in Europe before moveable type appeared. These sheets were collected together into book format and are called block books. See Mokyr (1990), pp. 48 – 49; Needham (1985), pp. 306, 311, 360. It should be noted that China led the world in the printing and use of paper money, which appeared in China around the early 9th century. During the Song Dynasty and the Yuan Dynasty (1279 – 1368) its use gradually spread and printing techniques improved. In the 13th century European travelers were very interested in and recorded the use of paper money in China. However, it did not appear in the West until the 17th century. See Needham (1985), pp. 96 – 100, 293.

over one millennium, woodblock printing by six centuries and moveable type printing by four centuries.[70]

During the 500 to 1300 period, in many other fields of science and technology China was among world leaders. For example, in knowledge of biological pesticides, China led the West during this period. In addition, owing in no small part to development in paper printing, it was during the period 1000 – 1300 that China experienced a flourishing of botanical writings of all kinds.[71] China's advanced paper/printing technology also provided an advantage in the dissemination of many other ideas across both time and space.

In summary, during the Song Dynasty as well as the centuries preceding it, China was one of the richest countries in the world and was at the same time the world leader in science and technology. According to the eminent economic historian of China, Mark Elvin, Song China was "beyond any reasonable doubt" the most developed economy in the world.[72] The body of evidence is persuasive and many eminent historians of science and technology have firmly arrived at this conclusion. Given Song China's position in the world, any economic growth experienced by China can not be reasonably seen as closing the gap with a much richer country nor can it be viewed as a "growth miracle" driven by technology adoption from abroad. From the point of view of science and technology, whatever happened to China during the Song Dynasty clearly was largely internally generated.

Kuznets' Definition of Modern Economic Growth

Before presenting arguments for the claim that Song China experienced "modern economic growth" as Kuznets defined the term, his definition needs to be provided. Here a brief definition shall be given.[73]

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[70] See Needham (1985), p. 3.
[71] See Needham (1986), pp. 356, 514.
[72] See Shiba (1970b), p. iii.
[73] For the full version see Kuznets (1966), p. 1. Two comments are in order. First, Kuznets tried to separate short-term fluctuations from sustained structural changes in a country's economic performance. Kuznets argued a period of thirty to fifty years was required to reveal the distinction. Accordingly, he required a span of at least fifty years before a change could be identified as long-run or sustained. In particular, he did not intend the term "sustained" to mean the continuation of the change to the present day (Kuznets (1966), pp. 26 – 27, 488). Therefore, since the Song Dynasty covered about three centuries, changes throughout this period were sustained in the sense that Kuznets intended the term to be applied. Second, there is one change of Kuznets' definition of modern economic growth made here that should be mentioned. Kuznets discusses a "sustained increase" in per-capita product and population. One possible meaning of this phrase in the English language is a one shot increase that is sustained as in an impulse function. This is clearly not what Kuznets meant by this phrase. I have therefore made a slight improvement in the definition by discussing a sustained increase in the growth rates of both per-capita product and population. In my opinion, this more clearly expresses Kuznets' intended meaning and rules out one shot permanent increases.

Kuznets' Definition:

> **Modern Economic Growth** – *a sustained increase in the growth rates of both per capita product and population accompanied by sweeping structural changes. These structural changes include: industrialization – changes in the industrial structure where both product and resources employed shift away from agriculture toward nonagricultural activities, urbanization – changes in the population distribution between countryside and cities, variation in economic status – changes in the relative economic position of groups with regard to employment status, industry of attachment and income, variation in the use of product – changes in the composition of household consumption, capital formation and government consumption and changes in the allocation of product by origin.*

Song China and Kuznets' Modern Economic Growth

In what follows, I shall present evidence that Song China experienced unprecedented growth in per capita product and population as well as industrialization, increased agricultural productivity, urbanization and the emergence of a middle class.

- *Per capita product and Population*

Systematic data for prices, quantities or wages for Song China do not exist at present. Therefore, all modern estimates of Song China per capita product growth or per capita GDP growth are estimates based on limited quantitative and qualitative evidence and the experience and judgment of modern growth and development economists who have considerable experience with economic data for countries over the last century or more. Figures for per capita product should not be considered as precise estimates, but rather particular scholars' rough estimates, which contain many assumptions and judgments.

This caveat is far less relevant for population. China's long run population time series is relatively reliable because of periodic censuses throughout China's dynastic history, including some over two millennia ago. This is not to say there are not issues

that raise concerns about the reliability of China's population data. These issues must be addressed and dealt with to derive reasonable estimates. Nonetheless, China's population time series is far more reliable quantitative evidence and relatively much more firmly based on sound evidence than rough estimates for aggregate product or GDP based largely on qualitative evidence. Still, it is important to consider the views of experienced quantitative economists to get a sense of possible magnitudes.

Parente and Prescott consider Song China in their recent study on growth and development. Their estimates for per capita GDP and population are reported below.[74]

Parente and Prescott's
China's GDP per capita
(relative to 1000 AD, with base $400)
and Population (millions)

	950 AD	*1250 AD*
GDP per capita	400	800
Population	50	100

Table 2.2

According to the late Angus Maddison, "it seems likely that there was an increase in per capita income" … and "there was clearly an increase in the pace of population growth" in China during the Song Dynasty.[75] Maddison also provides rough estimates on China's long-run economic performance:[76]

Maddison's estimates of
China's GDP per capita (1990 $)
and Population (millions)

	1 AD	*960 AD*	*1280 AD*
GDP per capita	450	450	600
Population	60	55	100

[74] Parente and Prescott (2000), p. 17, estimate per capita GDP and population roughly double during the 950 – 1250 period. I take a rough estimate of 50 million in 950 for illustrative purposes.
[75] Maddison (2007b), p. 29.
[76] Data is reported from Maddison (2007b), Table 1.3, p. 29 and Table D.1, p. 168. Note that Maddison reports GDP per capita in 1300 AD as $600. I take this as a rough estimate for the year 1280 AD. In the first edition of this publication Maddison reports GDP per capita as $600 for the year 1280 AD. See Maddison (1998), Table 1.3, p. 25.

Table 2.3

While I provide no new estimates, my view is that these scholars have underestimated per capita GDP growth of Song China. To what extent is difficult to ascertain. A major study will be required to provide a range for reasonable estimates of Song China's growth. However, we can say with far more certainty that Song China clearly experienced *unprecedented* population growth, most notably during 11th century. An estimated time series of China's long run population is presented below.[77]

Estimates of China's Total Population

Year (A.D.)	*Population (millions)*
1	50
800	50
1000	55
1100	120
1200	125

Table 2.4

Table 2.4 shows that China's total population, after around eight centuries of more or less zero growth, began to grow after the eighth century and experienced an

[77] My estimates are based on those of Bielenstein (1987, p. 150), Durand (1960, pp. 227-28) and Zhao and Xie (1985, graphs 3-1 and 3-2 in appendix). First, let us consider estimates for the first few centuries of the first millennium. Here I abstract from the short run effects of some first century A.D. major disasters – Yellow River flooding and internal civil war – and estimate a long run trend of about 50 million between 1 A.D. and 800 A.D. This is largely based on Bielenstein (1987, p. 150). Bielenstein hesitates to provide specific estimates around the Song Dynasty, so I make use of Durand's estimates for the years 1000, 1100, and 1200, which are 55, 120 and 125 million respectively (see Durand (1987, pp. 227 – 28)). There is one important point that Maddison (1997, 2007b) appears to have missed. Most of the population gains of the Song Dynasty were realized during the 11th century A.D. Durand (1960, p. 228) comments on this and concludes, "thus a stabilization of population after the rapid growth of the eleventh century is suggested." Bielenstein (1987, p. 154) estimates that China's population reached nearly 100 million by 1086 A.D. and 125 million around 1300 A.D. Zhao and Xie (1985, graphs 3-1 and 3-2 in appendix) estimate over a doubling of population in the eleventh century followed by a heavily flattened small increase in population during the closing century and a half of the Song Dynasty. Maddison (2007b) argues in Figure 1.1, p. 30 that the population gains were spread out evenly over the 1000 to 1300 period. The data is best for the 11th century and clearly indicates the majority of the Song population gain occurred during this century. It is important to note here that China's population during the Song Dynasty appears to be a rough "S" curve. This is consistent with what China's total population should look like if a demographic transition took place during the Song Dynasty. This is argued in detail in Edwards (2012b). In particular, it is argued that death rates dropped in the eleventh century and that birth rates dropped in the twelfth century. To the extent that it can be argued that China experienced a demographic transition in the Song Dynasty, this offers very strong supporting evidence of economic growth during the Song Dynasty.

unprecedented doubling during the eleventh century. Thereafter the growth rate of total population decreased considerably and began to stabilize around the late-twelfth century. Observe that not only did China's total population experience unprecedented growth during Song China, but it appears that the total population growth rate decreased considerably thereafter. It is important to note that this type of "S" curve pattern of total population usually occurs when a country goes through a demographic transition.[78]

- *Industrialization*

Song China experienced unprecedented industrialization and the iron industry played an important role. Robert Hartwell's detailed studies of Song China's iron industry reveals unprecedented growth. Based on tax records, Hartwell has produced production estimates of iron output for Song China.[79]

China's Iron Output Per-Capita and Population

Year	*Iron Output Per-capita (pounds per-capita)*	*Population (millions)*
1	0.22	59.6
806	0.5	54
998	1.2	54
1064	2.9	62
1078	3.1	81

Table 2.5

Table 2.5 indicates during the first eight centuries of the first millennium China's iron output per-capita roughly doubled. Over the next two centuries, it again roughly doubled. However, during the 11th century China's iron output per-capita nearly tripled. This unprecedented industrialization was not due to a decrease in population; indeed, during the 11th century China's population was experiencing

[78] Note that in another paper, Edwards (2011b), I argue that Song China indeed experienced a demographic transition. To the best of my knowledge, this is the first time a scholar has claimed that Song China experienced a demographic transition in the Chinese, Japanese and English literature.

[79] See Hartwell (1966), p. 34 for the figures reported in Tables 2.5 and 2.7. Note that for the year 1 AD, I use the iron estimate made by Donald B. Wagner. See Wagner (2008), p. 237. The 1 AD population figure comes from Maddison (2007a), Table A.1, p. 376. Hartwell's iron output estimates are based on tax records.

unprecedented increases. To better see the changes in growth rates of iron-output per capita, consider the data in terms of growth rates per-century.[80]

China's Growth Rate of
Iron Output Per-Capita

Period	*Per-century growth rate of iron output per-capita (pounds per-capita)*
1 – 800	11%
800 – 1000	55%
1000 – 1100	160%

Table 2.6

Note that in the late Tang Dynasty (618 – 907) there is a considerable increase in the growth rate of iron output per capita. During the 11th century (early Song Dynasty) the growth rate continues to increase to an unprecedented level. It is important to note that although there were wars during China's Song Dynasty (960 – 1279), government demand for iron weapons did not play a significant factor during the 11th century. During the Song Dynasty, China was in competition with several countries including Xi Xia (西夏), the Liao (遼), Jin (金) and the Mongols (蒙古人). Wars were not uncommon. After a major war with the Liao, a peace treaty was signed in January 1005 – the Chanyuan Peace Treaty (澶淵之盟).[81] The following century was a stable period of peace and prosperity for China. In the conflicts of the late 10th century, China built up a stock of weapons. By the early 11th century, the court expected its stockpile of weapons to last at least 20-30 years. Government demand for weapons in the 11th century *declined*.[82] An increase in demand for weapons can not therefore explain the striking growth in the iron industry during the 11th century.

China's 11th century iron output per-capita growth rate is large when compared to Western Europe's iron output per-capita growth rate during the 18th century. Table 2.7 indicates that China's rate of growth in this important sector was about ten times that of Western Europe's in their respective periods.[83]

[80] Here to simplify the presentation across centuries I round off the year 806 to 800, the year 998 to 1000 and lastly 1078 to 1100. The first two round offs do not substantially affect the estimates. The final round off is conservative in that it works to lower the growth rate for the 11th century.
[81] According to the Chinese Lunar calendar, some accounts date this treaty to 1004. See Liu Liyan (2000).
[82] See Wong (1975), p. 21.
[83] See Hartwell (1966), p. 34.

China vs. Western Europe:
Increases in Iron Output Per-Capita

Region	*Century*	*Percentage Increase (during the century)*
China	11th	250 %
Western Europe	18th	26 %

Table 2.7

- *Agricultural productivity*

- *Urbanization*

- *Changes in employment and the distribution of income*

Hereafter, this paper proceeds on the working assumption that Song China experienced "modern economic growth" as Simon Kuznets defined the term.

3. Economic Revolution – Two Types: Premodern and Modern

In this section, I contend that there are two types of modern economic growth – one non-science based and one science based. Kuznets' definition of "modern economic growth" will be used as a point of departure. His comparative study of the economic growth of nations, *Modern Economic Growth: Rate, Structure and Spread* (Kuznets (1966)), will be examined and expanded to include China during the Song Dynasty (960 – 1279) (Song China hereafter). Kuznets' study compared a group of countries over a two century period. My analysis of Kuznets' findings in light of the Song China episode leads to a natural reformulation of Kuznets' concept of "modern economic growth", which includes two types, one non-science based with low growth rates of per capita product and one science based with high growth rates of per capita product. Lastly, I state my definitions of the two types of modern economic growth, based on this reformulation.

Kuznets' Modern Economic Epoch – 2 Distinct Frameworks

As a point of departure, I use Simon Kuznets' definition of the term "modern economic growth".[84] I begin by analyzing his concepts "modern economic growth" and "the scientific epoch" (an economy characterized by the extended application of science to problems of economic production) – his two frameworks. My analysis is innovative in the integration of the Song China episode into Kuznets' multi-country comparative study. Kuznets strongly encouraged extensions of his comparative analysis and made specific suggestions, particularly with regard to premodern episodes which he called "indispensable for understanding much of the present". He stated that such extensions must be made even if the available evidence is of relatively low quality. The extension of Kuznets' comparative study to include Song China fits well into the type of extensions he invited.[85] An extremely important comment must now be made.

Simon Kuznets was interested in studying what many call the "modern period". What this means and the relevance of one's formulation remains a major topic in the social sciences. It must be explicitly stated that – in a general sense – Kuznets called the 1750 – 1950 period the "modern economic epoch". It is rarely recognized that in analyzing this era – namely the "modern economic epoch" – Kuznets actually used two distinct frameworks. At a fundamental level Kuznets identified these two frameworks as one resulting in a unified description of the "modern economic epoch". In order to briefly introduce this aspect of Kuznets' analysis, one need only understand that his definition of "modern economic growth" and that of "the scientific epoch" (an economy characterized by the extended application of science to the problems of economic production) are *distinct* concepts. This will be explained in detail subsequently.

In the postscript to his study of modern economic growth Kuznets stated, "The study summarized in the preceding chapters was designed on one guiding assumption: modern economic growth, once identified, would prove to be a significant, orderly, and distinctive body of long-term economic experience." After explaining the terms significant, orderly and distinctive, Kuznets stated, "The implication that a common source of growth, a common group of typical factors, determined such significantly widespread, systematically related, and distinctive growth trends, led to the concepts of the economic epoch and the epochal innovation, and to the use of the term "modern

[84] For his detailed definition see Kuznets (1966), p. 1.
[85] See Kuznets (1966), pp. 23, 31 – 32.

economic growth" to describe the current epoch of spreading application of science to processes of production and social organization." (underline added)[86] Here Kuznets reveals that from the very beginning of his analysis he assumed these two concepts or frameworks were the same – "modern economic growth" and "the scientific epoch" (an economy characterized by the extended application of science to problems of economic production). Kuznets argued that the most distinctive characteristic of "modern economic growth" was *high* growth rates of per capita product. In his postscript, Kuznets goes on to say, "By identifying modern economic growth with sustained high rates of increase in per capita product we have implicitly stated that such high rates are a common characteristic of modern economic growth."[87] Here, we can clearly see that Kuznets identified his definition of "modern economic growth" along with its *high* growth rates of per capita product with "the scientific epoch" (the application of science to the economy). In effect, Kuznets identified two distinct frameworks as one as a working assumption. In what follows, I shall argue that equating these two frameworks is incorrect – they are distinct frameworks. In particular, I show that a gap between these two frameworks can be detected from the perspective of either framework.

A brief description of Kuznets' two frameworks will be an instructive detour at this stage.[88] The first framework is qualitative – "the scientific epoch", while the second framework is quantitative – "modern economic growth". The distinction between Kuznets' qualitative and quantitative frameworks is emphasized. It is shown that these two frameworks do not coincide – that a gap exists. I analyze the gap from the perspective of both of Kuznets' frameworks – qualitative and quantitative. From the perspective of his qualitative framework, it is shown that a *timing gap* exists. From the perspective of his quantitative framework, it is shown that a *quantitative gap* exists. With the focus of analysis on the framework gap, my comparison of Song China and England leads to a natural reformulation of Kuznets' modern economic growth – resulting in the emergence of two distinct types: one non-science based with a low growth rate of per capita product and one science based with a high growth rate of per capita product. Next, Kuznets' two frameworks will be briefly introduced.

Kuznets' qualitative framework – "the scientific epoch"

Like social and economic historians before him, Kuznets tried to divide human history into useful periods for the purpose of analysis – i.e. to create a periodization system. In formulating his general concepts, Kuznets created a qualitative framework.

[86] See Kuznets (1966), p. 487.
[87] See Kuznets (1966), p. 488.
[88] This rough outline of Kuznets study is based on my reading of Kuznets (1966), pp. 1 – 16.

He called a period an "epoch" and argued that each epoch should have an "epochal innovation" that essentially distinguishes it from those which precede and follow.[89] He was particularly interested in what he called the "modern economic epoch". According to Kuznets, "the epochal innovation that distinguishes the modern economic epoch is the extended application of science to problems of economic production". Kuznets called this epoch "the scientific epoch" (Kuznets (1966), p. 9). Here, Kuznets used his qualitative framework to describe the "modern economic epoch".

Kuznets' definitions of science and science-based technology are given below:[90]

Science: *The study of observable and testable characteristics of the physical world in accordance with the canons of validity accepted by the groups of practitioners called scientists*.

Science-based Technology: *Applied knowledge which rests, in the reliability of its predictions and practices, upon the verified general knowledge in the sciences and upon specific observations on materials, and so on.*

Kuznets suggested that, in general, these concepts do not lend themselves to quantitative measurement.[91] Based on his qualitative observations, he identified the epochal innovation and defined his qualitative framework – "the scientific epoch".

Kuznets' quantitative framework – "modern economic growth"

With this qualitative framework established, Kuznets set out to measure the features of the modern economic epoch and create a quantitative framework. In particular, he performed a multi-country comparison, designed to highlight common quantitative features, using data from a group of countries during the 1750 – 1950 period. Using prices, quantities and other variables he identified important similarities and used them to define the term "modern economic growth".[92] Despite being the synthesis of a quantitative comparison, his specific definition of "modern economic growth" – his quantitative framework – was qualitative in nature. However, its foundation is obviously quantitative and he did clearly state some quantitative

[89] Kuznets argued such an epoch should cover an extended period, well over a century. See Kuznets (1966), p. 2.
[90] See Kuznets (1966), pp. 9 – 10.
[91] See Kuznets (1966), pp. 489 – 90.
[92] See Kuznets (1966), p. 1.

characteristics of this framework. It must be noted that the concepts of science and science-based technology were not used in his definition of "modern economic growth". (See Section 2 – page 25 – for a brief version of Kuznets' definition of modern economic growth.)

The important point is that Kuznets established a qualitative framework, "the scientific epoch", which is characterized by the extended application of science to problems of economic production. He then presented his quantitative framework – his definition of "modern economic growth", which is a synthesis of a quantitative comparison across countries. It is important to note that these two frameworks are based on distinct phenomena – one, the extended application of science to problems of economic production and the other, common patterns observed in economic variables. The issue that immediately arises is the relationship of these two frameworks. There coincidence is virtually perfect with one major exception – England (1750 – 1850). Let us consider the gap from the perspective of both the qualitative and quantitative frameworks, beginning with the former.

The Timing Gap

Kuznets observed that the beginning of modern economic growth as quantitatively measured *did not* coincide with the beginning of the extended application of science to problems of economic production in the English economy. Modern economic growth, as Kuznets measured it, began in England around 1750. However, according to Kuznets, the extended application of science to problems of economic production did not begin in England until about 1850.[93] In all other cases considered in his comparative study, including England (1850 – 1950), modern economic growth as measured began in the mid-19th or early 20th century and it was associated with the extended application of science to problems of economic production. England (1750 – 1850) is the only case for which modern economic

[93] According to Kuznets, the first major science-based technology was James Watt's steam engine, which was patented in 1769. See Kuznets (1966), p. 10. James Watt's improvement in the efficiency of the steam engine was the decisive technological breakthrough that allowed the steam engine to further develop and eventually usher in an "age of steam." Its first commercial application was in 1776, but it was not until 1830 that the first railroad appeared. According to Joel Mokyr, "Much of what steam did before 1830 could have been (and to a large extent was) readily carried out by alternative sources of inanimate power, especially water power." In addition, numerous studies have shown that the impact of the steam engine on the British economy was small before 1830. Only in the mid-nineteenth century did steam power begin to have a noticeable effect and even then it was initially quite modest. Nicolas Crafts estimates that during the 1830 to 1860 period steam accounted for only a little over 10 percent of total TFP growth. See Crafts (2004), pp. 528 – 529; Landes (1969), pp. 102 – 103 and Mokyr (2005), p. 125. See also Landes description of the slow development of the steam engine, Landes (1998), pp. 187 – 89. In short, during the 1750 to 1850 period, science did not experience a widespread application, although there was one major development – the steam engine. It is from the mid-nineteenth century that science begins to play a considerable role in England's economy.

growth began before the mid-19th century. Since this case lacked the extended application of science to problems of economic production, a timing gap of about one century exists between the beginning of his quantitative framework and the beginning of his qualitative framework.

In general, the lag between the early stage of England's Industrial Revolution (as variously conceived by different scholars) and the appearance of the widespread application of science in its economy during the mid-19th century is well documented and firmly established among economic historians and historians of science and technology.[94] For instance, in a major study of the technology of the iron industry Charles K. Hyde states:

> "*The innovations that revolutionized the British iron industry in the eighteenth century were not made by research scientists working in obscure laboratories, but rather by ironmasters attempting to solve particular technical or economic problems. Innovations did not occur independent of the economic structure and business conditions prevailing in the iron industry and in the national economy.*"[95]

Summing up the situation in the profession Joel Mokyr states:

> "*... a wide array of economic historians and historians of science and technology have held that the techniques developed during the British Industrial Revolution were generated by "hard heads and clever fingers" and owed little directly to scientific knowledge as we would define it today. Unlike the technologies that developed in Europe and the United States in the second half of the nineteenth century, science, in this view, had little guidance to offer to the Industrial Revolution*. "[96]

Although Kuznets is not alone in viewing the existence of a timing gap between the beginning of England's modern economic growth and the beginning of the widespread application of science to its economy, I shall focus on the timing gap between his two frameworks as it will prove useful later. Kuznets made very clear his views of the timing gap. He stated explicitly:

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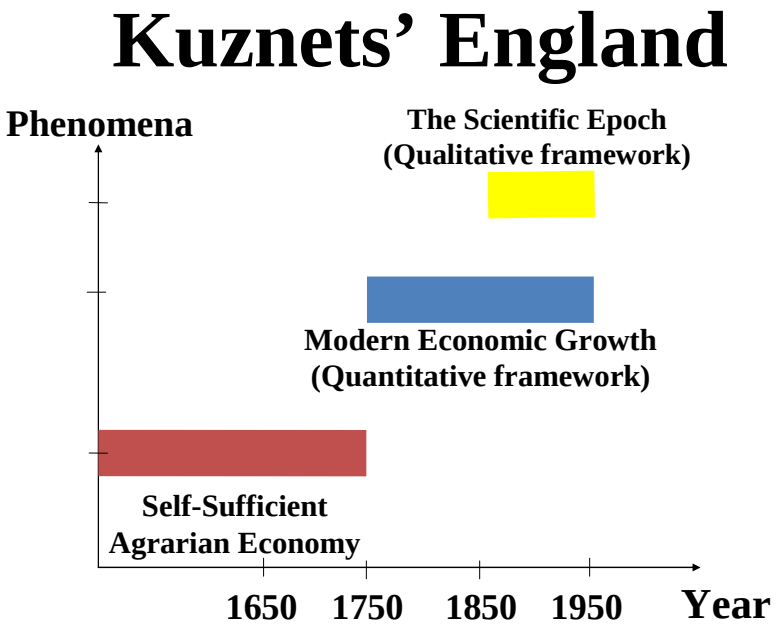
[94] See Landes (2006), p. 16; Mokyr (2002), p. 34; Polanyi (1962), p. 182. When science was later applied to the English economy on a widespread scale, some science came from England, but some also came from France and Germany. See Landes (1969), pp. 269 – 276; Mokyr (1990), pp. 106 – 111.
[95] See Hyde (1977), p. 7.
[96] See Mokyr (2002), p. 34.

> "*… we hasten to add that there may well be a case for arguing that the first century of modern economic growth – from 1750 to 1850 – was dominated by empirical inventions; and that it was only in the second half of the 19th century that the rapid growth of science and recognition of its usefulness brought about a conscious and systematic application of basic scientific discoveries to problems of economic production and human welfare.*"[97]

Kuznets goes on to describe the difficulty in explaining the timing gap:

> "*... (the difficulty) lies in the distinction between the influences that provide a given epoch with its "initial" impulse and the central role that the epochal innovation eventually assumes.*"[98]

In effect, Kuznets extended "the scientific epoch" back a century and identified it with his quantitative framework, "modern economic growth" – as depicted in Figures 3.1 through 3.4.



[97] See Kuznets (1966), p. 10. He goes on to comment, "… we may say that certainly since the second half of the nineteenth century, the major source of economic growth in the developed countries has been science-based technology – in the electrical, internal combustion, electronic, nuclear, and biological fields, among others." See Kuznets (1966), pp. 9 – 10.

[98] See Kuznets (1966), p. 11, ft. 3.

Figure 3.1

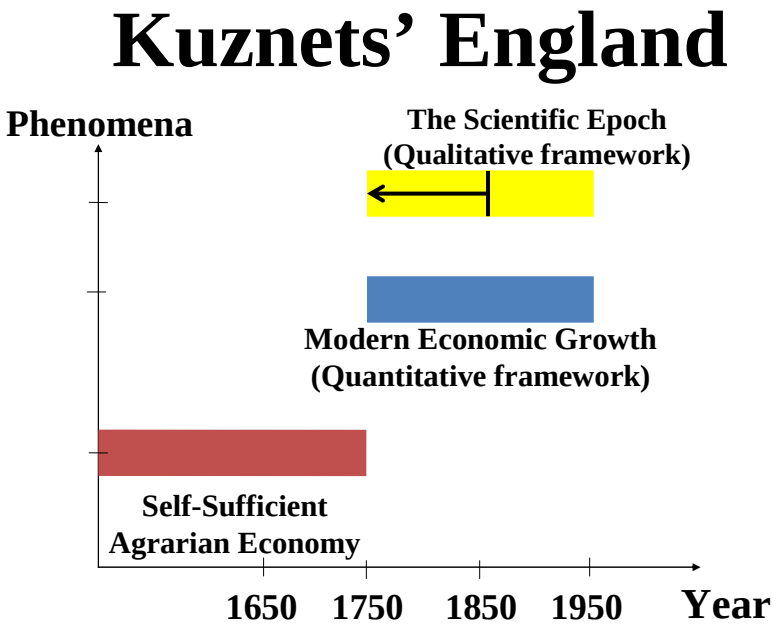


Figure 3.2

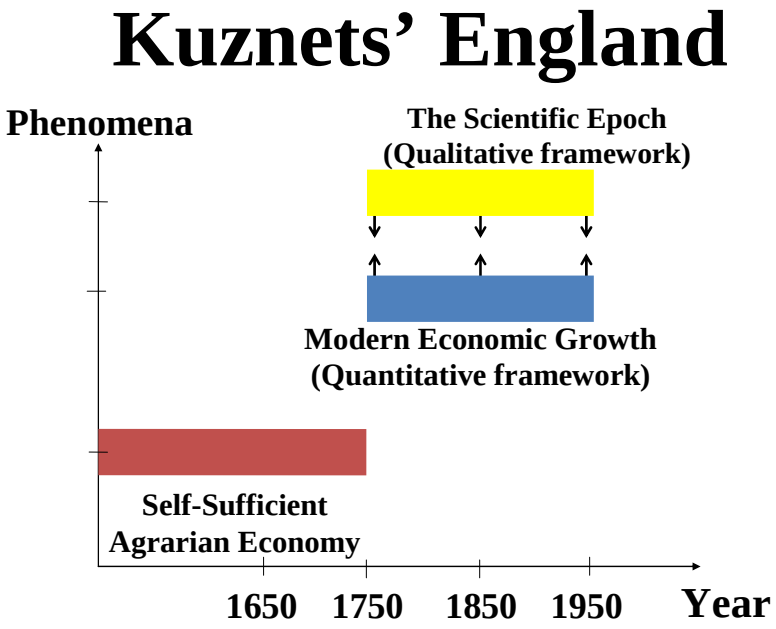


Figure 3.3

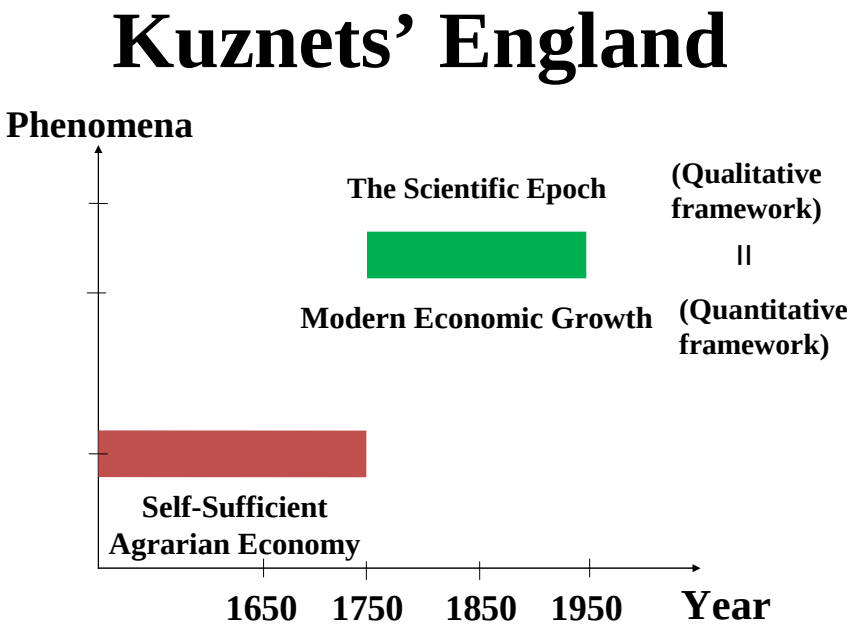


Figure 3.4

Challenging the Timing Gap's Traditional Interpretation – Song China

I do not challenge the observation that the timing gap exists between the beginnings of Kuznets' two frameworks. Rather, I challenge the traditional *interpretation* of this observation. The traditional interpretation has been to link the two frameworks in some way or to view this timing gap as a transitional stage. After noting his reservations, Kuznets extended his qualitative framework – "the scientific epoch" – back to 1750, despite the fact that this contradicted the English data. He stated his justification as follows:

> "*... yet, at the present juncture, it seems better to extend the period (the scientific epoch) to the mid-eighteenth century because the intellectual and cultural milieu within which the basic steam inventions were made also produced the burgeoning of modern science and brought about its more extended applications*."[99]

The purpose of Kuznets' study was to provide a framework to organize and analyze data related to the modern economic growth of nations.[100] However, in this

[99] See Kuznets (1966), pp. 10 – 11.
[100] See Kuznets (1966), p. 3, ft. 1.

crucial step, Kuznets implicitly adopts a theory without providing supporting evidence, effectively assuming away the timing gap, and in doing so equates the two frameworks as one.[101] I argue that this is incorrect and that these two frameworks reflect two distinct social phenomena with reasonable accuracy.

If one concentrates on the data since the 18th century, this identification can appear natural and inconsequential. Similarly, based on this limited data, it can seem very reasonable to accept the existence of the timing gap but view it as a transition period that requires explanation.[102] However, since the Second World War, with the increase in the number of professional social scientists, the data over longer periods and across other countries has dramatically expanded. The data for the pre-18th century period is often limited and qualitative. Yet, science dictates that the data is the data – period. Enough research has been carried out to suggest that there was at least one other episode of economic growth prior to modern economic growth in England – Song China. I am not the first to suggest such a comparison. Arguably, the main proponent of this type of comparison – i.e. comparing England's modern economic growth with other pre-modern episodes of economic growth – has been Eric L. Jones.[103] Here, I continue this tradition with the focus sharply placed on the gap between these two frameworks.

My comparison between Song China and England reveals that the two social phenomena underlying Kuznets' two frameworks are clearly distinct. Previously, I argued that Song China experienced "modern economic growth" as Simon Kuznets defined the term. Given all the extant evidence from Chinese written sources, archeological evidence, records of foreign travelers to China of the time and other sources, it is obvious that Song China did not experience the extended application of science to problems of economic production.[104] This comparison compels us to the conclusion, however seemingly improbable, that both Song China and England (1750 – 1850) experienced the same fundamental social phenomenon – modern

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[101] See Kuznets (1966), pp. 9 – 12, 15; and Kuznets (1973), pp. 165 – 66..

[102] The dominance of the effects of the extended application of science to the economy is deeply rooted in Kuznets analysis, as well as that of many other scholars since him. Kuznets states, "… it should be clear that all we suggest is that science-based technology and the broad views needed for its successful exploitation by human societies were so dominant in the countries that sustained modern economic growth as to constitute a distinctive feature of the modern economic epoch." See Kuznets (1966), p. 15. Yet there is one observation among Kuznets' data, England (1750 – 1850) that does not fit this characterization. All other observations in Kuznets' study begin in the mid-19th century or later. Kuznets treats England (1750 – 1850) as a type of transition. I argue that both his qualitative and quantitative measurements of the England (1750 – 1850) episode were sound but that his interpretation of them was incorrect.

[103] See Jones (1988); Lyons et al. (2008), pp. 274 – 85; and Mokyr (1999), p. 3.

[104] Note that Kuznets comments, "If we ask why the Industrial Revolution did not occur in China, for example, we are implicitly asking why modern science failed to develop there …" See Kuznets (1966), p. 463. Note that Kuznets is speaking loosely here when he focuses on the *existence* of modern science in China. More important was the lack of the extended *application* of science to problems of economic production.

economic growth *without* the extended application of science to problems of economic production. In my view, we are actually observing *two different types* of modern economic growth – one non-science based and one science based. These terms shall be given clear definitions in what follows next. Yet for the moment, note that the non-science based type characterizes both Song China and England (1750 – 1850), while the science based type characterizes England (1850 – 1950) and all other episodes of modern economic growth since the mid-19th century.

I argue that the traditional interpretation of the timing gap is incorrect. The two phenomena underlying Kuznets' two frameworks are distinct social phenomena. It is also incorrect, in my view, to characterize the timing gap as a transitional stage. To clarify terminology, I take the term "non-science based" to mean "*without* the extended application of science to problems of economic production" and the term "science based" to mean "*with* the extended application of science to problems of economic production". Song China presents a three century episode that clearly shows a country need not make the jump from non-science based modern economic growth to science based modern economic growth. Therefore the timing gap is not a transitional stage. To the extent that I have made the case for Song China's modern economic growth as Kuznets defined the term, a reformulation of Kuznets' "modern economic growth" is required. This reformulation of the traditional interpretation of Kuznets' two frameworks is summarized below in Figures 3.5 – 3.7.

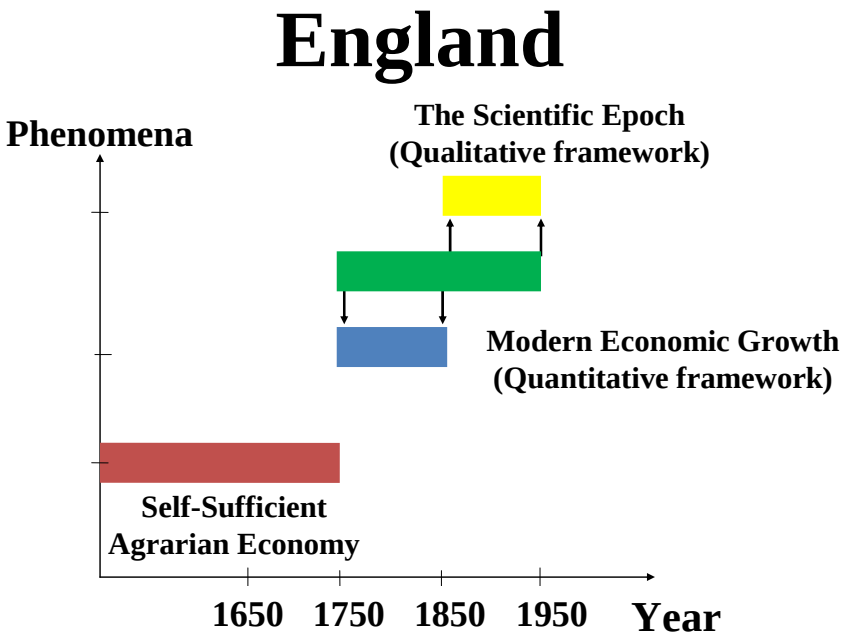

Figure 3.5

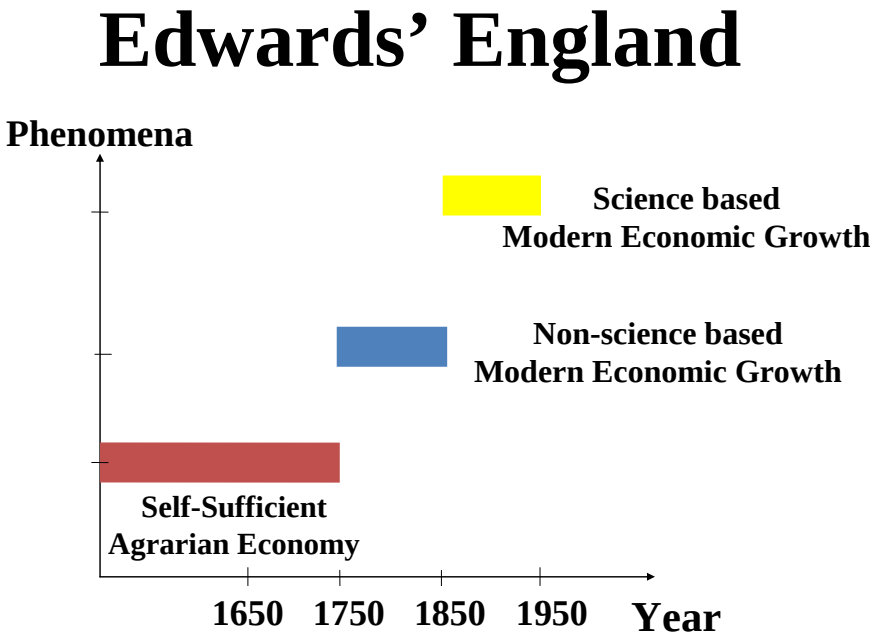

Figure 3.6

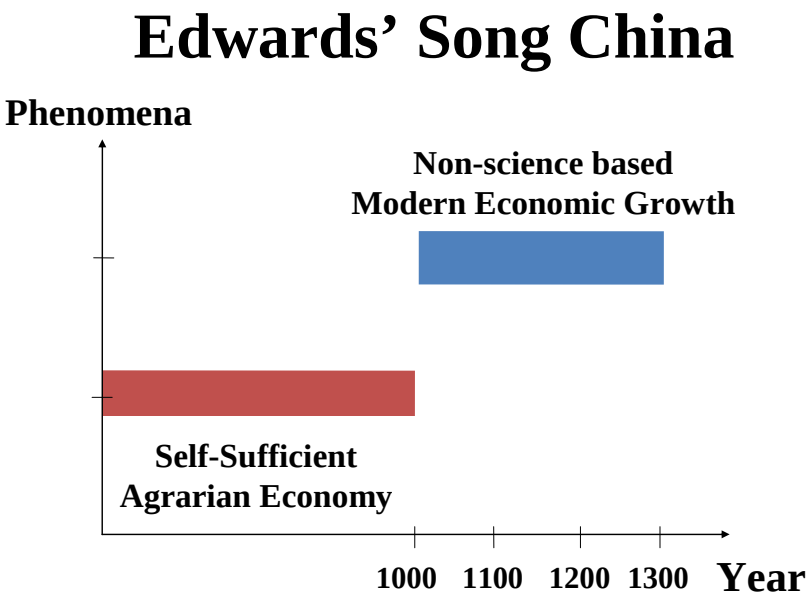

Figure 3.7

I argue that two types of modern economic growth have occurred – first,

modern economic growth *without* the extended application of science to problems of economic production (non-science based modern economic growth) and second, modern economic growth *with* the extended application of science to problems of economic production (science-based modern economic growth). Note that my view of England, as shown in Figure 3.6, differs from that of Kuznets', as shown in Figure 3.1, in that there is no overlap of his two frameworks during the 1850 – 1950 period – I argue they are *distinct* types of modern economic growth.

Thus far, this critical analysis of Kuznets' frameworks has been from his qualitative framework's perspective. That is, given modern economic growth as Kuznets quantitatively measured it, one can qualitatively observe whether or not there exists the extended application of science to the problems of economic production. Although there is much individual judgment behind this observation, I argue that this has been accomplished with reasonable certainty and point to the fact that there is a general consensus regarding the view that the widespread application of science in the English economy began around 1830 – 1870. The qualitative evidence supporting the case for two types of modern economic growth is excellent, at least in my view. But can we also detect two types of modern economic growth from the point of view of Kuznets' quantitative framework? In other words, what are the quantitative grounds for arguing that two types of modern economic growth occurred?

Kuznets' Collection of Countries Considered

Although much quantitative research has been done on many countries since the publication of Kuznets' study, I shall restrict much of my analysis to his data. While a superior method would be to completely repeat Kuznets' analysis using the best data currently available, such a study lies beyond the scope of this analysis. Although the quantitative magnitudes involved might well change with such a new study, it seems likely that Kuznets' general conclusions would remain valid. It was the data available to him at that time, along with their magnitudes, that compelled his conclusions and the formulation his two frameworks. With this caveat in mind, I consider Kuznets' quantitative conclusions.

Kuznets' study considered data for all countries for which there were long-term records – at least five decades.[105] Kuznets excluded countries with a sufficiently long record for three reasons: if they were Communist countries, if their populations were

[105] See Kuznets (1971), p. 10. Note that here I refer to Kuznets (1971), in which he makes some adjustments and changes to his original study (Kuznets (1966)). In his 1971 Nobel Prize lecture (republished in Kuznets (1973), pp. 165 – 84) he referred to his figures from Kuznets (1971) – in particular see his citation of quantitative conclusions (Kuznets (1973), p. 167, ft. 3). The main differences are updates and adjustments made to Table 2.5 in Kuznets (1966) (pp. 42 – 44) presented in Table 1 in Kuznets (1971) (pp. 11 – 14).

below a minimum level or if their high per capita product was due to exceptional natural resource endowment (e.g. oil).[106] There existed one major Communist country for which a sufficiently long record was available – the U.S.S.R. Kuznets provided a fairly detailed explanation for the exclusion of Communist countries and the U.S.S.R. in particular.[107] The key issue is estimating the value for aggregate output of a country. Specifically, when using the product approach one must sum up the value of all the final goods produced in a year. Quantities of each final good may be estimated, but one can not add apples to shirts. Quantities of the final goods must first be converted into a common unit, usually a monetary value (or numeraire). Prices serve this function. To calculate the total value of aggregate output, one first multiplies the quantity of each final good by its respective price, thereby converting the value of all final goods to a common unit. Summing up the resulting values of output across all final goods produces an estimate for the value of aggregate product. In this way, the set of prices serve as relative values for the different goods. In the developed countries which Kuznets considers, a market economy exists or is developing. In market economies, market prices reflect the value of goods and services of all people in that society, in their capacity as consumers and producers. In planned economies, planning prices reflect the value of goods and services of the government officials involved in setting the plan for the economy. Thus, two different types of values are behind market prices and planning prices. According to Kuznets, it is inappropriate to compare the values of aggregate output of these two different types of economies. One should first construct a common set of prices that is appropriate for both types of economies in estimating the value of aggregate output. Only then is it appropriate to compare the "values" of aggregate output across these two different types of countries. Kuznets argued that such a task is beyond the scope of his study.[108]

Kuznets also excluded countries with sufficient records for two other reasons. Countries with populations of less than one million were excluded. He argued that external influences of larger countries may dominate these small countries to such an extent that one may not be able to distinguish independent economic growth from external influences. Lastly, Kuznets excluded countries with a high per capita product which was due to an exceptional natural resource endowment, such as oil. Kuznets justified this by noting that such a country's high per capita product had little to do with the long run process of a nation's economic growth, which was the object of his study.[109]

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[106] See Kuznets (1966), pp. 488 – 89; Kuznets (1971), pp. 10, 19.

[107] Kuznets is implicit referring to planned economies here although he does not explicitly say this.

[108] This summary is based on my understanding of the grounds for Kuznets' exclusion of Communist countries. See Kuznets (1971), pp. 4, 10, 19, 303; and Kuznets (1966), pp. 347 – 48, 400, 489, 507 – 08.

[109] See Kuznets (1966), pp. 478, 488 – 89; Kuznets (1971), pp. 10, 19.

The Quantitative Gap

Although Kuznets' definition of modern economic growth was qualitative in content, he was very clear that its most significant quantitative characteristic was the *high* growth rate of per capita product.[110] What Kuznets meant by "high" is of critical importance because, as we shall see, he used this quantitative statement to *both* characterize and define (implicitly) his concept of modern economic growth.[111] In my previous analysis – based on the perspective of Kuznets' qualitative framework – I did not challenge the existence of the timing gap, but rather its traditional interpretation. Similar in this analysis, I do not challenge his measurement or meaning of the term "high", but argue that Kuznets mistakenly applied the term and in doing so failed to identify two distinct types of modern economic growth.

Two brief comments are worth making before I proceed. First, a comment about the quantitative data: As previously mentioned I shall concentrate on the data Kuznets used in his study but shall reevaluate his conclusions with more recent quantitative data. This reevaluation is preliminary in the sense that a systematic set of data across all periods and all countries considered is not constructed. Rather, I use two existing data sets that were not produced for the purpose of this analysis. This preliminary reevaluation will give us an idea of the changes of the magnitudes related to Kuznets' conclusions when we use data unavailable in the 1960s. I shall argue Kuznets made a critical mistake in the application of his term "high" and that consideration of this application with more recent and likely better, data reveals this mistake more obviously. Secondly, no data from the Song China episode will be needed to make this particular argument.

Next, I shall review the quantitative characteristics of modern economic growth as Kuznets reported them. Kuznets stated that several characteristics emerged from his quantitative analysis of modern economic growth. He explicitly stated (Kuznets (1966), p. 488):

"*By identifying modern economic growth with sustained high rates of*

[110] See Kuznets (1966), pp. 68 – 9.

[111] Kuznets explicitly acknowledged that his selection of countries was influenced by the "high" rates of increase of per capita product and population characteristic of modern economic growth. See Kuznets (1966) p. 63. We see here the interdependent relationship of the high growth rate of per capita product with the definition of modern economic growth at its most fundamental level. A country's selection was based on its "high" growth rates, by modern standards. And so countries in previous eras were excluded on the grounds that they did not meet the modern standard of "high" growth rates. Kuznets states that modern growth rates of per capita product and population were "far higher" than those observed in pre-1880 Japan and pre-1750 Europe. See Kuznets (1971), pp. 303 – 04. Kuznets also stated that the combination of high growth rates of per capita product and population of modern times (1750 – 1950) does not appear to characterize the premodern past. See Kuznets (1966), p. 20.

increase in per capita product we have implicitly stated that such high rates are a common characteristic of modern economic growth."

It is important to note that in his statement Kuznets refers to a concept – "high" – that can and should be quantified. Kuznets identified other characteristics of modern economic growth, but tended to emphasize the high growth rate of per capita product. However, he clearly acknowledged that there existed associated characteristics. As Kuznets put it (Kuznets (1966), p. 488):

"*In fact, … we find a variety of associated characteristics which suggest not only the important consequences of the high rate of growth of per capita product but also the mechanism by which this rate was realized, sustained, or impeded.*"

Again, note his use of the term "high". Later, he explicitly identified the most prominent characteristics, when he summarized the main characteristics of his study (Kuznets (1973), p. 167):

"*First and most obvious are the high rates of growth of per capita product and of population in the developed countries …*"[112]

Once again, the term "high" is clearly applied. Kuznets' study was largely quantitative and so it is only natural for his conclusions to emphasize important quantitative characteristics. He singled out the rate of growth of per capita product as the most important characteristic of modern economic growth (recall that his definition lacks reference to quantitative magnitudes). Consider the first sentence of Kuznets' definition of modern economic growth as reported in the first sentence of his study (Kuznets (1966), p. 1):

"*We identify the economic growth of nations as a sustained increase in per*

[112] Kuznets consistently divided the characteristics of modern economic growth into three broad categories: (i) aggregate growth rates, (ii) structural changes, and (iii) its international spread. See Kuznets (1966), pp. 30, 490; Kuznets (1973), pp. 167 – 69. The first category was most soundly based on clear quantitative patterns and included two main characteristics. The first, as quoted above, were the high rates of growth of per capita product and population, and second, the high rate of increase in productivity, i.e., of output per unit of all inputs. The characteristics in the second category were also based on observed quantitative patterns, but are less securely grounded and also rely to some extent on qualitative evidence. The third category is not relevant to this analysis. Note that in Kuznets original study he reported 15 main characteristics (Kuznets (1966), pp. 490 – 500), yet the general breakdown follows the above outlined three categories. Later, he summarized and synthesized these characteristics down to 6 main characteristics, where each of the three categories consisted of two characteristics – see Kuznets (1973), pp. 167 – 71.

capita or per worker product, most often accompanied by an increase in population and usually by sweeping structural changes."

The use of the phrases "most often" and "usually" must be noted here. Although Kuznets does not imply quantitative magnitudes, his use of these qualifying terms in his definition of modern economic growth strongly indicates a ranking of the *relative* importance of the three aspects. Kuznets viewed long-run increases in per capita product as more important than those of population and – in my interpretation – the high rate of population growth as the second most prominent quantitative characteristic.[113] For the typical country, relative to the observable past, Kuznets observed that the *increase* in the long-run growth rate of per capita product was about twice as high as the *increase* in the long-run growth rate of population.[114] This observation suggests that when reliable estimates of both per capita product and population are available, increases in per capita product are more easily detected.

These arguments strongly suggest that Kuznets viewed the "high" growth rate of per capita product as being the most important quantitative characteristic of modern economic growth. It is certainly not controversial among macroeconomists and quantitative economists to emphasize this feature of economic growth. In fact, one could argue that it is the most common quantitative feature analyzed in recent decades. For example, in his paper on economic development, Robert E. Lucas Jr. states, "By the problem of economic development I mean simply the problem of accounting for the observed pattern, across countries and across time, in levels and rates of growth of per capita income."[115] Over a decade later, Lucas uses the term "industrial revolution" to refer to the onset of sustained growth in per capita incomes.[116] Another example is a recent study by Stephen L. Parente and Edward C. Prescott that focuses on analyzing per capita output.[117]

I will focus, for the time being, on per capita product as did Kuznets in his study. The question is what Kuznets meant by "high" rate of growth of per capita product. He emphasized comparison of as many countries as the data allow over a long term in

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[113] As noted in the previous quotation, Kuznets characterized the *high* growth rate of population (along with the *high* growth rate of per capita product) as being the "first and most obvious" characteristic of modern economic growth – Kuznets (1973). In a least a couple key syntheses, Kuznets singles out the high growth rate of per capita product over the high growth rate of population as being more important and indeed in one instance identifies the high growth rate of per capita product with modern economic growth – see Kuznets (1966), pp. 69, 488. These observations by Kuznets along with his clear emphasis on growth rates of per capita product over those of population in his definition (Kuznets (1966), p. 1) are the basis of my view.

[114] See Kuznets (1971), pp. 303 – 04, Kuznets (1973), pp. 1, 167 and the footnotes and the sources cited.

[115] See Lucas (1988), p. 3.

[116] See Lucas (2002), p. 112.

[117] See Parente and Prescott (2000), p. 11. Note that they use the terms per capita output and per capita income interchangeably.

order to identify and distinguish common characteristics from specific circumstances.[118] Following Kuznets' analysis, we shall concentrate on the long-run average over each country's period of modern economic growth.[119] There are 14 countries considered. Kuznets represented a country's per capita product growth rate over a long period by calculating its "coefficient of multiplication in a century". For example, for a given country, a coefficient of 3.0 means its per capita product tripled in a century, while a coefficient of 1.8 means its per capita product increased by 80% in a century. The coefficient of multiplication in a century for the 14 countries averaged 6.3, while the median was 5.4.[120] With the estimates of these countries in mind, Kuznets provides some summary statistics.[121]

Kuznets' Modern Economic Growth of Nations:
Coefficient of Multiplication of Per Capita Product
Per Century

Type of Country	*Coefficient of Multiplication of Per Capita Product Per Century (or range)*
Typical MEG country	5
Typically low growth MEG country	4
Most countries	3.7 – 7.9

Table 3.1

Kuznets commonly refers to a five-fold increase in per capita product for a typical country that experienced modern economic growth.[122] He also notes that a

[118] See Kuznets (1966), p. 32.
[119] See Kuznets (1971), p. 21.
[120] The countries and their respective coefficients are: Japan – 16.4, Sweden – 12.6, Italy – 7.8, Norway – 6.9, Denmark – 6.3, Canada – 5.6, Germany – 5.4, France – 5.3, United States – 5.0, Switzerland – 4.5, Belgium – 3.8, Netherlands – 3.3, Britain – 3.2, Australia – 2.7. See Kuznets (1971), Table 1, pp. 11 – 21.
[121] The data from Table 1 in Kuznets (1971) (pp. 11 – 19) is chosen over his original Table 2.5 in Kuznets (1966) (pp. 64 – 5) for two reasons. First, Kuznets made some adjustments and changes to his original table and it is in Table 1 that Kuznets reports the country coefficients based on their long-run average during their entire experience of modern economic growth. His original table only reports sub-periods. Second, Kuznets chose the figures in Kuznets (1971) in summarizing his quantitative findings in his Nobel Lecture – see Kuznets (1973), p. 167, ft. 3; Kuznets (1966), pp. 67, 69; Kuznets (1971), pp. 22, 303 – 04. Note the figure for most countries is reported for 9 of the 14 countries as identified by Kuznets (1971), p. 22. Finally, note that in quantitatively summarizing his original data, he reports the range for all countries is from about 4 to 14 (Kuznets (1966), p. 490), while the range for his updated figures is about 3 to 16. Thus, the fundamental argument presented here is not sensitive to which data is used – Table 2.5 from Kuznets (1966) or Table 1 from Kuznets (1971).
[122] Kuznets (1971), pp. 303 – 04; Kuznets (1973), p. 169, ft. 3. Note that on occasion Kuznets also

four-fold increase in per capita product is a low growth rate for such countries.[123] With this quantitative background, let us consider the England episode more carefully. I take the episode England (1750 – 1950) and divide it into two episodes, England (1750 – 1850) and England (1850 – 1950).

Recall that when we divided England into these two centuries, from Kuznets' qualitative framework's perspective, a timing gap was observed, allowing us to clearly detect two types of modern economic growth. The first type was characterized by the absence of the extended application of science to problems of economic production, which was limited to the England (1750 – 1850) episode only. All other episodes, including England (1850 – 1950), were of the second type, which were characterized by the existence of the extended application of science to problems of economic production. In this way we could clearly see that England (1750 – 1850) was the non-science based modern economic growth type and distinct from the science based modern economic growth type. At this point, we are conducting a similar analysis with regard to the magnitude of growth rates of per capita product. The issue is whether we can detect a considerable quantitative gap in the magnitudes of the growth rate of per capita product for England (1750 – 1850) and all other cases, including England (1850 – 1950). Based on Kuznets' data we can compute the coefficient of multiplication of per capita product per century for this decomposition of the English episode.

Kuznets' Estimates for England:
Coefficient of Multiplication of Per Capita Product Per Century

Region (era)	*Coefficient of Multiplication of Per Capita Product Per Century*
England (1750 – 1850)	2.4

Table 3.2

mentions the extremely high increase of the growth rates of per capita product and population as being a distinctive quantitative feature of modern economic growth. Yet this is always pointed out in the context of describing high growth rates. No doubt we can find examples in the past where a country's per capita product and/or population growth rate increased by a factor of 20. But such an example almost surely would be in the context of a 20-fold increase of a nearly zero growth rate. This feature alone is clearly not what Kuznets had in mind. See Kuznets (1973), p. 1.

[123] Note that this statement of Kuznets is made with reference to his Table 2.5 in Kuznets (1966), see pp. 67, 69, 490 – 91 and 504. This is a conservative statement in the sense that his updated table tends to exhibit a slight increase in the figures, at least in some of the extreme observations.

Observe that Kuznets' estimated growth rate for England (1750 – 1850) of 2.4 is far lower than his reported growth rate of 5 for the typical modern economic growth country.[124] Note that this estimated growth rate of 2.4 is also considerably lower than the growth rate of 4, which he identified as the "typical lower growth rate" for modern economic growth countries. In fact, the growth rate for England (1750 – 1850) is the lowest of all episodes of modern economic growth that Kuznets considered. Simply stated, Kuznets' quantitative standard for "high" growth rates of per capita product (4 or 5) is very questionable to the England (1750 – 1850) episode.[125] Kuznets may have mistakenly applied this standard to England (1750 – 1850), in my opinion.

A few comments about this observation are in order. Some uncertainty exists regarding the quantitative foundation of my conclusion of Kuznets analysis of England (1750 – 1850). Kuznets made clear that for some countries considered the long-term economic records are "relatively poor." There is much variability and diversity in his findings – so much so that these differences cannot be reduced to "fully testable order."[126] Only fairly clear, general findings can be trusted with any reasonable certainty – as opposed to specific and limited features. Much judgment is necessarily required to interpret Kuznets' findings and he often shows some

[124] The estimate in Table 3.2 was calculated as follows. The century 1750 to 1850 was divided into four sub-periods – (i) 1750 – 1775, (ii) 1775 – 1795, (iii) 1795 – 1805 and (iv) 1806 – 1850. For each sub-period a constant growth rate per century was assumed. For sub-periods (i), (ii) and (iv) the growth rates per century estimated by Kuznets (1.2, 1.8 and 3.3 respectively) for Britain were used – see Kuznets (1971), Table 1, p. 11. For sub-period (iii) the average growth rate per century of period (ii) and (iv) was used – 2.55. Weighting each of the four growth rates per century by their relative time lengths (0.25, 0.20, 0.10 and 0.45) and summing produces the estimate reported. Kuznets adopts a round, conservative figure in presenting the typical MEG country's coefficient as 5. England's coefficient of 2.4 is also lower than the actual average (6.3) as well as the median (5.4). These are calculated from the reported 14 long-run coefficients as identified by Kuznets (1971), p. 21 in reference to Table 1. Note that in these averages / median estimates the coefficient for England (1750 – 1950), which was 3.2, was used. The coefficient of multiplication in a century for England (1850 – 1950) was 3.5. Such a decomposition of England and removal of the England (1750 – 1850) episode from the calculation would only have a small increasing effect on the average and median. This would slightly increase the difference between England (1750 – 1850) and the average and the median of the other 14 countries, including England (1850 – 1950).

[125] The use of a standard for the coefficient of multiplication of per capita product per century of between 4 and 5 is based on the previously cited estimates and statements by Kuznets. Particular weight must be given to three key summarizing / characterizing statements. In his summary of findings of the long-term records of the countries considered, Kuznets refers to "more than a fivefold rise in per capita product" over a century. See Kuznets (1971), pp. 303 – 04. Another quantitative summarizing statement also refers to rates, "which mean roughly a multiplication over a century by five for product per capita …". See Kuznets (1973), p. 167 for the statement and distinct reference to this quantitative summary on page 1, footnote 1 of the same source. Finally, in his original study when summarizing the main quantitative features for per capita product, he states, "Except for Australia, the decade rates of growth in per capita product are well above 10 per cent" – corresponding to a 2.6 coefficient of multiplication per century – see Kuznets (1966), p. 67. If one excludes Australia, the next lowest long-run modern economic growth rate of a decade is 13.4 per cent, which translates to about a 3.5 fold increase over a century. See Table 2.5 on pages 64 – 65. Kuznets goes on to say, "In general, in subsequent discussion we assume a rate of growth in per capita product of 15 per cent per decade as a typically low limit" – which translates to a four-fold increase over a century, see Kuznets (1966), p. 67.

[126] See Kuznets (1966), pp. 502, 509.

skepticism about conclusions that are not based on broad patterns. We should also view any firm claim involving orders of magnitude with some skepticism.

Up to this point, however, we have considered Kuznets' quantitative findings based on the data available to him at that time. It is possible to rework Kuznets' study based – all else being equal – on better quality data and over an expanded collection of countries that have experienced modern economic growth for a longer period of time. In what follows, I analyze more recent data to see how his quantitative findings change – in particular, Kuznets' "coefficient of multiplication for per capita product per century" for the average country and the typically low country will be considered. Finally, England (1750 – 1850) will be compared to the other cases to see if a quantitative gap can be detected between the magnitudes of their growth rates of per capita product.

I begin by adopting Kuznets' beginning period for modern economic growth – the mid-18th century – and extend it to 2010. The difficulty lies in identifying countries that have begun modern economic growth and when it started in each case. This is arguably the crucial step in this extension of Kuznets' analysis, which involves selecting countries and time periods to perform a quantitative comparison. I solve this problem as follows. I begin by breaking down the 1750 – 2010 period into three sub-periods. This division is based on the availability of economic data. The first sub-period is taken to be 1750 – 1850. This choice is justified by the observation that Kuznets (and many others since him) viewed England as the sole country to have experienced modern economic growth from the mid-18th century up to the mid-19th century. The second sub-period is 1850 – 1960. This choice is dictated by the opportunity to extend the data used for analysis from the 1850 – 1950 period by one decade to match the natural dividing year of 1960. A significant amount of economic data is available due to the efforts of Summers and Heston and their associates over the past several decades. From 1960 to 2010 data for a large collection of countries becomes available. The third sub-period is 1960 – 2010. This sub-period was chosen to coincide with data available in the Penn World Tables and to provide a period that met Kuznets' minimum period of consideration for study of long-run economic growth – five decades. The resulting three sub-periods: i) 1750 – 1850, ii) 1850 – 1960, and iii) 1960 – 2010 are considered in what follows.

Let us begin with the first two sub-periods. The key issue is the choice of countries which are viewed to have experienced modern economic growth. For the period 1750 to 1850, I take England as the only country to experience modern economic growth. For the period 1850 – 1960, I adopt Kuznets' choices of countries from his original study but use more recent estimates for these countries as reported by Angus Maddison (Maddison (2007)). Let us first consider how Kuznets'

quantitative results hold up when reevaluated with updated data.[127]

Kuznets' Modern Economic Growth of Nations:
Coefficient of Multiplication of Per Capita Product
Per Century
REVISED VERSION – Using Maddison's Data

Type of Estimate	1750 – 1850 (1 country – England)	1850 – 1960 (14 countries)
Average	1.8	4.7
Median	1.8	4.9
Range	1.8	3.2 – 6.3

Table 3.3

There are two important features of Table 3.3. Most important is the lower estimate for the coefficient of multiplication of per capita product (per capita GDP) for England during the 1750 to 1850 period. A coefficient of 1.8 is estimated. A lower figure than Kuznets' original coefficient of 2.4 (see Table 3.2). Given the focus on this estimate, a brief discussion is required. The estimates of England's per capita product during this period are largely backward projections based on mid-19th century data. As such, they are sensitive to assumptions about the relative importance of weights assigned to different sectors of the economy. In the 1950s and 1960s important quantitative work on England's economic growth was carried out by Walther Hoffmann (Hoffmann (1955)) as well as Phyllis Deane and W.A. Cole (Deane and Cole (1962)). These studies are important because they were the source of data used by Kuznets in his study.[128] Over the last couple decades a major quantitative reevaluation of these figures has come to a consensus. According to Knick Harley, "The sharp increases in the growth rate of industrial production and income during the last quarter of the eighteenth century now appear to have been an artifact of

[127] For England (1750 – 1850) data for the United Kingdom was used from Maddison (2007), Table A7, p. 382. The reported figure was based on an estimate of $1423.0 for 1750 and $2483.5 for 1850. The former estimate was based on Maddison's estimates for 1700 and 1820 by assuming a constant growth rate per decade. The latter estimate was based on Maddison's estimates for 1820 and 1870 by assuming a constant growth rate per decade. The resulting coefficient is 1.75. Note that if one were to extrapolate from 1820 to 1850 using the preceding period's constant growth rate per decade, the resulting estimate would be $1843.9, which corresponds to a coefficient of 1.30. The data used for the 1850 – 1960 sub-period is from Maddison (2007), see Appendix 1.

[128] See Kuznets (1971), pp. 11 and 15 – note Lines 1 and 2 on the former page and their data sources on the latter.

inappropriate index construction by Hoffmann and Deane and Cole."[129] Nicholas Crafts and Knick Harley have demonstrated the growth rate of per capita product was much lower than previously thought because the Deane and Cole estimates drastically underestimated the value of per capita product in the 18th century.[130] Angus Maddison commented on this:[131]

> "*The evidence now available suggests that the transition to accelerated growth started around 1820, not 1760 as Kuznets thought. The work of Crafts and others on British performance in the eighteenth century helped demolish the old notion of a sudden take-off in the second half of that century*."

To reiterate the first important point, improved estimates have led to a decrease in the England (1750 – 1850) coefficient of multiplication. It appears likely that it was not 2.4 as Kuznets estimated based on Deane and Cole (1962). More likely it was less than 2. It is important to note that the other modern economic growth countries identified by Kuznets (during the 1850 – 1960 sub-period) also had an opportunity to change in this recalculation. Maddison used the best data available to him, which was surely better than what Kuznets used. Although we see changes in the coefficient of multiplication for some of the countries during the 1850 – 1960 period, the average remained about the same as Kuznets' estimate (Maddison's average and median coefficient are both slightly less than 5, while Kuznets' average was about 6 and the

[129] See Harley (1999), pp. 162 – 65.

[130] We can use new estimates from Crafts and Harley to recalculate Kuznets' coefficient of multiplication. Based on their revisions one can estimate that for 1750, the per capita income in Britain was around $387 (U.S. 1970 $) and in 1850 it rose to around $633 – resulting in a coefficient of multiplication of 1.64. It is important to note two points. First, it is widely regarded that science began its widespread application in Britain around 1830 to 1870. According to Harley, "Modern economic growth became fully established in Britain only in the railway age" – which began in 1830 (see Harley (1999), p. 192). Second, according to estimates by Crafts and Harley per capita income in Britain rose from $387 to $500 in eight decades beginning in 1750 – a less than 4% growth rate per decade, while in the period 1830 to 1850, it increased to 16%. Thus, the last two decades of the 1750 – 1850 century had a major impact on its coefficient of multiplication. To get an idea of what Britain might look like without the effects of the application of science to the economy, one could obtain a rough guesstimate for a lower bound by using the 1800 to 1830 growth rate and extrapolating the final two decades to obtain a non-scientific "lower-bound" on per capita income of about $550, which would correspond to a coefficient of multiplication of 1.43 (notably lower than the 1.64 coefficient based on estimates by Crafts and Harley). I do not suggest that this lower-bound estimate is a reasonable counter-factual estimate. It can only be used as a very rough guide to get a quantitative sense of what "might" have happened. This discussion shows that while there are ongoing debates about the actual growth rate of per capita product in Britain during the 1750 – 1850 period, the revised estimates all suggest something on the order of 1.5 to 1.9 for a coefficient of multiplication per century. The estimates used in constructing England's coefficient during the 1750 – 1850 period (first column in Table 3.3) came from Maddison (2007), who was aware of the deficiencies of the data in Deane and Cole (1962). For discussion on the influence of Crafts and Harley estimates effectively lowering the previously established growth rates see also Jones (1988), pp. 25 – 26; Mokyr (1999), pp. 9 – 12.

[131] See Maddison (2007), p. 303.

median around 5). The second important point to note is that with the improved data we can more clearly detect a quantitative gap between the coefficient of multiplication of per capita product for that of England (1750 – 1850) and for those of the other countries of the 1850 – 1960 period. Due to the decrease in England's growth rate, we can see *more clearly* the absence of a "high" growth rate of per capita product for England (1750 – 1850) relative to Kuznets' quantitative standards. The coefficient for England (1750 – 1850) is the lowest among all the countries considered here. An increase of about 80% of the coefficient for England (1750 – 1850) is required to match the next lowest coefficient and a near tripling is required to attain the median. It is clear that the growth rate of per capita product for England (1750 – 1850) is considerably lower than that of the other countries considered in the 1850 – 1960 period.

For the final period, 1960 – 2010, my procedures essentially follow those of Kuznets. Countries with a population of less than one million are not considered. I do, however, consider Communist countries as there has been an effort by scholars to provide data to remedy the problem of comparability that had concerned Kuznets. The Penn World Tables report per capita GDP for 189 countries. For the 1960 to 2010 period, any country that had data available was considered – reducing the total to 110 countries.[132] From these 110, 18 were excluded for having insufficiently large populations. The final problem is to identify the countries among the remaining 92 that experienced modern economic growth. A simple rule was applied to accomplish this: if a country experienced an increase in per capita GDP over the 1960 – 2010 period it was considered. In other words, countries which experienced a *decline* in per capita GDP were excluded. There were 7 such countries, most of which are African countries marred by wars. The resulting sample of 85 countries was used for the 1960 – 2010 period. For each sub-period, a constant growth rate per decade was assumed and Kuznets' "coefficient of multiplication of per capita GDP per century" was calculated. The averages for all three sub-periods are reported below:[133]

Kuznets' Modern Economic Growth of Nations:
Coefficient of Multiplication of Per Capita Product
Per Century
REVISED AND EXTENDED VERSION – Using Maddison's data and PWT 7.1

[132] There are 190 countries in total. Among them are two data series made available for China – version 1 and version 2 (the official series and the adjusted series, respectfully). I consider the latter and discard the former to avoid counting a single country twice.
[133] See Table 3.3 and source for the first two sub-periods. The data for the 1960 – 2010 sub-period is from PWT 7.1, see Appendix 2.

Type of Estimate	1750 – 1850 (1 country – England)	1850 – 1960 (14 countries)	1960 – 2010 (85 countries)
Average	1.8	4.7	21.6
Median	1.8	4.9	6.4
Range	1.8	3.2 – 6.3	1.1 – 298.5

Table 3.4

Table 3.4 reproduces the previous table's two sub-periods and adds the 1960 – 2010 sub-period. We can see in Table 3.4 that – on average – growth rates have increased dramatically in the most recent period, with an average of 22. A closer look at the data reveals that this high average coefficient of multiplication (for 85 countries) is largely driven by the growth miracles of the later 20th century.[134] If we look at Taiwan and Japan (ranked #1 and #11 respectively out of 85), their coefficients of multiplication were about 300 and 30 respectively. A more conservative approach might be to consider the median in this sub-period, for which the coefficient was 6.4 – still near or greater than the average for the 1850 to 1960 period.

Kuznets' original analysis, when England was divided into two sub-periods, (1750 – 1850) and (1850 – 1950), revealed that England (1750 – 1850) had the lowest growth rate among all the countries he considered. In this case, the coefficient of multiplication of per capita product per century (coefficient hereafter) was 2.4, less than what Kuznets' called the typically low growth rate of a country experiencing modern economic growth (which had a coefficient of around 4 – see Table 3.1). Based on improved data three decades later, according to Maddison, the quantitative gap between the coefficients for England (1750 – 1850) and the other countries has *increased*. In this updated estimate the coefficient for England (1750 – 1850) decreased to 1.8, about half of the next slowest growth country's coefficient and far below the mean and median, both almost 5 (see Table 3.3).[135] When comparing the coefficient of England (1750 – 1850) with that of the average growth country during the 1960 – 2010 sub-period, the quantitative gap becomes obvious. In conclusion, the coefficient of multiplication of per capita product for England (1750 – 1850) is much lower than that of all other countries that experienced modern economic growth during the 1850 – 1960 period and far lower than that of the average since 1960 (see Table 3.4).

[134] The estimates for the period 1960 – 2010 come from the PWT 7.1 – see Appendix 2. The observation that the growth rate of the fastest growing economy has been increasing over time has been previously noted – see Parente and Prescott (2000), Figure 2.3, p. 22.

[135] This comparison, based on more modern estimates, is slightly different than Kuznets' original comparison only in that the second period is extended by one decade.

I conclude from this discussion that the growth rate of England (1750 – 1850) is not "high" by post-1850 quantitative standards and that there exists a quantitative gap in terms of growth rates between England (1750 – 1850) and the typical post-1850 period country. From this quantitative gap in growth rates of per capita product we can detect *two types* of modern economic growth, in my opinion, one with a low growth rate and one with a high growth rate.

I believe this observation reveals the *quantitative wedge* driven between the growth rates of those countries with the extended application of science to problems of economic production and those without. The widespread application of science to the economy clearly has a direct effect on the magnitude of long-run productivity gains. In addition, there are feedback effects based on economic growth through the development of a professional group of scientists, which further increase the stock of scientific knowledge and induce greater productivity gains. The development of modern transportation and communication technology dramatically reduced the period required to spread scientific based technologies. Late entrants to science based modern economic growth were given the unprecedented opportunity to quickly adopt many modern scientific technologies with dramatic productivity gains. This situation describes the late 20th century "growth miracles" in my view.[136] Crucial here are that these observed large magnitudes are the effects of science *and* are limited to the post mid-19th century era. Kuznets explicitly expressed the view that high rates of growth and the rapid structural shifts of modern economic growth were associated with the application of science to problems of production.[137] It is certainly reasonable to argue that the "high" rates of growth of per capita product and rapid structural changes are the results of the extended application of science to problems of economic production, which are limited to post-1850 cases.

Two Different Types of Modern Economic Growth: Timing & Quantitative Gaps

In summary, let us review Kuznets' two distinct frameworks over the 1750 – 1950 period and the gaps between them. First, Kuznets defined his qualitative

[136] See Parente and Prescott (2000), Figure 2.3, p. 22 for evidence that the growth rate of the world's fastest growing countries has dramatically increased over time and that during the late 20th century the growth rate leaders were clearly episodes of "closing the gap" with the technological leader.

[137] See Kuznets (1966), p. 487 and Kuznets (1971), pp. 322 – 23. Kuznets explicitly cited examples such as steam and electric power and the social organizations that are compatible with efficiently employing these technologies – see Kuznets (1973), pp. 165 – 66. In his discussion of the "rapid" structural shifts of modern economic growth, Kuznets cites changes in the distribution of labor between agricultural and non-agricultural sectors. But he cites data from the United States during the 1870 – 1960 period and Belgium during the 1846 – 1961 period (see Kuznets (1973), p. 168, ft. 5). Similarly, Kuznets used many late 19th century urban population figures in his analysis of the rapidity of urbanization (see Kuznets (1971), pp. 21 – 22, ft. 4).

framework – the scientific epoch – based on the extended application of science to problems of economic production. Kuznets observed that a *timing gap* exists this period. Second, he defined his quantitative framework of "modern economic growth" as characterized by a "high" growth rate of per capita product. One notable outlier among the growth rates of the episodes considered reveals a *quantitative gap* exists within this framework. These gaps are summarized in the table below.

Per Capita Product Growth Rate	**Type of Modern Economic Growth**	
	Non-science based	***Science based***
Low	England (1750 – 1850)	
High		All 1850-1950 cases

Table 3.5

Table 3.5 illustrates the combined effects of both gaps. Recall, for our purposes England's two centuries of modern economic growth is divided into two distinct episodes – England (1750 – 1850) and England (1850 – 1950). According to Kuznets, only England experienced modern economic growth during the 1750 – 1850 period. All other episodes occurred during the 1850 – 1950 period (including the England (1850 – 1950) case). First, the timing gap of Kuznets' qualitative framework clearly separates the case of England (1750 – 1850) from all others in the 1850 – 1950 period (including England (1850 – 1950)). The England (1750 – 1850) episode lacks the extended application of science to problems of economic production – i.e. it is a case of non-science based modern economic growth. All other episodes observed during the 1850 – 1950 period are characterized by the extended application of science to problems of economic production – i.e. they are all cases of science based modern economic growth. Second, the quantitative gap of Kuznets' quantitative framework

distinguishes England (1750 – 1850) from all other observed episodes during the 1850 – 1950 period (including England (1850 – 1950)). The growth rate of per capita product of the England (1750 – 1850) episode is the lowest of all cases considered. The quantitative gap becomes even more obvious when we shift from the original data available to Kuznets in the 1960s to more modern data, which removes defects in the original data. With respect to Kuznets' quantitative standards, England (1750 – 1850) experienced a low growth rate of per capita product relative to those of other episodes. Given the large long-run productivity gains from the widespread application of modern science in an economy, it is expected that non-science based episodes of modern economic growth would have considerably lower growth rates of per capita product. I argue that this analysis reveals two types of modern economic growth – one non-science based with a low growth rate of per capita product and one science based with a high growth rate of per capita product.

Song China & the Quantitative Gap

The observation that China's economy during the Song Dynasty (960 – 1279) did not experience the extended application of science to problems of economic production is accepted by the academic community. But there remains the issue of Song China's growth rate of per capita product. The analysis in the preceding section was limited to data for per capita product during the post-1750 period. In the context of the analysis in this study, one should consider the comparison of growth rates of per capita product between England (1750 – 1850) and Song China. The fundamental problem is that quantitative data for the pre-1850 period is limited in both quantity and quality. Conclusions based on estimated magnitudes of per capita product growth rates are only as sound as the data on which they are based. Recent research has improved our understanding of England (1750 – 1850) but for the Song China episode, quantitative data is scarce and of relatively poor quality. Applying a strict quantitative threshold to define or distinguish "low" from "high" growth rates for Song China is unreasonable, in my opinion, given the existing quantitative data. Consider the example of recent adjustments made to the growth rate of per capita product for England (1750 – 1850). Modern scholars in the 1960s, using the quantitative data available, estimated England's coefficient of multiplication of per capita product in a century to be 2.4. Subsequent scholars critically evaluated this estimate reducing it to around 1.8 – about a 25% decrease. If modern scholars using relatively extensive quantitative evidence can make a 25% error in their estimate of a growth rate for a case three centuries ago, we should not expect accurate estimates of growth rates for a

case one millennium ago where data is scarce and of lesser quality.

To make reasonably accurate estimates for long-run growth rates of per capita product or income, two basic approaches exist – the product approach and the income approach. In the former, data on prices and quantities of final goods from a number of sectors of the economy is required. The existence of such systematic data is very rare prior to 1850. For the latter approach, wage data is required for a broad sample of workers in the economy where a similar situation exists. We must try to quantify aspects of economic growth regardless of the quantity and reliability of the data. However, we must also consider the soundness of the data on which these estimates are based when forming our conclusions. Although one cannot rule out future archeological discoveries of new data, it seems unlikely that we will ever be able to produce quantitative estimates of growth rates of per capita product or income for Song China that will allow us to reliably apply quantitative standards for assessment. I see no point in entering a debate on whether a coefficient of multiplication in a century for per capita product was 1.3 or 1.9 when these estimates are based on limited data from a millennium ago. For this reason, I do not believe it will be possible beyond very broad ranges of magnitude to compare the growth rates of per capita product of Song China and England (1750 – 1850). However, the objectivity of quantitative analysis remains extremely important. Even in this case, we should not give up.

Kuznets' analysis of modern economic growth emphasized growth rates of per capita product as most important. The fundamental problem with these estimates arises when attempting to estimate aggregate output or income. Kuznets argued the *second* most important characteristic of modern economic growth was the increase in growth rates of population. Relatively speaking, over very long periods, population data is far superior to extant data that forms the basis for estimates of aggregate output or income. Since the earliest times, states have conducted censuses for tax purposes. We do have ancient census data from the Roman Empire and the Han Empire from around two millennia ago. Population data does not come without serious problems of its own – issues of coverage, evasion and estimation of number of people per household are central issues for demographic historians. Since Kuznets also emphasized an increase in the growth rate of population, I suggest that when looking for episodes of economic growth prior to a few centuries ago, we search for cases where there is an unprecedented increase in the growth rate of population. Quantitative analysis based on these changes appears to be a more reliable foundation. Of course, an unprecedented increase in the growth rate of population is only a first order indicator of possible economic growth. Other quantitative evidence must be investigated as well and qualitative data must be considered and given appropriate

weight in forming a conclusion regarding episodes of economic growth. Despite all its problems, China's long run population data is the best in the world – it has the longest and most continuous coverage.[138] For the episode of Song China, we have relatively good population data. China's population time series clearly indicates an unprecedented increase in the growth rate of population in the early Song Dynasty (960 – 1279). See the below figure for China's stylized population time series and the range for most estimates for demographic historians of China.[139]

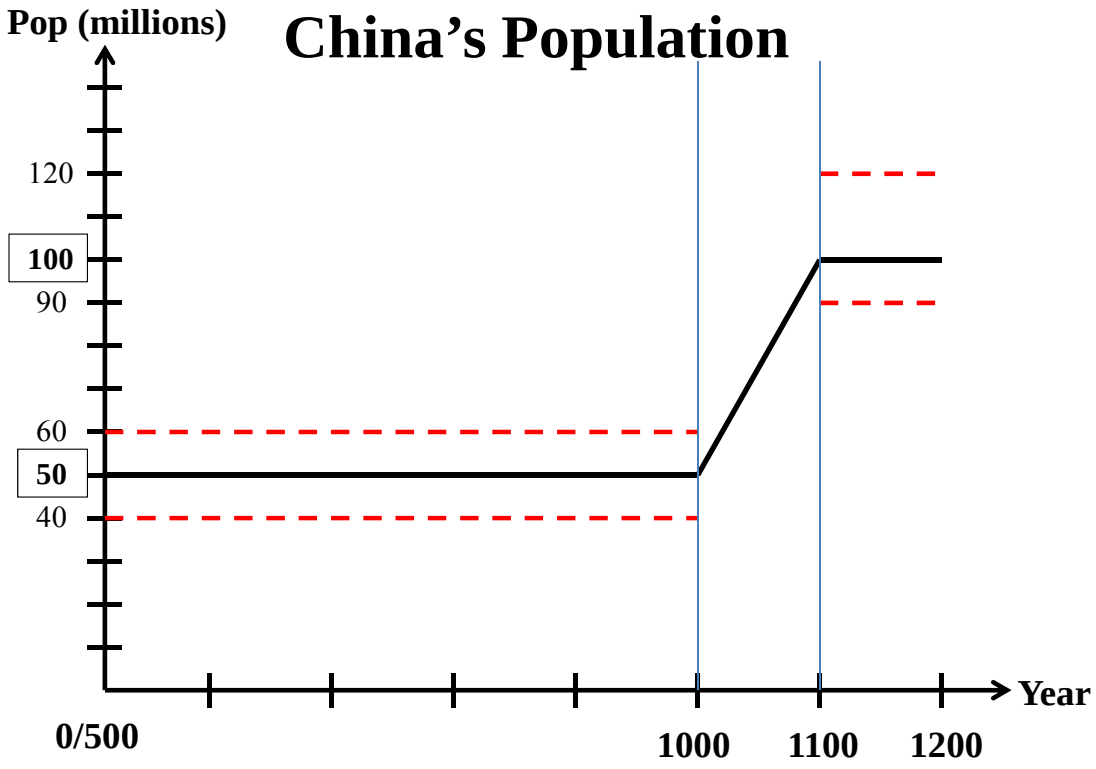

Figure 10

In Figure 10, China's total population is reported in millions and the 500 – 1200 AD period is considered. The solid black line represents a rough trend line for the total population of China – about 50 million during the 500 – 1000 AD period and 100 million during the 1100 – 1200 AD period. For the former period, most estimates center around 50 – 55 million, while for the latter period they center around 100 – 110 million. The dotted red lines indicate the range of estimates for total population as

[138] See Maddison (2007b), p. 165.
[139] See footnote 63, p. 20 in this paper for a description of my estimates for China's population in Table 2.4. The ranges of population estimates here, 40 – 60 million for the 500 – 1000 AD period and 90 – 120 million for the 1100 – 1200 AD period, are based on my reading of many population historians' estimates.

reported by almost all demographic historians of China. In particular, for the 500 – 1000 AD period, population estimates generally fall within the range of 40 – 60 million. For the 1100 – 1200 AD period, population estimates generally fall within the range of 90 – 120 million. With reasonable certainty we can detect an unprecedented increase in the growth rate of population in China during the 11th century – roughly a doubling from 50 to 100 million. Note that an unprecedented increase can be observed for a variety of estimates within the ranges of both periods (i.e. for the ranges reported, the magnitude of the population increase during the 11th century was somewhere between a 50% and a 3-fold increase). Thus, we have relatively sound *quantitative evidence* that supports Kuznets' second characteristic of modern economic growth – an increase in the growth rate of population. We have also seen previously (Table 2.5 on page 21) that iron output per capita nearly tripled in the 11th century. Thus the best quantitative evidence available for Song China's economy points clearly to increased growth rates in *both* per capita product and population. A vast amount of qualitative data for Song China combined with this quantitative evidence strongly suggests modern economic growth. It is difficult to compare the magnitude of these growth rate increases relative to England (1750 – 1850), but this is not essential to the main point. It appears that Song China experienced non-science based modern economic growth – as did England (1750 – 1850). I argue these two episodes with their lack of the extended application of science to problems of economic production and low growth rates of per capita product strongly suggest the existence of two types of modern economic growth. Kuznets was mistaken to identify his two frameworks as one, at least in my opinion.[140]

Definition: Two Types of Economic Growth

Based on the analysis in this section I conclude by presenting my definitions of the two types of economic growth as follows.

Definition:

Premodern Economic Revolution: "modern economic growth" as Kuznets defined the term without the extended application of science to problems of economic production.

Modern Economic Revolution: "modern economic growth" as Kuznets defined the

[140] It must be said in fairness that Kuznets did not have the benefit of the evidence for Song China and that only when such an episode is observed would one tend to identify England (1750 – 1850) as a distinct type of modern economic growth. Eric L. Jones has argued along similar lines to those presented here – see Jones (1988).

term with the extended application of science to problems of economic production.

Economic Revolution: *Premodern Economic Revolution* and/or *Modern Economic Revolution*.

In short, I argue there are two types of Economic Revolution, one non-science based (Premodern) and one science based (Modern), the former is associated with a low growth rate of per capita product and the later a high growth rate of per capita product. I shall use the following terminology interchangeably, where the terms on the right – Premodern Economic Revolution and Modern Economic Revolution – are defined above.

Terminology:

Non-science based = *Premodern*

Science based = *Modern*

Further discussion

I shall conclude this section with a discussion of a related distinction in the literature and a comment about science and the work of Joseph Needham. It should be noted that decoupling science from modern economic growth is not completely novel. There exists a large literature on the modern economic growth of Europe that makes a related distinction. In this tradition a distinction is made between what is called the "first Industrial Revolution" and the "second Industrial Revolution." While not the first to make this distinction, David Landes has been arguably the most notable proponent in emphasizing the existence and importance of the "second Industrial Revolution." There is somewhat of a consensus in that the technologies applied in the second Industrial Revolution were science-based, whereas those of the former lack science and were empirical in nature.[141]

In this literature the definitions of the first and second Industrial Revolutions are usually dominated by particular technologies or sectors, although they also often

[141] I largely follow David Landes' definition here. See Landes (1969), p. 1; Landes (1998), pp. 186. Hull attributes the original use of the term "second Industrial Revolution" to Patrick Geddes in a 1915 publication. See Hull (1999). It should be noted that Mokyr's "microinventions" and "macroinventions" shows a similar parallel. See Mokyr (1990), pp. 9 – 15 and Ch. 11.

refer to many of the changes associated with these developments. The first Industrial Revolution is often characterized by a collection of technological advances including: the mechanization of production (spinning jenny and cotton gin), development of the inanimate power (water wheels and steam engine), chemicals and improvements in transportation (steam powered trains). The sectors most often associated with these technological innovations include: textiles, iron, coal and railway transport. It should be noted that the only innovation here that might be called "scientific" in nature is the steam engine.[142] According to Joel Mokyr, "The first Industrial Revolution – and most technological developments preceding it – had little or no scientific base. It created a chemical industry with no chemistry, an iron industry without metallurgy, power machinery without thermodynamics. Engineering, medical technology, and agriculture until 1850 were pragmatic bodies of applied knowledge in which things were known to work, but rarely was it understood why they worked."[143]

The second Industrial Revolution, which began in the mid-19th century but is traditionally dated to the 1870 – 1914 period, is most often characterized by a series of major technological innovations that had a large impact on the economy in the long run. These technologies are: electricity, chemistry and the internal combustion engine.[144] With the discovery of electricity came the introduction of the telegraph and the electric light bulb. Discoveries in chemistry lead to improved fertilizers, synthetic materials such as rubber and plastic as well as improved material inputs for many products. Discoveries in the treatment process lowered the cost of steel, which had better physical qualities for many industrial purposes than wrought iron. The internal combustion engine led to the automobile and dramatically lowered transportation costs for many people. This collection of discoveries is often referred to as the second Industrial Revolution. In contrast, my framework, extending that of Kuznets, does not define epochs by particular or group of innovations. Rather the defining characteristic, or epochal innovation, is a critical extent of the application science to the problems of economic production. There is a large consensus that the technologies of the second Industrial Revolution are science-based. However, there is clearly some scientific analysis involved in Watt's steam engine of the late 18th century. In my framework, there is no black and white distinction. It is a matter of degree. Although there clearly was some science being applied in the economy in the late 18th century, it was largely limited to the steam engine. Following Kuznets, the application of science to

[142] However, recent research has showed that the impact of this steam power on England's productivity growth was small and largely not realized until around the mid-19th century. See Crafts (2004).
[143] See Mokyr (1998), p. 1. In my view this description can be equally applied to Song China.
[144] This definition largely follows that of Landes, see Landes (1969), p. 4. Note that subsequently Landes lists two other features – precision manufacturing and assembly-line production. See Landes (1969), p. 235. Rosenberg defines the second Industrial Revolution as new chemical technologies, electrical industries, the internal-combustion engine, precision manufacture and the assembly line. See Rosenberg (1982).

problems of economic production began to be widespread around the mid-19th century. Roughly speaking, the different extent of the application of science to the economy emphasized here underpins the differences in innovations between the first and second Industrial Revolutions. In this sense, the framework used here is related to the traditional first and second Industrial Revolutions.

It is also interesting to note that two eminent economic historians offer strikingly similar descriptions of China near the end of the Song Dynasty and Britain near the end of the first Industrial Revolution. Mark Elvin presents the following description of China's agriculture during the late Song Dynasty and subsequent few centuries: "Yields per acre were very nearly as high as was possible without the use of advanced industrial-scientific inputs such as selected seed, chemical fertilizers and pesticides, machinery and pumps powered by the internal combustion engine or electricity, concrete and so on."[145] He goes on to say, "Pre-modern water transport was close to a similar ceiling of efficiency."[146]

David Landes describes the late first Industrial Revolution as follows: "Britain's rates of industrial growth and increase in productivity show a distinct falling-off after the mid nineteenth century decades of high prosperity. They do not turn up again until after 1900. From 1870 on, with the exception of a branch like steel, which was transformed by a series of fundamental advances in technique, British industry had exhausted the gains implicit in the original cluster of innovations that had constituted the (first) Industrial Revolution. More precisely, it had exhausted the big gains. … Not until a series of major advances opened new areas of investment around the turn of the century was this deceleration reversed. These years saw the lusty childhood, if not the birth, of electrical power and motors; organic chemistry and synthetics; the internal-combustion engine and automotive devices; precision manufacture and assembly-line production – a cluster of innovations that have earned the name of the Second Industrial Revolution."[147] These observations suggest that essentially both 1300 China and 1850 England had developed and applied technologies from their non-science based economic growth to their limits. Further significant gains in productivity would require the application of science. Thereafter, their paths diverged and England began to apply science to its economy while China did not.

A comment regarding science and Joseph Needham is warranted here. Insofar as the relationship between science and the economy is concerned, we can divide this issue into two parts. How science came to exist and how it came to be applied to the economy. The former question is clearly related to the so-called "Needham Puzzle,"

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[145] Elvin (1973), p. 306.
[146] Elvin (1973), p. 312.
[147] Parentheses added. Landes (1969), pp. 234 – 35. Joel Mokyr has made a similar observation. See Mokyr (1990), p. 297.

or at least one version of it: Why did China with all its technological advantages not develop science? The appearance of science is an important question, but one that is beyond the scope of this study. The second question presumes the existence of science and asks how it came to be applied to the economy. There are two points in my analysis related to this issue. First, science is stripped from any role in the onset of non-science based economic growth. Second, the role of the application of science in the economy most properly lies in explaining the increase in *already considerably positive growth rates* of per capita product and population.

4. Case 0's – Song China and England (1750 – 1850)

The goal of this study is to define the "*onset* of economic growth" with the objective of finding its cause. An argument can be made for a comparison between Song China and England (1750 – 1850) which is perhaps superior to comparisons with other episodes in that these two have the same cause. When the ultimate goal is to identify cause, episodes with the same cause are preferred. To develop this argument my use of the term "onset" needs to be explained.

By my definition, the *"onset"* of economic growth occurs when it appears in a nation which has no contact with a country experiencing economic growth. The reason for explicit definition regarding the nature of a country's transition is that it has important consequences when considering causation. When analyzing a phenomenon, one must first identify the unit of observation. I follow Kuznets' view that the unit of study for economic growth is the state, which includes all the people and resources under the government's jurisdiction.[148] Hereafter, the state or nation is taken to be the unit of observation. Economic growth is a social disease among nations, or at least observationally equivalent to one. There exists a Case 0 nation, and all subsequent cases are caused by social contact with the Case 0 nation or with another country that contracted economic growth through a chain of contact countries leading back to the Case 0 country.[149] The cause of the *spread* must almost certainly be related to contact with another country that has contracted the disease. But what about the Case 0 nation? Since there was no such contact, the cause of the *onset* must almost surely be different than the cause of the *spread* (just as Case 0 for the plague came from one human contact with an animal while thereafter human social contact was the cause). This

[148] Strictly speaking, Kuznets argued this for the case of his "modern economic growth." See Kuznets (1951). I adopt this view for my definition of economics growth, which is based on Kuznets' definition of "modern economic growth."

[149] Kuznets called the Case 0 nation the "pioneer" country to distinguish it from the countries to which modern economic growth spread, which he called "follower" countries. See Kuznets (1966), p. 497.

painfully explicit description helps make clear the importance, when thinking about causal factors, of distinguishing between a Case 0 nation and those to which it subsequently spreads through social contact.[150]

Until now, scholars have believed that the only Case 0 nation to have existed is England. I argue that this view is incorrect. Previously, I argued that Song China experienced economic growth at a time when China was one of the world's richest countries and the world leader in science and technology. During the Song Dynasty and the preceding centuries, China had no contact with another country that was experiencing economic growth.[151] In particular, I argue that Song China experienced the *onset* of economic growth. However, this episode ceased and did not spread to other countries – important issues that will not be addressed here.

Scholars have studied the case of England's economic growth for over two centuries with no consensus as to its defining characteristics, the date of onset or its cause. England is a difficult case to study. This episode is a noisy one with many signals, some interrelated, some not. It is very difficult to identify key features of this phenomenon, much less their cause, when studying England's episode in isolation. It seems, then, that one of the best ways to discover both defining features and causal factor is by comparison.

As our ultimate goal is to discover the cause, we should compare England with other countries. But what country should be compared with England? "Why England and not country X?" is a common theme in many recent studies.[152] Even if one were to discover an answer in such a study, the question being asked is not the focus here. The answer would explain why country X did not experience economic growth and how England *could*. It does not squarely address the question "what caused England to experience the onset of economic growth?" Comparisons between England and other countries that subsequently experienced economic growth are essentially comparisons between an onset case and a spread case. I argue these two cases very likely have different causes. It seems unlikely that comparing two cases with different causes will help in discovering the cause for either of them. At a minimum, the cumulative knowledge of all of these comparative studies with England, including those with countries that did not experience economic growth and those that

[150] In principle, there will always be the possibility of spontaneous onset of economic growth in a country just as another country experiencing economic growth comes into contact with it. While acknowledging this logical possibility, it is extremely unlikely given world events from 1750.

[151] Here, contact means the arrival of ideas or people from another country. It can also be said that prior to 1400, China had no contact with another country that was its superior in science or technology.

[152] For some recent examples see Greif and Tabellini (2010), Greif et al. (2012), Landes (2006), Lin (1995), Pomeranz (2000), Rosenthal and Wong (2011), Shiue and Keller (2007), and Wong (1997). Some of these studies compare Western Europe to China. Such studies are open to the criticism that their focus on Western Europe as a whole conflicts with the fact that the unit of observation is the state, at least as far as Kuznets' observations are concerned.

experienced the spread, has not generated a consensus as to what caused England's economic growth. The comparison between Song China and England (1750 – 1850) offers a superior comparison. Since they are both onset cases they very likely have the same cause.

Section 4 Summary: It is argued that the comparison between Song China and England (1750 – 1850) offers a superior comparison because, unlike many other comparisons made with England, these two episodes have the same cause.

5. Embryonic Stage & onset of Economic Revolution

My goal is to define the "onset of Economic Revolution". The appropriateness of any definition is relative to its purpose or the question being asked. The ultimate objective of this line of inquiry is to discover the cause of the onset of economic growth.

It will be useful to review the previous arguments. My premise is that there are two types of economic growth, one non-science based (premodern) and one science based (modern). I have argued that both China during the Song Dynasty (960 – 1279) (Song China hereafter) and England (1750 – 1850) are episodes of non-science based (premodern) economic growth. Furthermore, the onset of economic growth and its spread are different social phenomena in that they have different causes. The onset occurs when economic growth appears in a nation which has no contact with another country experiencing economic growth. This is in contrast to the situation where economic growth spreads through social contact among nations. Since the spread is almost surely related to social contact with a country experiencing economic growth and the onset is not, these social phenomena almost surely have different causes. Since both Song China and England (1750 – 1850) are episodes of a non-science based economic growth and since both are onset cases, I contend that they are the same social phenomena with the same cause. In this sense, the Song China comparison with England (1750 – 1850) offers an extremely high chance of revealing the cause relative to other comparisons.

Kuznets' comparative study of modern economic growth serves as the starting point for my analysis. Kuznets compared a collection of countries, identified important common features and used these to produce his definition of modern economic growth. It should be noted that in his comparison, Kuznets did not distinguish between the onset and spread of modern economic growth. Nonetheless, his observation that England (1750 – 1850) experienced modern economic growth (as he defined it) stands independent of the other cases considered. Surely it was the

commonalities of these features in the other cases that influenced Kuznets to choose them. But this does not change the fact that Kuznets observed these features in the case of England (1750 – 1850). Indeed, it is my goal to use these common features as a basis for comparison between two onset cases to further reveal features that will suggest the cause of the onset of non-science based economic growth.

Scholars have long believed that the only episode of the onset of economic growth is England. I argue that Song China is an episode as well. To the extent that I have made this case, we now are in an unprecedented situation in the social sciences. Scholars have long studied a single episode of the onset of non-science based economic growth with little fundamental progress. For the first time, we can compare two cases. In my view the Song China episode contains important information not yet utilized. This new comparison offers the potential of discovery.

We are now poised to compare Song China and England (1750 – 1850) in order to find common characteristics of the *onset* of economic growth and use these characteristics for definition. It is worth noting that Kuznets' definition of "modern economic growth", which serves as a starting point for my definitions, has advantages over others – e.g. characteristics of per-capita product time series or the first and second Industrial Revolution. Rather than simply report changes in the per-capita product time series or describe some specific technologies or sectors, Kuznets' definition captures a *social process*. With this in mind one can extrapolate from this social process while comparing Song China and England (1750 – 1850) and attempt to identify its earliest beginnings.

My comparison between Song China and England (1750 – 1850) focuses on the period immediately preceding non-science based economic growth and aims to discover commonalities. New common characteristics preceding non-science based economic growth are identified, allowing us to define the onset of non-science based economic growth in more detail. The specific nature of these characteristics allows us to date both onset episodes with more precision. Collectively, I define the common characteristics that largely precede non-science based economic growth as the "Embryonic stage."

My comparison reveals a metamorphosis during a period preceding non-science based economic growth and continuing into it which sheds the structures of a self-sufficient agrarian economy and lays the foundation for economic growth. In my comparison the Embryonic stage, i.e. this collection of observed common characteristics, is identified as the turning point between the self-sufficient agrarian economy and non-science based economic growth.

The Embryonic stage is identified as four common characteristics, which I call phases. The order of the phases does not necessarily imply a clear intertemporal order.

For example, in some instances Phase 2 may precede Phase 1. Generally speaking, however, the first three phases occur in order. Phase 4 occurs concurrent with the previous three.

The four phases of the Embryonic stage are: 1) urbanization and commercialization of the countryside, 2) improvements in the internal transportation network, 3) regional specialization, and 4) development of markets and supporting organizations such as those providing transportation of goods and related improvements in money and credit.

For a stylized development of Song China's phases 1, 2 and 3 see Maps 1 – 6 below.

For a stylized development of England's phases 1, 2 and 3 see Maps 7 – 12 below.

Next, I will provide a general description of the four phases and thereafter identify them in both episodes – Song China and England (1750 – 1850). The first phase is the urbanization of the countryside: new small towns and villages appear in rural areas throughout the country. Many of these differ in character from their predecessors in that they are commerce based. Many older towns and villages increase their commercial character as well. Changes occur in the relative prosperity of the towns and villages. Some previously well established ones decline while others achieve rapid prosperity. Many begin to increase interaction with rural areas within their immediate vicinity. Those which experience growth begin to extend their interaction with somewhat more distant towns and villages. These developments increase demands on the local transportation system.

The second phase is improvements in the internal transportation system. Previously, the internal transportation system was limited to a few major arteries largely connecting the capital city to other big cities and to key agricultural areas or important military locations. As the number of towns and villages in the countryside increase and the interaction among them increases, the existing road, canal and river systems become strained. Increased traffic requires improvements in the internal transportation system to maintain these activities. Roads are repaired while existing rivers and canals are cleared. More importantly, small new roads are built and rivers and canals are extended to better connect expanding towns and villages. As the interaction between the towns and villages increases some towns become local hubs that connect nearby urban centers. As the local hubs develop, a hierarchy of hubs emerges and the preexisting arteries of the old transportation system extend to new regions. These developments result in the unprecedented appearance of national markets for many goods. In this way the internal transportation system, which was

originally a limited network of major arteries centered at the capital, develops into a network of roads, canals and rivers that reaches every area of the nation.[153]

It is important to note that urbanization of the countryside and improvements in the internal transportation system are the telltale signs of the onset of economic growth. The first two phases naturally lead to a third.

The third phase is regional specialization. The growth in number and size of towns and villages coupled with their increased capacity for interaction allows an area to specialize in what it naturally produces relatively well and can now transport to regions throughout the country. The extension of the internal transportation system leads to regional specialization.

The fourth phase is development of markets and supporting organizations such as those providing transportation of goods and related improvements in credit. These developments occur concurrent with the urbanization of the countryside, improvements in the internal transportation system and regional specialization. As new towns and villages appear, increased exchange of goods begins in the local area. As a network of towns and villages and links among them develops, the exchange of goods increases and allows for specialized production. This first takes place at the individual production unit level and then develops into regional specialization. Markets develop along with the increases in exchange. Transport merchants appear and deliver goods from producers to consumers over increasing distances during this process. Credit organizations appear to solve new payment problems associated with the delivery of an increasing number of goods to more and distant locations.

Phase I – Urbanization of the countryside

- Song China

During the 760 – 1000 period many small and medium sized towns appeared throughout the countryside of China. Some were situated around regional centers of civil or military personnel while others developed around landed estates. Many rural towns appeared at key land and river transportation locations. Still others appeared near previously existing market centers. During this period we also see an increase in the number of periodic markets. During the later eighth and ninth centuries many of the market towns became walled to protect them from attacks by bandits. Although

[153] Note that the maritime trade that consists of transporting goods along the coast to other domestic port towns is also a part of this system. The support systems of this type of transportation also see expansion and improvement. Foreign maritime trade may well also develop, but this is not considered as fundamentally important to the improvements in the internal transportation system. This process of development of the internal transportation system is largely driven by effects of the urbanization of the countryside.

these developments were uneven over time and space, the general trend of an increasing number of rural towns is clear. These urban centers increasingly engaged in commercial activities.[154] From the early Song Dynasty (960 – 1279), these commercial centers in the countryside continued to flourish as commercial activities continued throughout the dynasty.

- England

From the mid-seventeenth century there was an increase in the number of new towns in the countryside of England. Most notably was the appearance of unincorporated towns such as Liverpool, Manchester, Leeds and Birmingham. These towns grew in number and size throughout England and began to develop commercial activities to such an extent that they began to overshadow well established medieval administrative seats such as Lancaster, York, Chester and Stafford. Economic specialization in industry became increasingly common among these urban centers in the countryside. By 1700 at least half of the urban centers specialized industrially to some extent. By around 1720 one can identify a growing measure of specialization within regional networks of towns. Workshops first emerged in the 1750s and 1760s, preceding some important technological innovations. From the mid-eighteenth century civic improvement became the rage. Old town gates were demolished while streets and bridges were widened. Brick houses came into vogue and covered market halls were built to bring traders off the streets. Theaters, libraries, concert halls and newsrooms began to appear in many towns. In sum, economic specialization first forged in the post-Restoration period throughout the countryside remained the driving force behind urban change in the late eighteenth century.[155]

Phase II – Improvements in the internal transportation system

- Song China

Beginning in the mid-eighth century, China witnessed increased activities in maintenance and new development in its transportation system. Because southern China has more mountains and rivers, many of these developments took the form of

[154] For the appearance of rural towns near regional government centers see Hino (1938), Sudo (1962) and Umehara (1958). For those that appeared near landed estates see Kato (1952), pp. 208 – 60. For towns that came into existence at key land and river communication points and nearby pre-existing market towns see Hino (1967) and Sudo (1965), pp. 783 – 866. For a general treatment of the appearance and development of the market towns in the countryside see Chen (2003), Fu (1989), Kato (1952), pp. 380 – 421, Long (1997), Nishioka (2004), p. 29; Sogabe (1958), (1965), Sudo (1950).

[155] Chalkin (1974); Clark (1984), pp. 14 – 30, 41 – 3; Clark and Slack (1972), (1976); Ellis (1997), (2001); Landes (1969), pp. 51 – 2; Souden (1984), pp. 134, 161; and Szostak (1991), p. 5.

improvements in river and canal transportation, but roads also saw improvements. In northern China the reverse was true – road maintenance and extension played a larger role, but water transportation also saw improvements.

The increased pace of development in constructing new traffic routes was particularly noticeable in southern China during the mid-eighth and ninth centuries. During the ninth century the transportation system near many southern cities witnessed unprecedented developments. For instance, the road system nearby the southern city of Nanjing improved considerably. Throughout the southeastern province of Fujian the transportation system rapidly developed and the city of Fuzhou grew into a major commercial city in the Fujian province. During the Song Dynasty, as commerce in other southeastern provinces increased, the road system extended into mountainous regions to an unprecedented degree. Beginning in the later eighth and ninth centuries, road surfacing appeared on a large scale and during the Song Dynasty became widespread. Placing stones or bricks on roads was particularly important in the south where rain was frequent. Avoiding muddy roads was vital to maintaining traffic flow. The bridges built in China during the Song Dynasty included a much wider variety of structures and shapes and were of better quality than seen in previous dynasties. The stone bridges built in China during the mid-twelfth century reached unprecedented levels in terms of length, weight-bearing capacity and low cost of construction.[156]

From the mid eighth century the inland water transportation system experienced unprecedented expansion and growth. Water increasingly flowed to a larger area, particularly in southern China. Shipbuilding in the Song Dynasty made great improvements. Ships built for water transport grew into a sophisticated collection of dozens of specialized ship types based on function, i.e. cargo, passengers, soldiers, fishing, night-soil, etc. In addition, regional differences in ships developed to adapt to different waterway requirements. Rivers and lakes became interconnected to an extent not seen before. The private shipping sector managed by merchants grew independent from commerce and shipping contracts and insurance developed. The shipping industry improved so as to transport a larger quantity over longer distances and, in doing so, expanded markets. Multiple pound locks became common in canals to allow safe vertical movement of ships. During the Song Dynasty, trees were planted along river banks to prevent soil erosion and flooding. New and more efficient water gates appeared, improving the control of water in canals and the irrigation of agricultural fields. With the improvement of water control for irrigation came the proliferation of walled water fields and the use of water wheels that powered various stone rolling

[156] Cao (2002), p. 270; Cao (2005), pp. 29, 155 – 156; Chen (1992), p. 175; Ihara (2000), p. 53; Jiangsusheng Nanjingshi gonglu guanlichu shizhi bianshen weiyuanhui (1989), p. 127; Zhongguo gonglu jiaotongshi bianshen weiyuanhui (1994), pp. 306, 311, 335, 344.

production such as for processing paper and tea. Coastal trade also witnessed improvements. During the ninth century, sea walls made of stone (whereas they were made of soil previously) became contiguous. During the Song Dynasty sea walls increased in number and became larger and oblique, reducing the power of waves. In ocean going vessels, gaps in the wooden hulls were reduced with the increased use of iron nails and the use of lime and tong oil. In addition, water-tight cabins became increasingly used. Progress in the transportation system accommodated the increasing number of people engaged in trade, transportation and industry.[157]

- England

From the mid-seventeenth century on, there was a continuous and growing investment of public and private resources in the extension of the river system and the construction of new roads and bridges. Generally, rivers and harbors were improved first and followed by road expansion. There was increased interest in transport improvements between 1662 and 1670, which saw the passage of nine river acts. It is important to note that from this period on river legislation became more concerned with the extension of navigation and not, as in previous years, with the repair or maintenance of existing navigation. It was river navigation, mostly from the late seventeenth century, that enabled large numbers of inland towns, old and new, to develop a vast number of specialty manufactures and to find markets in London and other leading cities, or abroad. By 1750 there were over a thousand miles of navigable streams in Britain.

The century after 1660 saw substantial improvements in the means of carriage, especially the provision of wheeled vehicles. The first turnpike authority was established in 1663 while the next in 1695. In the late 17th century, local Justices of the Peace responded to the increasing volume of traffic by providing guide stoops, causeys and stone bridges. By 1700, there was a marked interest in street widening in provincial capital towns. By the 1720s all bridges were made of stone, in contrast to their wood predecessors. The inability of the parish governments' repair system to deal with the increased amount of traffic led to the formation of turnpike trusts which were empowered to levy tolls. From the 1690s the establishment of turnpikes trusts notably quickened in pace. This process accelerated throughout much of the eighteenth century. Increased use of packhorses and employment of middlemen contributed to expanding internal trade. Road books became popular among the

[157] Aoyama (1931), p. 41, (1963), pp. 243-44, (1993), pp. 718-19, 723; Fu (1989), p. 238; Lu (2004), p. 59; Ma (1971), pp. 16-17; Qi (1987), p. 102; Shiba (1965), p. 463, (1967), pp. 43, 46, 56-7; Wang and Zhang (1990), pp. 328, 344; Yang (2008), pp. 772 – 773; Zheng (2007), p. 443; Zhongguo gonglu jiaotongshi bianshen weiyuanhui (1994), pp. 335, 344.

increasing number of travelers. A railway network developed from 1830 and by 1900 a system of main lines emerged that connected London with the main other inland cities.

The increasing amount of construction and repair of roads, rivers and harbors in the second half of the seventeenth century was the beginning of a concerted attempt to mitigate the restrictions imposed by inadequate transport facilities. The improvement of the transport system resulted from the increased traffic which in turn made further expansion possible.[158]

Phase III – Regional specialization

- Song China

After the mid-eighth century the self-sufficient economy of China experienced a noticeable shift towards large-scale specialized production for the market. Individual production units and organizations began to specialize in a single product to sell in the expanding markets. Many such units specialized in goods such as rice, wheat, lighting oil, candles, dyes, oranges, litchi nuts, vegetables, sugar and sugarcane, lumber, cattle, fish, sheep, paper, lacquer, textiles and iron.[159] As the transportation system expanded and markets stretched into new regions, regional specialization developed. Litchi nuts were produced in the southwestern and southeastern regions. However, the Litchi nuts of the coastal province of Fujian were of the best quality and a national market developed for them. Tea growing districts were centered in Sichuan and in southern China. Tea drinking became a major drink among all ranks of society during the Song Dynasty. Numerous varieties of types and qualities of tea were produced for national markets and tea merchants handled the transportation to and storage of tea to many markets. High quality "Palace Hall" paper began to be produced in the mid-tenth century in a southern region of China and by the Song Dynasty it had gained a national reputation. During the Song Dynasty bark and bamboo paper were produced in Mingzhou and spilt rattan paper was produced in Hangzhou.[160]

- England

[158] For both water and road transportation, see Albert (1972), pp. 11 – 13, 17 – 23; Bogart (2011); Clark (1984), p. 23; Clark and Slack (1976); Hey (1980); Jones (2010), pp. 193 – 97; Landes (1969), pp. 46 – 7; and Ville (2004), p. 305.

[159] See Shiba (1968), pp. 143, 149-50, 159, 182, 185, 193-94, 197, 200, 204-09, 214-15, 218-21, 223-33, 235-58, 262-63 and 270-71.

[160] Shiba (1968), pp. 158 – 66, 204; Shiba (1970), pp. 89-90.

Phase IV – Development of markets and supporting organizations

- Song China

- England

6. Summary, Discussion and Conclusion

The goal of this study is to define the "onset of Economic Revolution" with the objective of finding its cause. In developing this study I have argued that there two types of Economic Revolution – one non-science based (Premodern) and one science based (Modern). For many readers, the most difficult aspect of my analysis to accept will be the role of technology in Premodern Economic Revolution. The apparent contradiction with the well established foundation of economic growth – the dominant influence of technology – will likely be met with skepticism at first glance. Before proceeding a comment about technology is in order. Thereafter a brief summary will be presented, followed by discussions about the onset/spread of Economic Revolution and their relationship to technology and the Embryonic Stage. Finally, my concluding comments are provided.

First, technology, broadly defined, includes many factors such as science, scientific production technologies, non-scientific production technologies, the organization of production, human capital and others. The focus of my analysis is limited to one aspect of technology – the widespread application of science and scientific technologies in the economy. I argue that there are two types of Economic Revolution. The first type, Premodern Economic Revolution (non-science based) takes place when science and scientific technologies *are not in* widespread use but all other factors of technology are at work. The second type, Modern Economic Revolution (science based) takes place when science and scientific technologies *are in* widespread use and all other factors of technology are at work. In short, science and its applications are absent in one – the Premodern – type of Economic Revolution. Yet in this type of non-science based economic growth all other aspects of technology are at play – increased rate of technological innovation (albeit non-science based), changes in the organization of production, increases in the quality and variety of skills and so on. Therefore, it would be incorrect to interpret my conception of non-science

based Economic Revolution as fundamentally different from 20th century economic growth in the West except for the widespread application of science and scientific technologies to the economy. Lastly, it should be noted that there is very little controversy that Premodern Economic Revolution (non-science based) has been identified in the data – the first century of Economic Revolution in England, and, as I shall argue, China during the Song Dynasty (960 – 1279) (Song China hereafter).

A fundamental tenet of modern economic growth and development is the view that an increase in the growth rate of per capita product (or maintaining the growth rate for a country on the technological frontier) requires an increase in productivity, most often associated with technological innovation. In short, an increased growth rate of per capita product is associated with an increase in the pace of technological innovation. It is important to note that in the case of Song China, the lack of application of science to the economy *does not mean* that no increase in the rate of technological innovation occurred. Indeed, the Song Dynasty (960 – 1279) is generally viewed as the most technologically innovative period in China's imperial history.

During the Song Dynasty (960 – 1279) and its preceding centuries, China experienced an increase in its rate of technological innovation. The figures reported below are based on data of significant inventions reported by Joseph Needham and others.[161]

China's Rate of Technological Innovation

Period	*Innovations Per Century*
600 – 750	5
750 – 1000	8
1000 – 1250	15

Table 6.2

Table 6.2 reveals that the innovation rate per century increased in the late Tang Dynasty (608 – 907) and nearly doubled during the Song Dynasty. These figures support the commonly held view that Song China was more technologically creative

[161] Two sources of dated significant inventions are used to construct the innovation rates reported. Temple (1986) dates 111 significant innovations in a variety of sectors. Temple's work is based on that of Needham's. Li (1981) dates 80 significant agricultural tool inventions. These innovations are first dated by century. When calculating the reported figures for the periods considered, a constant rate of innovation is assumed within each century and dynasty.

than during the previous centuries. Here we see that there is no conflict with the basic tenet that an increase in the growth rate of per capita product is associated with an increased rate of technological innovation. In short, no science does not mean no technological innovation.

Summary

I contend that there are two types of Economic Revolution – (i) Premodern Economic Revolution (non-science based), associated with a low growth rate of per capita product and (ii) Modern Economic Revolution (science based), associated with a high growth rate of per capita product. To understand my claim it is necessary to have a full understanding of the foundation laid out by Kuznets at the outset of his study of the growth of nations, Kuznets (1966). Kuznets began his comparative study by creating two frameworks, one qualitative and one quantitative. He started with the qualitative arguing that the past can be divided into periods (at least one century long), which he called epochs. Further, each epoch can be characterized by what he called an "epochal innovation" – the dominant characteristic which distinguishes the epoch from those before and after. Kuznets was particularly interested in what he called the "modern economic epoch". The epochal innovation that distinguishes this epoch is "the extended application of science to problems of economic production." Indeed, Kuznets also referred to this epoch as "the scientific epoch". With this qualitative framework as a backdrop, Kuznets then set out to measure various economic variables in a comparative study of sixteen countries. He identified regularities in the data and used observed common features to define his quantitative framework – "modern economic growth", which he defined to be a sustained increase in per capita product, accompanied by an increase in population and sweeping structural changes.[162] It must be noted that neither science nor its application is a part of Kuznets' definition of "modern economic growth". In this way, Kuznets defined two distinct frameworks: one qualitative (the scientific epoch) and one quantitative (modern economic growth). According to Kuznets, these two frameworks coincided with one exception – England (1750 – 1850). His qualitative framework, the scientific epoch (based on the extended application of science to problems of economic production), was identified as the period 1850 – 1950, while his quantitative framework, modern economic growth (based on observed patterns in economic variables) was identified as the period 1750 – 1950. Kuznets observed that during the first century of modern economic growth in England (1750 – 1850), the extended application of science was clearly

[162] See Section 2, pp. 24 – 25, above for a more detailed presentation of Kuznets' definition and for his definition in full see Kuznets (1966), p. 1.

absent.[163] In all other cases in his comparative study the two frameworks coincided. Despite this conflicting observation, Kuznets identified these two frameworks and dated them both to the period 1750 – 1950.

I argue that China during the Song Dynasty (960 – 1279) (Song China hereafter) experienced "modern economic growth" as Kuznets defined the term. In addition, the application of science was clearly absent in the Song China episode. From these observations, I argue that Kuznets was incorrect. In particular, Kuznets' qualitative and quantitative frameworks are distinct and should not be identified with each other. Song China and England (1750 – 1850) both experienced "modern economic growth", as Kuznets defined the term, without the extended application of science to problems of economic production. The fact that the Song China episode covered three centuries clearly reveals that England's first century of "modern economic growth" was not a transitory phase to "the scientific epoch".[164]

Kuznets argued that the most important characteristic of modern economic growth is a "high" growth rate of per capita product. I have shown, using Kuznets' and more modern data, that the growth rate of per capita product of England (1750 – 1850) likely does not meet Kuznets' standard for a "high" growth rate. Given that Song China and England (1750 – 1850) lack both the extended application of science to economic problems and "high" growth rates of per capita product, I argue these two episodes do not meet Kuznets' intended meaning of "modern economic growth" with the extended application of science to economic problems along with its associated high growth rate of per capita product. Rather, I contend that we are actually observing two different types of "modern economic growth" – one non-science based (Premodern), one science based (Modern).

With this distinction in mind, I define two types of economic growth. The first type, Premodern Economic Revolution is taken to be "modern economic growth" as Kuznets defined the term *without* the extended application of science to problems of economic production, and is characterized by a low growth rate of per capita product. I use the terms "Premodern" and "non-science based" synonymously. The second type,

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[163] Kuznets observed that the steam engine was in its early developmental stage in England (1750 – 1850), but he regarded this as the only major application of science in the economy during this period. Yet, this single example did not warrant the characterization of the "*extended* application of science" in the economy for Kuznets, nor has it for many subsequent scholars. For a discussion of the role and impact of the initial developmental stage of the steam engine during this period see Section 3 above, pp. 34 (ft. 93), 38.

[164] Some may argue that Song China's episode did not continue until the present and that it was only a short-lived case – either argument justifying its exclusion from analysis. This view has two fundamental problems. First, Kuznets clearly stated otherwise and in fact explicitly encouraged such extensions of his analysis. For more on Kuznets' elaboration with references see pp. 7 – 8 above. Eric L. Jones has made related arguments – see Jones (1988). Second, if one views Song China's three century period as short-lived, then one must wait until the year 2050 to see if the rise of the West will be classified as short-lived.

Modern Economic Revolution is taken to be "modern economic growth" as Kuznets defined the term *with* the extended application of science to problems of economic production, and is characterized by a high growth rate of per capita product. I use the terms "Modern" and "science based" synonymously. Finally, I use the term Economic Revolution to mean Premodern Economic Revolution and/or Modern Economic Revolution.

Thus, we have two episodes of Premodern Economic Revolution, Song China and England (1750 – 1850), while England (1850 – 1950) and the other cases in Kuznets' study are identified as Modern Economic Growth. The cases of Song China and England (1750 – 1850) are the focus of this study.

This study aims to define the "*onset* of Economic Revolution." Definitions are relative to a purpose. World history shows that all onset cases were in fact episodes of Premodern Economic Revolution. All post-1800 cases of Economic Revolution were either a transition from Premodern to Modern Economic Revolution, as was the case in England, or were spread cases. The eventual goal of this line of inquiry is discover the cause of the onset of Economic Revolution. Therefore, causation is a fundamental factor in any such definition. I argue that the two episodes of Premodern Economic Revolution experienced by Song China and England (1750 – 1850) very likely had the same cause. To follow this argument, the distinction between the *onset* and the *spread* must be clearly understood. The *onset* occurs when Economic Revolution appears in a nation which has no contact with another country experiencing Economic Revolution. This is in contrast to the situation where Economic Revolution *spreads* through social contact among nations. Since the spread is almost surely related to social contact with a country experiencing Economic Revolution and the onset is not, these social phenomena must have different causes. These causes are an extremely fundamental distinction which is developed in fuller detail in the following discussion section. I argue that Song China and England (1750 – 1850) are both onset cases and therefore very likely have the same cause – one that can better be revealed by a comparison of onsets.

Finally, I compare Song China and England (1750 – 1850). In order to develop my definition of the onset of Premodern Economic Revolution, I include common features that precede its onset. In my comparison, I identify a set of common changes, which I collectively define as the "Embryonic Stage." The Embryonic Stage consists of four phases: 1) urbanization and commercialization of the countryside, 2) improvements in the internal transportation network, 3) regional specialization, and 4) development of markets and supporting organizations such as those providing transportation of goods and related improvements in money and credit. I argue that the appearance of the Embryonic Stage is the turning point for the onset of Premodern

Economic Revolution. An important aspect of the Embryonic Stage is that it provides the environment to change the nature of both firms and households, which are the fundamental building blocks of any economy. These aspects of the Embryonic Stage are more fully elaborated in the discussion section below. I complete my analysis by defining the "onset of Economic Revolution" as an episode of Premodern Economic Revolution that is preceded by the Embryonic Stage.[165]

Discussion

- *Onset, Spread and Technology*

Economists understand that there are different types of economic growth, at least during the 20th century. Let me begin by describing a well established distinction between two kinds of economic growth. There has been significant research on the economic growth of nations since the Second World War. One lesson drawn from this research is that technology, broadly defined,[166] is the engine of economic growth. Kuznets spoke of this as the "stock of useful knowledge".[167] Yet it is widely held that there are different kinds of economic growth. If a country's economy is efficiently using the best available technology, it is identified as a frontier country. Those not using their existing technologies efficiently or not having adopted the best technology available are called non-frontier countries. Given that technology is the engine of growth, the only way for a frontier country to increase its productivity in the long run is to discover new technologies. For non-frontier countries, productivity gains can be realized by simply using existing technologies more efficiently or adopting better technologies from other countries. A country does not have to reinvent the automobile, but rather to facilitate the adoption of existing technologies from abroad to increase its productivity. It is fair to say that there is a consensus among economists that these are two different kinds of economic growth. The institutions and policies needed to increase productivity in these two kinds of economies are fundamentally different.

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[165] Note that, as mentioned earlier, world history shows that the only onset cases were episodes of Premodern Economic Revolution. Thus the two terms "onset of Economic Revolution" and "onset of Premodern Economic Revolution" are in fact the same phenomenon – since no episode of the "onset of Modern Economic Revolution" occurred and the use of my term "Economic Revolution" means "Premodern Economic Revolution" and/or "Modern Economic Revolution".

[166] Specifically, in terms of modern growth theory by technology I mean both human capital and total factor productivity.

[167] See Kuznets (1966), pp. 6, 30. Mokyr provides a different definition of useful knowledge and decomposes it into what he calls *prescriptive* knowledge and *propositional* knowledge. Prescriptive knowledge is instructional knowledge or techniques. Propositional knowledge is knowledge about natural phenomena and regularities. It is important to note that Mokyr's concept of propositional knowledge includes science as well as types of knowledge outside of the limits of science. See Mokyr (2002), pp. 1 – 27, especially 4 – 7, 52.

In my view, economists have not sufficiently distinguished between two other types of economic growth – the *onset* and the *spread*. The lack of a clear distinction between these two types is hindering progress in our understanding of long run economic growth, at least in my opinion. In what follows, I shall try to clarify this distinction and explain why it is of crucial importance.

I follow Kuznets' view that the unit of study for economic growth is the state, which includes all the people and resources under the government's jurisdiction.[168] Hereafter, the state or nation is taken to be the unit of observation. Economic Revolution is a social disease among nations, or at least observationally equivalent to one. There exists a Case 0 nation, and all subsequent spread cases are caused by social contact with the Case 0 nation or with another country that contracted Economic Revolution through a chain of contact countries leading back to the Case 0 country.[169] The cause of the *spread* must be related to contact with an Economic Revolution country. But what about the Case 0 nation? Since there was no such contact, the cause of the *onset* must be different than the cause of the *spread* (just as Case 0 for the plague came from one human contact with an animal while thereafter human social contact was the cause). This painfully explicit description helps make clear the importance, when thinking about causal factors, of distinguishing between a Case 0 nation and those to which it subsequently spreads through social contact.[170] In sum, the cause of the onset case is *different* from the cause of the subsequent spread cases.

While accurate as a first order level of analysis of this issue, a good explanation of the distinction between onset and spread should more explicitly identify the mechanisms at work behind these social processes. Here, I explain the mechanism that, as I see it, has been at play for the spread and argue that it could not have been at work in onset cases.

To begin this discussion, let us consider a well established tenant of 20th century economic growth as a point of departure. Arguably the most fundamental tenet of modern economic growth and development is that technology (broadly defined to include total factor productivity (TFP) and human capital) accounts for most productivity gains in the late 20th century. A frontier country, i.e. a country with the highest level of technology, must internally improve its technology in order to realize sustained long-run economic growth in per capita product. More relevant to this discussion is the diffusion of technology from the frontier country to non-frontier

[168] Strictly speaking, Kuznets argued this for the case of his "modern economic growth." See Kuznets (1951). I adopt this view for my definition of Economic Revolution, which is based on Kuznets' definition of "modern economic growth."

[169] Kuznets called the Case 0 nation the "pioneer" country to distinguish it from the countries to which modern economic growth spread, which he called "follower" countries. See Kuznets (1966), p. 497.

[170] In principle, there will always be the possibility of spontaneous onset of Economic Revolution in a country just as another country experiencing Economic Revolution comes into contact with it. While acknowledging this logical possibility, it is extremely unlikely given world events from 1750.

countries.[171] Somewhat of a consensus has developed that the key for non-frontier countries to catching up is adoption of the best technologies available and using them efficiently. In sum, in the second half of the 20th century, the diffusion of technology has played a major role in increasing long-run growth rates in per capita product of non-frontier countries.[172] While we should not blindly adopt this observation and apply it to the spread of Economic Revolution during the 19th and early 20th centuries, it serves as a useful point of departure. Lastly, it should be mentioned that technology, as used here, can be embodied in goods and/or ideas transmitted via experience, communication between people or books. In short, a production technology is an "idea".

When considering any long-run view of the role of technology diffusion with the spread of Economic Revolution, one fact immediately stands out. Technology diffusion across countries has been taking place for many millennia. It is well known that paper, gunpowder and the compass all spread from China to the West. The social contact associated with these Chinese inventions did not initiate an Economic Revolution in Europe. In addition, Europe has many examples of its own. Gutenberg's moveable type mechanized printing press appeared in Mainz, Germany in the mid-15th century. Within about half a century this technology had spread throughout Western Europe and around 1000 printing presses were in operation throughout Germany, Italy, France, the Netherlands, Switzerland, Spain, Belgium and many other places. Yet the spread of this important technology did not initiate an Economic

[171] Strictly speaking one should not use countries in this portion of the analysis. Industries would be more appropriate. This is because a single country with all the highest level of technology in every sector does not exist at present. For instance, Korea may have the highest level of technology in mobile phones while Japan might have the world's best technology in automobile production. Nonetheless, this over simplification will serve its purpose – to convey a related concept.

[172] For some important contributions to this literature see Lucas (1988), (2002), (2009), Parente and Prescott (2000), and Prescott (1998). Note that Parente and Prescott explain relative differences in per capita income levels but not in their growth rates. This intuition derived from their study of about 100 countries over the 1960 to 1985 period, where they observed both growth miracles and disasters (see Parente and Prescott (1993)). They concluded that the large growth rates were transitional and that the main feature was a shift in the steady state. In addition, the focus of their study was different. As they state: "… our primary concern is with the relative economic performances of countries subsequent to the industrial revolution." (see Parente and Prescott (2000), p. 3). Ngai (2004) has made a notable comment regarding the timing of the onset of modern growth. In my opinion, the intuition behind Parente and Prescott's choice to emphasize levels should not be accepted in toto when one is considering the issue of the spread of Economic Revolution that took place in the 19th and early 20th centuries because the driver in the dramatic relative mobility they observe is a massive gap in the level of technology between countries. As Parente and Prescott state, "A necessary precondition for a country to undergo a development miracle is that the country is not exploiting a significant amount of the stock of usable knowledge and therefore is poor relative to the industrial leader." (see Parente and Prescott (2000), p. 4). I point out that this massive gap in technology did not exist in the 19th century when the Economic Revolution was spreading from England to the European continent. It may prove to be correct, but at a minimum we should not expect to see such dramatic increases in growth rates as Economic Revolution spreads early on. For this reason, I have focused on long-run growth rates in this study and do not see this as contradictory to the view of Parente and Prescott. For the diffusion of the Industrial Revolution see also Lucas (2009).

Revolution. In fact, the basic idea of mechanized production was not adopted in any other sectors for mass production of goods. The diffusion was limited to the book printing industry. Superior technologies have been transferred from one country to another for thousands of years. Such diffusion was either limited or dissipated in terms of initiating Economic Revolution. Why did the diffusion of technology around the mid-19th century suddenly set off the spread of Economic Revolutions and not before?

My theory is that there are two important factors that explain this important question. The first factor is world history of technology, which has two key characteristics that both changed around the mid-19th century. The second factor is an important, yet underappreciated, political economy feature.

Let us consider the first factor – world history of technology. There are two key characteristics of the spread of technology throughout the world that changed around the mid-19th century. The first characteristic is the nature of production technology. Production technologies from the mid-19th century had two notable aspects: (i) there was science involved in the development of these technologies (i.e. they were *scientific production technologies*), including the steam engine, chemicals and others, (ii) the productivity gains associated with the adoption of these technologies were huge by the standards prior to the mid-19th century. The second characteristic of world history of technology was the increase in the frequency and number of technologies that spread across countries. Prior to the mid-19th century only very infrequently did a new production technology, (associated with modest productivity gains) transfer from one country to another. From the mid-19th century, countries that came in contact with Modern Economic Revolution countries were bombarded with numerous scientific production technologies, each of which offered large productivity gains. These two characteristics of the world history of technology can be observed in differences of growth rates of per capita product among countries that began the spread of Modern Economic Revolution at different times.

A closer observation of the last couple of centuries of economic development offers strong support to my claims regarding world history of technology. Let us begin with some extreme cases of the late 20th century. Most of the spectacular episodes took place in the Far East where contact with Modern Economic Revolution countries occurred late relative to Europe and its offshoots. The economic growth miracles of Japan, Taiwan, Hong Kong, Singapore and South Korea – and more recently post-1978 China – exhibited two important characteristics. First, their growth rates of per capita product during the late 20th century were much higher than those observed previously throughout the world. Although there are exceptions, the growth rates of per capita product of many countries in the late 20th century were far higher than

experienced during the 19th century.[173] This has been most forcefully pointed out by Parente and Prescott.[174] The reason is fairly well established. When exposed to Modern Economic Revolution countries, and their advanced scientific technologies, in the late 20th century, there was a large technology gap between the domestic production technologies of countries in the Far East and those of the West. According to Parente and Prescott, regarding the economic growth miracles of the late 20th century,

> "All of these growth miracles are a recent phenomenon and are limited to countries that initially were far behind the industrial leader when their miracle began. … This suggests that the potential for rapid growth is greater the farther behind a country is from the industrial leader. Late entrants to modern economic growth have, in fact, typically doubled their per capita incomes in far less time than early entrants did."[175]

Parente and Prescott also state,

> "A necessary precondition for a country to undergo a development miracle is that the country is not exploiting a significant amount of the stock of useable knowledge and therefore is poor relative to the industrial leader."[176]

It is important to point out that modern growth economists have concentrated on the post World War II period since there has been an explosion in the availability of quality economic data covering this peiod. However, this general process of follower countries catching up to the leaders at an increasing rate has been occurring for a much longer time period than economists have recently assumed.

Parente and Prescott partially address this issue,

> "Western Europe was never in a position to experience a development miracle because it never met the precondition of a large stock of

[173] Lucas points out that not all countries in the Far East experience a miracle through a comparison between the economic performance of the Philippines and South Korea during the 1960 – 88 period – see Lucas (2002), pp. 71 – 2. Parente and Prescott make a related observation – see Parente and Prescott (1993).
[174] See Parente and Prescott (2000), pp. 20 – 24 and especially Figure 2.3, p. 22.
[175] See Parente and Prescott (2000), p. 21.
[176] See Parente and Prescott (2000), p. 4.

unexploited knowledge."[177]

It is important to note that the growth rate of England and the European continental countries did not approach the extremely high rates of growth observed in the late 20th century cases of Japan, Taiwan, Hong Kong, Singapore and South Korea. However, it is not often recognized that differences in growth rates of per capita have been observed in 19th century European countries. The seminal work of Alexander Gerschenkron clearly established a European observation in his book *Economic Backwardness in Historical Perspective*. Gershenkron argued, all else equal, that the later a European country began industrialization the higher the growth rate of its per capita product. The reason for this, according to Gershenkron, was that the later a 19th century European country began industrialization the more new foreign technologies were available for use in the "backward" country. This was a main theme in Gershenkron's research and he made clear statements of his views. According to Gershenkron,

> "It is the main proposition of this essay that in a number of important historical instances industrialization processes, when launched at length in a backward country, showed considerable differences, as compared with more advanced countries, not only with regard to the speed of development (the rate of industrial growth) but also with regard to the productive and organizational structures of industry which emerged from the process."[178]

Gershenkron goes on to say,

> "Assuming an adequate endowment of usable resources, and assuming that the great blocks to industrialization had been removed, the opportunities inherent in industrialization may be said to vary directly with the backwardness of the country. Industrialization always seemed the more promising the greater the backlog of technological innovations which the backward country could take over from the more advanced country. Borrowed technology, so much and so rightly stressed by Veblen, was one of the primary factors assuring a high speed of development in a backward country entering the stage of industrialization. … But all these superficialities tend to blur the basic fact that the contingency of large

[177] See Parente and Prescott (2000), p. 4.
[178] See Gershenkron (1962), p. 7.

> imports of foreign machinery and of foreign know-how, and the concomitant opportunities for rapid industrialization with the passage of time, increasingly widened the gulf between economic potentialities and economic actualities in backward countries."[179]

Gerschenkron pointed out important factors that could affect the timing and nature of the beginning of industrialization in a backward country, including the state, banks, ideologies and other factors. Yet the general pattern he identified is clear – all else equal, the later a country began industrialization the faster its industry sector grew and the main reason for the higher growth rate was the number of advanced technologies that could be adopted from the industrial leaders. Thus, the same general pattern can be observed from the mid-19th century through the entire 20th century – the later a country comes in contact with a Modern Economic Revolution country and begins to adopt the scientific production technologies, the faster its growth rate of per capita product because the technology gap is increasing.

To review the argument, the goal is to identify the mechanism of the spread of Economic Revolution and to show that it could not have been at work in onset cases. The specific question at hand is: Why did the diffusion of technology around the mid-19th century suddenly set off the spread of Economic Revolutions and not before?

I argue there are two important factors that explain this important question. The first factor is world history of technology, which witnessed two changes around the mid 19th century. Regarding the history of world technology, I have argued that, although there are exceptions, the *magnitude* of the growth rate of per capita product is generally higher the later a country experiences the spread of Modern Economic Revolution. Again, technological diffusion has been going on for millennia. So why did not European countries initiate Economic Revolution when the Guttenberg mechanical printing press spread throughout Europe in the late 15th century? I point out that there are two key differences in the diffusion of technology between the periods before and after the mid-19th century. First, the nature of technology changed – scientific production technologies with very high productivity gains began to diffuse from England around the mid-19th century and subsequently from other countries as Modern Economic Revolution spread. Second, there were many such technologies that diffused at a higher frequency than before the mid-19th century. My argument thus far only explains, beginning in the mid-19th century, the later the spread of Modern Economic Revolution occurs the higher the growth rate of per capita product.

My second factor is related to these observations of the history of technology

[179] See Gershenkron (1962), p. 8.

and does reveal a mechanism for the spread of Modern Economic Revolution. It is a political economy factor. To continue this explanation further I must introduce a minimal amount of theory in order to explain the mechanism I claim is at work. I contend that there are local social groups in all countries that block technological adoption from abroad. Each individual country had its own particularities, which determined differences in outcomes. This should not distract us from focusing on common factors. The central factor in the spread of Modern Economic Revolution is the coordination costs of the local blocking groups in each country. Various groups resist change in order to protect their power, economic interests, social status and government backed privileges. Prior to the mid-19th century technologies with limited productivity gains infrequently diffused from country to country. Paper, gunpowder and the compass all diffused from China to the West. The Guttenberg mechanized printing press spread throughout Europe in the latter 15th century. All of these examples had a major impact on human societies – improvements in literacy, warfare and the opportunities for maritime exploration are all human achievements of the first order. But none of them initiated Economic Revolution as they diffused. Why? I contend that the limited productivity gains and infrequent appearance of these technologies did little to alter the power structure (coordination costs) of local societies throughout the world. This dramatically changed around the mid-19th century. When a country is presented with the opportunity to adopt steam powered trains, efficient coal power, the telephone, electricity, the automobile and other highly productive technologies – all within a relatively short time period – it has the effect of increasing the coordination costs of local social groups that block the adoption of these technologies. Some in the blocking group defect while other groups increase their efforts to adopt these scientific technologies and work for the needed social and institutional changes required to support these changes and improve their livelihood. I claim the more scientific technologies and the higher the productivity gains possible from their use, the more difficult it becomes for groups to block their adoption and spread (i.e. the coordination costs of blocking increase). In my view, this is why the diffusion of technology across countries was slow and limited for several millennia prior to the mid-19th century. Thereafter, the world changed rapidly as Modern Economic Revolution spread throughout most of the world.

Observations on the *nature* of the spread as it occurred over the last couple centuries provide support for my claim. Let us begin, again, with the late 20th century – the growth miracles of the Far East. Two observations are reasonably clear in the cases of Japan, Taiwan, Hong Kong, Singapore and South Korea. First, these countries were exposed to a relative large gap in the level of technology and the number of technologies from the West within a fairly short period of time. Second, in

each case the entire country moved rapidly towards modernization. Granted, different regions and sectors developed unevenly – but the dramatic movement towards modernization within 50 – 100 years is both undeniable and unprecedented in their respect histories. In short, when a country of the late 20th century was exposed to many highly productive scientific technologies, resistance to modernization was fairly minimal.

These late 20th century growth miracles stand in sharp contrast to the Gerschenkon's observations of the spread of Modern Economic Revolution in Europe in the 19th century when these countries were exposed to fewer scientific technologies and the productivity gains were higher than those of the pre-19th century era, but much lower than those of the late 20th century. It is instructive to note Gerschenkron's observations and conclusions regarding the spread of industrialization in the 19th century.

Early in the spread of Modern Economic Revolution two of the most important technologies were railroads and coal, which are complements and both require major investments. One main organization capable of initiating the adoption and development of railroads and coal was the bank. France offers an important example. Industrial banking developed in France with the growth of Credit Mobilier Bank established by the Pereire brothers in the mid-19th century. The goal of this bank was to invest in railroads, factories, canals, buidt ports and modernize cities not only in France but in other countries. It is important to note that financial ventures had previously appeared in France and other countries, but without major successful changes. The Pereire brothers with their Credit Mobilier Bank posed a threat to the "old wealth" of French banking, most notably the Rothschilds, who resisted these movements towards financing the modernization of France. In the end, the Rothschilds won, but only in principle. They effectively blocked the Pereire brothers establishment of the Austrian Credit-Anstalt, but were able to do so only because they stepped in and began the modernization of Austria themselves, building railroads and industrializing the country. In this case the "old wealth" won the battle but lost the war to the "new wealth". Similar banking institutions subsequently appeared in Germany, Austria and Italy and became intimately involved in industrial enterprise and railroad development.[180] It is crucial to note that financial ventures had appeared in Belgium, Germany and France before the mid-19th century, but none of them succeeded in effectively challenging the "old wealth" or initiating major changes on a large scale. I contend that appearance of the railroads, advanced coal fuel, mining techniques and other scientific production technologies was the main factor that changed the environment allowing "new wealth" and other challengers to overthrow

[180] See Gerschenkron (1962), pp. 11 - 16

or force the old guard into modernizing Continental Europe in the 19th century.

The contrast between Continental Europe in the 19th century and the Far East growth miracles highlights the key mechanism of the spread of Modern Economic Revolution. In Japan and other Far East countries in the late-20th century, resistance was slight and the whole country – meaning virtually all regions and industries – moved rapidly towards modernization, i.e. the adoption and development of many foreign, highly productive scientific technologies. In the case of 19th century Continental Europe, the changes toward modernization were relatively limited, slower and centered on the few scientific technologies of the time – especially railroads and coal. I argue that the coordination costs of blocking the adoption of many highly productive scientific production technologies in late-20th century Japan increased dramatically, allowing nationwide changes to take place relatively quickly, accompanied by the dramatic increase in the Japanese growth rate of per capita product. In the case of Continental Europe, fewer moderately productive scientific production technologies appeared and while there was an increase in the coordination costs of the blocking groups, it was relatively modest compared to the increase in late-20th century Japan. Gerschenkron made some important comments regarding the nature of Continental European industrialization in the 19th century,

> "… the tendencies in backward countries to concentrate much of their efforts on introduction of the most modern and expensive technology, their stress on large-scale plant, and their interest in developing investment-goods industries need not necessarily be regarded as flowing mainly from a quest for prestige and from economic megalomania."[181]

The consequence was that industrialization was slower, not as widespread and less dramatic in 19th century Continental Europe relative to late 20th century Japan. Nonetheless, all of Continental Europe eventually experienced the spread of Modern Economic Revolution. Gerschenkron suggestively expresses a similar view of the mechanism of the spread of Modern Economic Growth,

> "*In viewing the economic history of Europe in the nineteenth century, the impression is very strong that only when industrial development could commence on a large scale did the tension between the preindustrialization conditions and the benefits expected from industrialization become sufficiently strong to overcome the existing obstacles and to liberate the forces that made for industrial*

[181] See Gerschenkron (1962), p. 26.

progress."[182]

Gershenkron goes on to say,

> "*This aspect of the development may be conceived in terms of Toynbee's relation between challenge and response. His general observation that very frequently small challenges do not produce any responses and that the volume of response begins to grow very rapidly (at least up to a point) as the volume of the challenge increases seems to be quite applicable here. The challenge, that is to say, the "tension," must be considerable before a response in terms of industrial development will materialize. The foregoing sketch purported to list a number of basic factors which historically were peculiar to economic situations in backward countries and made for higher speed of growth and different productive structure of industries.*"[183]

In sum, I contend that the diffusion of numerous and highly productive scientific technologies from the mid-19th century across countries, through its concomitant effect of increases in the coordination costs of blocking groups, accounts for the spread of Modern Economic Revolution. In addition, increases over time of the technology gap between Modern Economic Revolution countries and other countries accounts for ***both*** the increasing ease of the spread of Modern Economic Revolution[184] and the increasing growth rate of per capita product. Two final comments are worthy of note. First, my theory of the spread of Modern Economic Revolution offers an explanation to the question of why pre-19th century episodes of Premodern Economic Revolution did not spread – without scientific technologies they lacked the quantity and quality of technologies to affect change in nearby countries. I contend this is why Song China's episode of Premodern Economic Revolution did not spread. Second, this mechanism of the spread of Economic Revolution can not have been present in onset cases. Consequently, the cause of the onset of Economic

[182] See Gerschenkron (1962), p. 11.
[183] See Gerschenkron (1962), p. 11.
[184] Note that improvements in transportation and communication technologies, in particular, brought countries in contact with each other faster and more frequently. Parente and Prescott have brought up a related point. Motivated to explain a different observation, they state: "Finally, the narrowing of the gap between the industrial leader and the rest of the world that has occurred subsequent to 1970 also leads us to search for a theory of relative income differences. The reason is that increases in interactions among people throughout the world should result in more countries' adopting the better economic institutions of the rich industrialized nations. Thus we are led to consider theories of relative income differences whereby a country's policy determines when it enters modern economic growth and …" See Parente and Prescott (2000), p. 25. In my view they are struggling with related issues.

Revolution is different than the cause of the spread of Economic Revolution. Therefore, when the goal is to discover the cause of the onset of Economic Revolution, the Song China vs. England (1750 – 1850) comparison is superior to comparisons between England and spread cases.[185]

Conclusion

My comparison of Song China and England (1750 – 1850) clearly establishes that England was not the first country to experience unprecedented increases in the growth rates of *both* per capita product and population as well as structural changes and an increased rate of technological innovation. Furthermore, the contrast between Song China and England (1750 – 1850) requires the completion of a development within Western European economic history circles that has been brewing for decades – namely the realization that there are two types of Economic Revolution. The Song China vs. England (1750 – 1850) comparison is the more appropriate when one's goal is to identify their cause. My analysis reveals that both of these episodes were preceded by what I call an Embryonic Stage. This observation elevates the research of a generation of scholars of English economic history to a new level as the power of comparison clearly shows that the development of markets, changes in the organization of production and other changes are *common features* to the onset of Economic Revolution in two cases, as opposed to being a *particular feature* limited to England's experience.

Kent Deng, Jack Goldstone, Eric L. Jones, Morgan Kelly, Angus Maddison, Stephen L. Parente, Edward C. Prescott, and Jan de Vries among others noted the mounting evidence that England was not the first country to experience unprecedented increases in the growth rates of *both* per capita product and population as well as structural shifts.[186] This research has largely withstood criticism but has yet

[185] Although Song China and England (1750 – 1850) share many similarities, they have differences. One could make the argument that their differences are sufficiently stark so as to render the comparison inappropriate. I argue that this view is based on the idea that there is one stylized model experience of economic growth. Kuznets pointed out that in the 1850 – 1950 period the range of growth rates of per capita product was fairly high. During this period the range of growth rates of population was even higher. In addition, there was no clear association between growth rates of per capita product and growth rates of population across countries (see Kuznets (1971), pp. 22 – 23). In short, there was a wide variety of experiences of science based modern economic growth during the 1850 – 1950 period. Similarly, I argue that we should not expect to see a single stylized experience across countries that experience the onset of Premodern (non-science based) Economic Revolution. Each country has its own specific historical developments and these country-specific conditions can cause differences in observed patterns. Classification of a type of social phenomenon must leave some variability in particulars while still capturing general trends. In this way, while acknowledging their differences, I argue the Song China and England (1750 – 1850) comparison is useful.

[186] See Deng (2013); Goldstone (2002); Jones (2000), pp. xxxv – xli, 35 – 8, 73 – 84, 149 – 67; Kelly

to replace aspects of the traditional view of England's "primacy". According to Eric L. Jones, there has been a bias against addressing and integrating evidence that challenged the traditional view of England.[187] According to Jones, the main reason for this lack of change in the profession's view is largely due to incentives within the academic community. The "sociological features of the profession" are such that amending and extending well established views is rewarded much more than challenging them. In addition, the costs involved in making effective comparisons of early economic growth episodes are extremely high given the fragmented, specialized nature of world economic history and language barriers.[188] However, these are not concerns of science. Song China is relevant for the study of long run economic growth. The scientific grounds for ignoring this major episode are fragile, particularly when they contradict the existing traditional interpretation of England's economic experience. Economic historians of England rarely consider Song China and are often dismissive of comparisons with previous episodes of economic growth that have identified – Eric L. Jones and Jan de Vries are arguably the main counterexamples.

Without doubt, one of the most eminent scholars of English economic history is Professor Joel Mokyr who reflects the current economic history profession in the West. Prof. Mokyr has clearly acknowledged that there were previous episodes of economic growth prior to England's experience. Nonetheless, he continues to focus on England's experience in order to learn about what caused the onset of economic growth.

According to Prof. Mokyr:

> "The cartoon story of a preindustrial static society before 1750 with fixed technology, no capital accumulation, little or no labor mobility, and a population hemmed in by Malthusian boundaries is no long taken seriously. Jones (1988) has stressed this point more than anyone else. At the same time Jones points out that before 1750 period of growth were followed by retrenchment and stagnation. The Industrial Revolution was

(1997); Maddison (2007), Tables A1 and A7, pp. 376, 382; Parente and Prescott (2000), pp. 17 – 8; Vries (2001) and Vries and Woude (1997). It should be noted that even modern growth theorists have begun to study early episodes of economic growth. For instance Acemoglu and Zilibotti (1997) study the economic growth of 14th century Florence, 16th century Genoa and 18th century Amsterdam, Desmet and Parente (2012) consider English developments predating industrialization and in an extremely stimulating article Kelly (1997) considers the onset of economic growth in Song China. There are two important themes common to these three economic growth studies (i.e. Acemoglu and Zilibotti (1997), Desmet and Parente (2012) and Kelly (1997)). First, market expansion is a major driving force in increases in per capita product in their models. Second, growth does not occur because of technological externalities.

[187] Read an interview of Eric L. Jones in Lyons et al. (2008), pp. 279 – 82

[188] Lyons et al. (2008), pp. 278 – 82.

> "revolutionary" because the technological progress it witnessed and the subsequent transformation of the economy were not ephemeral events and moved society to a ***permanent*** different economic trajectory."[189]

Prof. Mokyr, continues:

> "What the Industrial Revolution meant, therefore, was that after 1750 the fetters on sustainable economic change were shaken off. … What ultimately matters is the **irreversibility** of the events."[190]

Those who hold these views will have to wait until the year 2069 to discover whether the Rise of the West will outlast Song China's three and a quarter centuries of Economic Revolution. Clearly, dismissing Song China's episode of economic growth on the grounds that it was short-lived is an illogical claim. A more interesting fact can be clearly observed, and that is the difference in the *magnitudes* of the growth rates of per capita product and population. Indeed, according to Simon Kuznets,

> "The increase in both population and per capita product is not the unique feature of recent growth: even in pre-modern times the population of several countries grew and enjoyed a rising per capita product. The distinctive features of modern economic growth are the **extremely high rates of increase** – at least five times as high for population and at least ten times as high for per capita product as in the observable past."[191]

This observation begins to lead down a path that has already been blazed by some prominent European economic historians. A major criticism of a "now discredited" aspect of the traditional Industrial Revolution is that England's transition from the neo-Malthusian model to Kuznet's Modern Economic Growth did not take off abruptly in the late 18th century, as previously thought. Rather, many have argued two types of economic growth can be detected in England's experience. While there are various views as to the beginning of the first type of economic growth, they all share one common feature – that the transition from the first to the second type of economic growth took place around the late 19th century. According to Jan de Vries, "Conceivably, the solution to our problems could be the addition of a third growth model – appropriate from, say, the seventeenth century to c. 1870 – to stand between the two existing ones [the neo-Malthusian and Modern Economic Growth

[189] See Mokyr (1999), p. 3.
[190] See Mokyr (1999), p. 127.
[191] See Kuznets (1973), p. 1.

models].”[192] Douglass North has previously argued that there were two Economic Revolutions. His Second Economic Revolution is related to my Modern Economic Revolution in that both are steeped in the notion of science being applied in the economy. North argues that the Second Economic Revolution began in the second half of the 19th century. He also argues that “the Industrial Revolution was an acceleration in the rate of innovation, the origins of which go back well before the traditional chronology (1750 – 1830).”[193] Edward A. Wrigley holds the view that England experienced two types of economic growth and that they are “so markedly dissimilar in nature and with such different chronology that it is questionable whether their understanding is well served by using a single umbrella term to describe them; perhaps the course of change would be more easily and accurately understood if they were more clearly distinguished and the industrial revolution were regarded as their joint product.”[194] Wrigley views coal as the key feature. According to Wrigley, “In the period before the conventional industrial revolution the English economy was remarkably successful relative to other European countries. … The period down to the early nineteenth century may be regarded as a period in which the sources of growth were mainly those of an advanced organic economy. Thereafter the mineral-based energy economy was increasingly dominant as the vehicle of growth.”[195]

Within the field of European economic history, a tradition of two types of Industrial Revolution has developed – The First Industrial Revolution and the Second Industrial Revolution. The First Industrial Revolution is often identified with the traditional Industrial Revolution (1760 – 1830), while the Second Industrial Revolution is identified by historians and economists as the rise of science-based industry along with its associated new technologies, whose beginning dates to the later 19th century. Although not the first, David Landes has been the most notable proponent of this distinction.[196] Summing up the situation three decades later, Jan de Vries comments, “For many years, the notion of a ‘second industrial revolution’ in the late nineteenth century has rattled about the literature of our discipline without ever achieving a solid historiographical position.”[197]

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[192] Parentheses added – see Vries (2001), p. 184.

[193] See North (1981), p. 159 – 160. Note that North’s “First Economic Revolution” is completely unrelated to my “Premodern Economic Revolution”. North’s First Economic Revolution is the transition from hunting and gathering to settled agriculture – i.e. the Neolithic Revolution. See North (1981), pp. 72 – 77. Although North does not characterize an observed phenomenon as a distinct type of economic growth, he does clearly state that this phenomenon – market expansion, changes in the organization of production, increased specialization of production and increasing transaction costs – clearly predate the traditional chronology of the Industrial Revolution – (1750 – 1830). See North (1981), pp. 159, 167 – 70.

[194] See Wrigley (1988), pp. 11 – 12.

[195] See Wrigley (1988), pp. 16 – 17.

[196] See Hull (1999) and Landes (1969), pp. 1 – 12, 196.

[197] See Vries (2001), pp. 183 – 184.

My quantitative analysis of growth rates of post-1750 economic growth episodes and the comparison with Song China merely highlights what many European economic historians have been arguing for decades. There are two types of Economic Revolution. The weight of a three century episode of a fifth of humanity clearly thrusts this view to new prominence. My view is that we need to have two types of Economic Revolution, one non-science based (Premodern) and one science based (Modern). All onset cases of Economic Revolution were Premodern, non-science based, and laid the foundation for the subsequent development of Modern, science based, Economic Revolution. In short, science is a jet engine for the economy but it is not what got us off the ground.[198]

Finally, my analysis reveals that two cases of the "onset of Economic Revolution" were preceded by a collection of social changes that I call the Embryonic Stage. Once again, this observation through the power of comparison highlights a generation of research by prominent English social and economic historians including Maxine Berg, Eric L. Jones, Franklin Mendels and others.[199] My comparison shows that the English Economic Revolution did not begin with innovations in textiles, iron and the steam engine. Rather, its origins more properly reside in the shift towards specialized production, market development, increased consumption of a variety of goods among a larger cut of society, changes in the organization of production, transportation improvements, concentration of industries and regional specialization – all of which preceded the appearance of the spinning jenny.[200]

In conclusion, I contend that the study of the onset of Economic Revolution can no longer ignore Song China, a three century experience of one fifth of the world's population. In science, the introduction of new data often causes tectonic changes in

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[198] An important, but distinct, question is why science was first extensively applied to the economy in the West rather than China, which had many early advantages. Yet, it must be emphasized that this issue most properly lies in explaining why one country's growth rate of per capita product is greater than the positive growth rate of another country – and *not* what caused the onset of Economic Revolution. This has been often referred to as the "Needham Puzzle".

[199] Berg (1991, 1994, 1999); Berg et al. (1983); Jones (1968, 2010); Jones (2000), pp. xxxiv – xxxv; Kriedte et al. (1981); Mendels (1972); Szostak (1991), pp. 3 – 13; and Vries and Woude (1997), as well as the much underappreciated work Westerfield (1968).

[200] According to Rick Szostak, "The first workshops emerge in the 1750s and 1760s. The upsurge in technological innovation dates from the 1760s." Continuing, Szostak points out "the overriding reason for the concentration of various industries in particular regions during the eighteenth century is the drop in transport costs. Indeed, it would be an incredible coincidence were the same process to be observed in many branches of the textile, iron, pottery, and other industries without there being some common cause." See Szostak (1991), pp. 5 and 13. In addition, recent work by Gregory Clark suggest that the long run trend of England's population to income per person from 1200 to 1650 exhibits a trend break around the later year and that, "After 1650 the implied technology curve shifts upward, but not fast enough to cause significant increases in output per person." See Clark (2007), pp. 29 – 30. Patrick O'Brien points out that the distinguishing feature of English and Dutch agriculture was a capacity to sustain families off the land (see O'Brien (1985), p. 785). This no doubt contributed to structural shifts in production and changes in the pattern of consumption.

accepted theories and characterizations that contradict the new data. Ignorance of data is no defense. Fundamental changes in our understanding of the onset of Economic Revolution appear to be on the horizon. The future is now shifting to the search for the causes of the early phases of the Embyronic Stage ca. 1660 in England's onset case and ca. 760 in Song China's onset case.

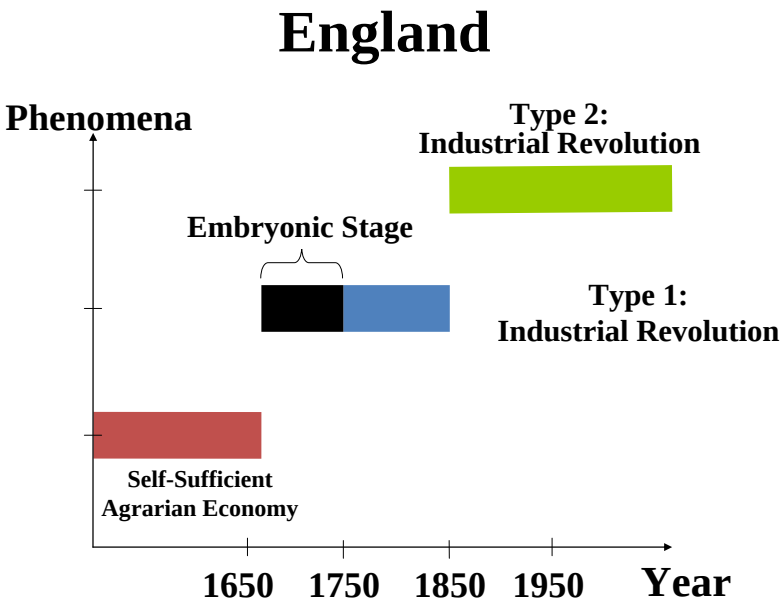


Figure 1

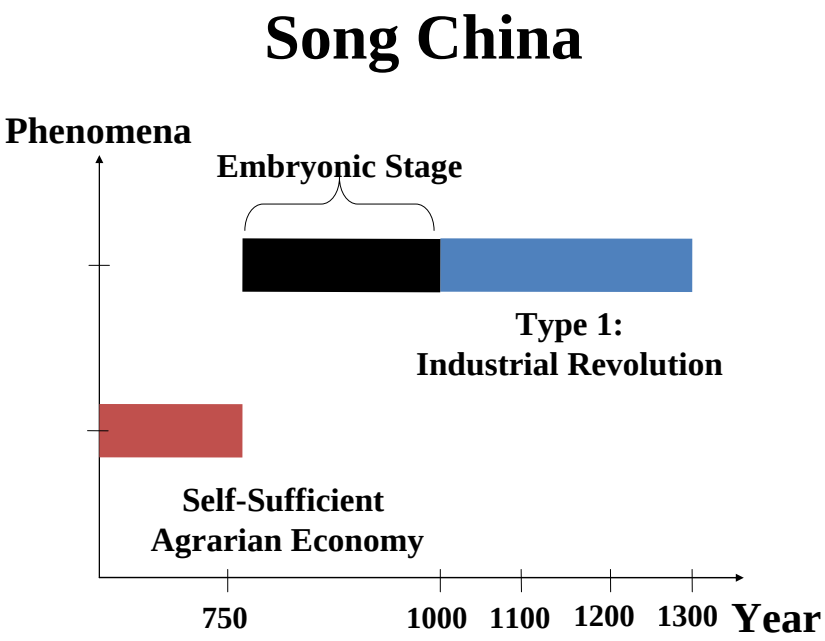
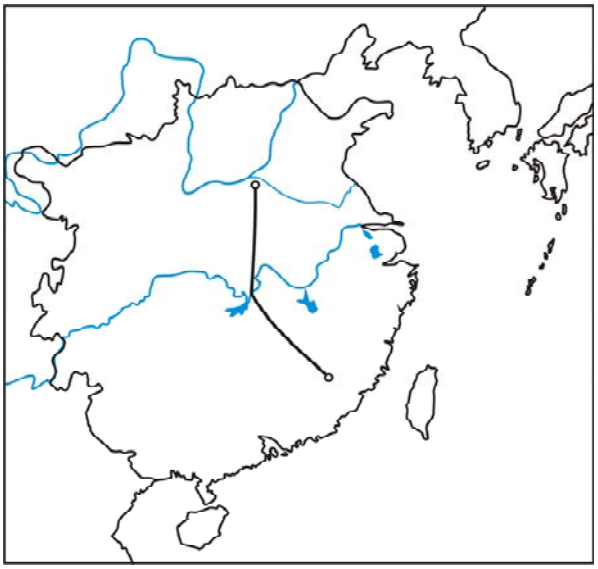


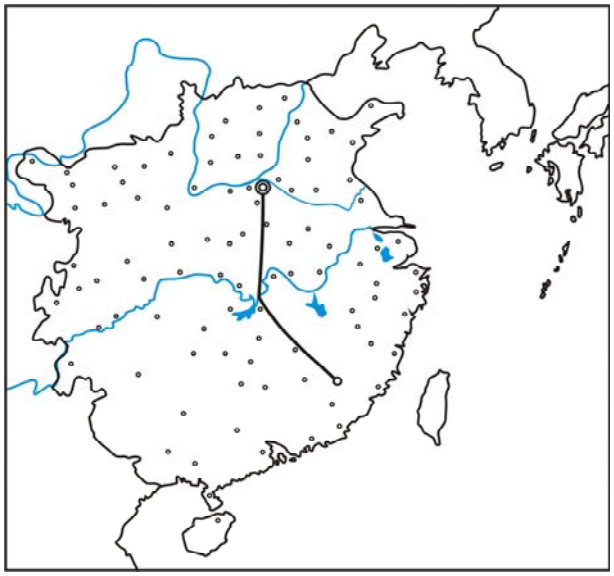
Figure 2

Self-Sufficient Agrarian Economy



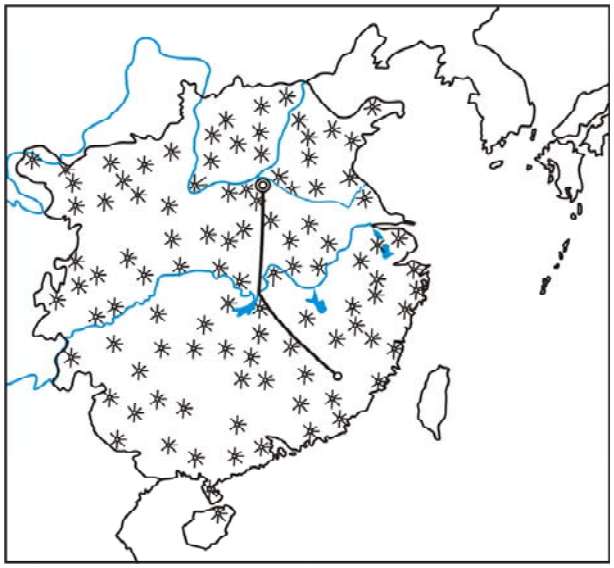
Map 1

Phase 1 Urbanization of Countryside



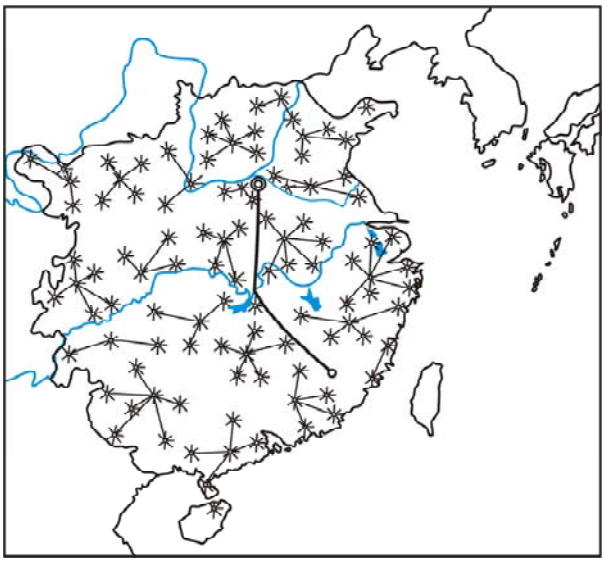
Map 2

Phase 2a Internal Transportation System Improves - *Local*



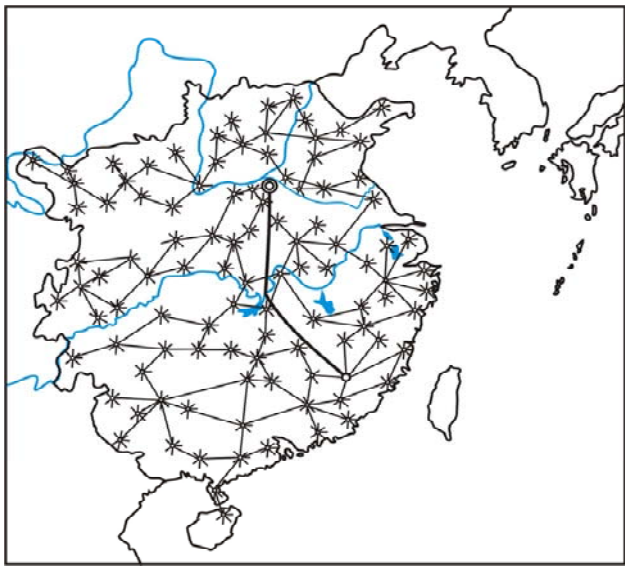
Map 3

Phase 2b Internal Transportation System Improves - *Regional*



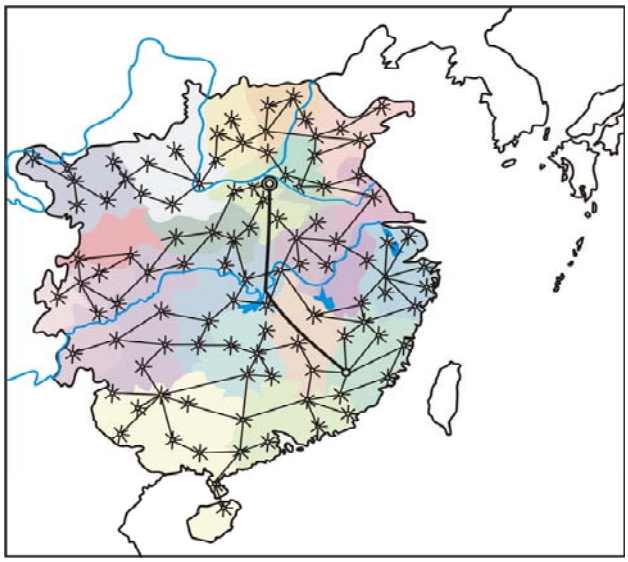
Map 4

Phase 2c Internal Transportation System Improves - *National*



Map 5

Phase 3 Regional Specialization & Increase Quantity/Variety of Consumer Goods

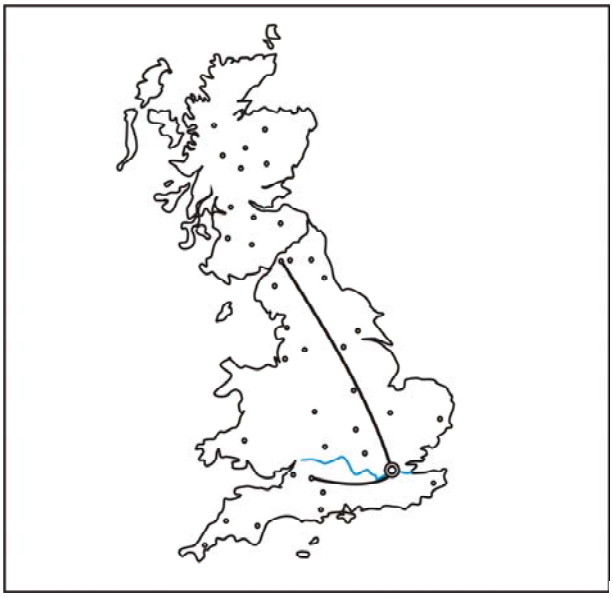


Map 6

Self-Sufficient Agrarian Economy

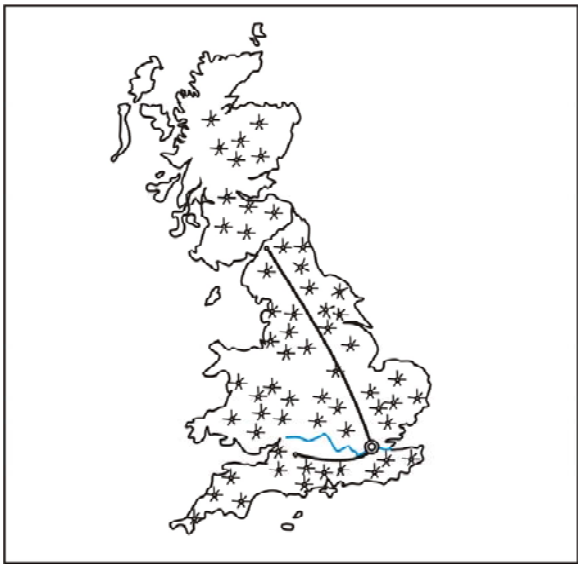
Map 7

Phase 1 Urbanization of Countryside



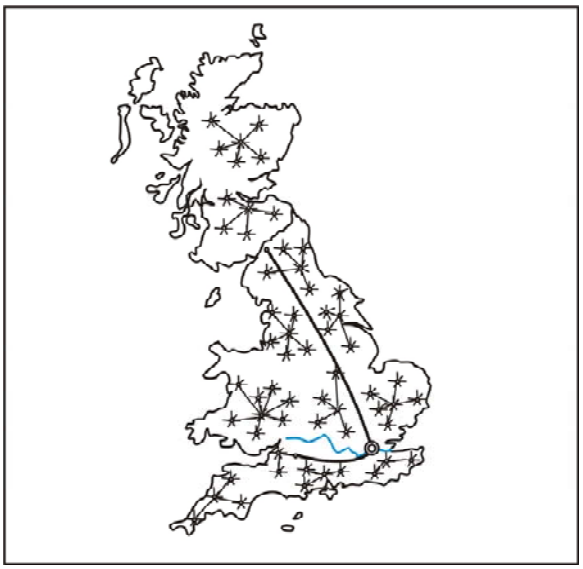
Map 8

Phase 2a Internal Transportation System Improves - *Local*



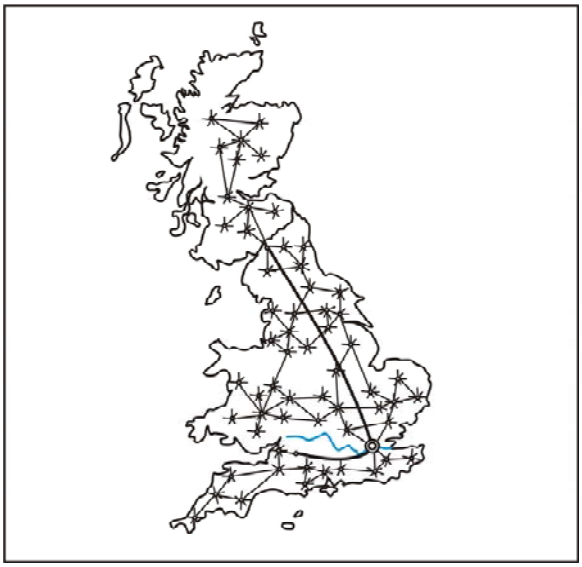
Map 9

Phase 2b Internal Transportation System Improves - *Regional*



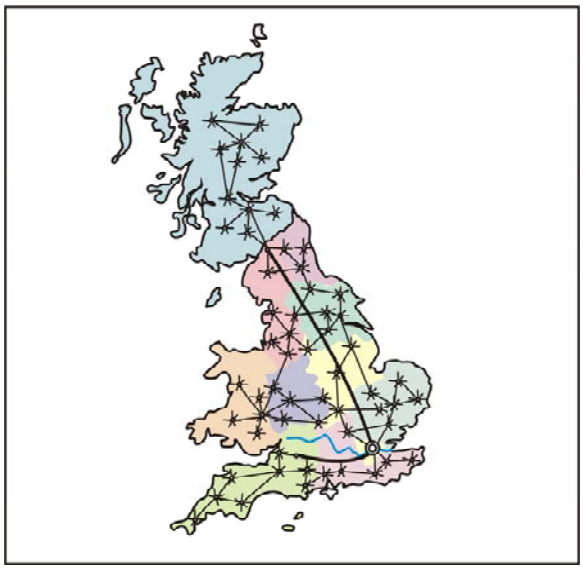
Map 10

Phase 2c Internal Transportation System Improves - *National*



Map 11

Phase 3 Regional Specialization & Increase Quantity/Variety of Consumer Goods



Map 12

Appendix 1

Maddison Estimates for Kuznets' Growth Countries

(1850 – 1960)

Country	Per Capita GDP (1990 $) 1850	Per Capita GDP (1990 $) 1960	Coefficient of Multiplication for per capita GDP per century
1. United Kingdom	2484	8813	3.162
2. France	1534	7834	4.403
3. Belgium	2024	7738	3.384
4. Netherlands	2344	8417	3.197
5. Germany	1485	6332	3.737
6. Switzerland	1616	12,274	6.317
7. Denmark	1671	9402	4.809
8. Norway	1100	7474	5.708
9. Sweden	1458	9114	5.292
10. Italy	1333	5676	3.733
11. Japan	709	4172	5.009
12. United States	1874	12,181	5.483
13. Canada	1318	9633	6.100
14. Australia	1566	9278	5.040
Average			4.670
Median			4.909

Source: Maddison (2007), Table A.7, p. 382 (for all European countries, Japan and the United States) and Table 2.9b, p. 104 (for Canada and Australia). For Kuznets' choice of these countries see Kuznets (1971), Table 1 (pp. 11 – 19) and p. 21. Note estimations for 1850 were based on 1820 and 1870 figures, assuming a constant rate of growth per decade. Similarly, estimates for 1960 were based on figures for 1950 and 1973, assuming a constant rate of growth per decade.

Appendix 2

PPP Converted GDP Per Capita (Laspeyres),

derived from growth rates of c, g, I, at 2005 constant prices.

From PWT 7.1

Country	Per Capita GDP (2005 constant prices) 1960	Per Capita GDP (2005 constant prices) 2010	Coefficient of Multiplication for per capita GDP per century
Taiwan	1858.93	32117.7	298.5127
Korea, Republic of	1670.01	26613.77	253.9655
Singapore	4398.08	55838.63	161.1919
Hong Kong	3289.57	38688.13	138.3175
China Version 2	771.66	7746.07	100.7653
Thailand	962.06	8065.57	70.28551
Malaysia	1453.49	11961.5	67.72472
Romania	1362.35	9376.19	47.36695
Sri Lanka	607.34	4065.56	44.81021
Indonesia	665.15	3965.8	35.54859
Japan	5594.34	31453.08	31.6103
Egypt	924.05	4852.64	27.57815
Panama	2141.62	10849.33	25.6638
Morocco	718.03	3621.14	25.43346
India	724.1	3476.78	23.05459
Ireland	7280.31	34902.26	22.98303
Portugal	4181.73	19785.7	22.38674
Dominican Republic	2316.21	10506.05	20.5742
Greece	5588.32	25225.52	20.37594
Spain	6333.99	27332.01	18.62037
Norway	12507.81	50490.91	16.29536
Puerto Rico	5703.74	22824.05	16.01275
Israel	6989.9	26037.84	13.87612
Pakistan	617.34	2297.18	13.84654

Austria	10545.55	38585.63	13.38791
Finland	9034.38	32991.91	13.33577
Belgium	10164.39	35558.52	12.2384
Chile	3700.16	12526.56	11.461
Brazil	2469.09	8324.7	11.36746
Turkey	3183.76	10439.91	10.75258
Italy	8718.92	28380.92	10.59565
Mauritania	620.57	1939.39	9.76672
France	10192.79	31299.3	9.429379
United Kingdom	11204.61	34266.97	9.35315
Tanzania	388.13	1177.7	9.206932
Denmark	11606.58	33716.83	8.438882
Canada	12901.18	37110.4	8.274322
Netherlands	13436.56	38189.65	8.07821
Australia	15206.08	41107.49	7.308149
United States	15387.73	41376.08	7.230188
Colombia	2940.69	7534.48	6.564597
Mozambique	308.76	781.18	6.401182
Sweden	14312.62	36132.56	6.373224
Syria	1541.8	3791.49	6.047331
Mexico	4942.11	11939.77	5.836696
Ecuador	2579.06	6226.08	5.827825
Uruguay	5010.99	11717.63	5.46805
Costa Rica	4953.44	11502.85	5.392586
Iran	4103.09	9429.37	5.28133
Paraguay	1782.86	4068.75	5.208199
Congo, Republic of	999.96	2253.73	5.079705
Philippines	1466.49	3193.63	4.74254
Peru	3462.64	7410.97	4.580738
Nepal	537.63	1144.87	4.534667
Guatemala	2941.68	6089.8	4.285635
Argentina	6033.05	12337.59	4.182027
Malawi	330.99	654.91	3.915016
New Zealand	14269.15	27788.35	3.792533
Papua New Guinea	1452.85	2783.88	3.671635
South Africa	3937.99	7508.78	3.635713
Switzerland	21029.95	39985.62	3.615191
Mali	529.74	997.7	3.547108

El Salvador	3353.97	6167.54	3.38147
Burkina Faso	518.3	929.69	3.217466
Ethiopia	384.55	680.99	3.135998
Uganda	658.76	1101.53	2.796007
Chad	812.05	1331.75	2.689552
Ghana	1288.6	2093.44	2.639276
Honduras	2227.19	3578.29	2.581288
Bangladesh	853.59	1370.98	2.579667
Benin	744.86	1176.75	2.495854
Algeria	4073.28	6260.21	2.362051
Bolivia	2614.34	3743.15	2.049983
Rwanda	758.4	1025.14	1.827131
Cote d`Ivoire	958.58	1283.36	1.792422
Jamaica	6456.31	8542.39	1.750613
Venezuela	6989.59	9070.93	1.684225
Cameroon	1419.17	1747.94	1.516995
Kenya	1019.06	1246.3	1.495704
Burundi	347.67	395.89	1.296626
Zambia	1360.8	1518.04	1.244451
Zimbabwe	287.84	318.8	1.226689
Nigeria	1558.35	1692.78	1.17997
Senegal	1413.11	1468.91	1.080534
Togo	709.6	732.85	1.066603
AVERAGE			21.55411

PWT 7.1 – Alan Heston, Robert Summers and Bettina Aten, Penn World Table Version 7.1, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, Nov. 2012.

For all countries the 1960 and 2010 figures are from the “rgdpl” series – PPP Converted GDP Per Capita (Laspeyres), derived from growth rates of c, g, I, at 2005 constant prices.

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