Abstract: I argue that China during the Song Dynasty (960 – 1279 AD) (Song China hereafter) experienced the onset of an Industrial Revolution, preceding England’s by several centuries. The concept of Industrial Revolution is extended to include two types – one non-science based and one science-based. 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 Industrial Revolution, which more clearly identifies and dates the social process. This has important implications for theories of its cause.

Keywords: Economic development, growth theory, China

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1. Introduction

Arguably, the most important question in all of the social sciences is: “What caused the Industrial 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 on the important features of this social process. Without a 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 the fundamental features of the onset of the Industrial Revolution with the purpose of identifying its cause.

England’s Industrial 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 by emphasizing the quantitative economic aspects. This starting point may seem overly restrictive to some but I would suggest withholding judgment at this point, since the analysis here will take us deep into qualitative territory and also to aspects that border non-economic features.

From an economic perspective, there is somewhat of a consensus that the distinctive quantitative features of an Industrial Revolution are sustained increases in the growth rates of both per capita product and population. These features serve as the starting point of Simon Kuznets’ quantitative analysis of long-run economic growth. In a major study of 16 countries over the 1750 – 1950 period, Kuznets identified a set of quantitative regularities and used these features to define what he called “modern economic growth.”

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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.
per capita product and population played a prominent role in Kuznets’ definition of “modern economic growth”, but he also went beyond them to include structural changes. In this study, the term Industrial Revolution is based on Simon Kuznets’ definition of “modern economic growth”. As mentioned previously, there is no consensus as to what are the fundamental features of the Industrial Revolution. I do not mean to imply that this definition is superior to all others; it is one of many. It should be noted that Kuznets’ definition of “modern economic growth” is well established and contributed in no small part to his 1971 Nobel Prize. The goal of this study is to produce a new definition for the “onset of an Industrial Revolution.” By my definition, “onset” begins in a country without contact with another country experiencing an Industrial Revolution. This is in contrast to the “spread” of an Industrial Revolution which involves contact with another country experiencing an Industrial Revolution. Judgments regarding the appropriateness of definitions, I suggest, should focus on the resulting definition of the “onset of an Industrial Revolution” produced here rather than the initial reliance on Kuznets’ “modern economic growth.”

Kuznets’ research in his 1966 book serves as a point of departure for my analysis. I expand Kuznets’ comparative analysis of “modern economic growth” to include another economic episode, that of China during the Song Dynasty (960 – 1279 AD) (Song China hereafter). I conclude that Song China experienced “modern economic growth” as Kuznets defined the term. Furthermore, the addition of the Song China episode requires a reformulation of Kuznets’ “modern economic growth” so as to include two types – one non-science based and one science based. Consequently, this necessitates a corresponding reformulation of the Industrial Revolution to include two types as well. Finally, I use the two episodes of Song China and England to produce a new definition of the “onset of an Industrial Revolution.” I argue this new definition more clearly identifies and dates the onset of an Industrial Revolution and has important implications for theories of its cause.

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 “the Industrial Revolution” is reformulated to include two types – one non-science based and one science based. Section 4 argues that when the goal is to discover the cause of the onset of an Industrial Revolution, a comparison between Song China and England is the most likely to make progress. Section 5, based on the

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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 See Modern Economic Growth: Rate, Structure and Spread published in 1966 by Simon Kuznets.
8 Specifically, the analysis in Kuznets (1966), which compares the long-run economic performance of 16 countries, is expanded to include Song China.
Song China and England episodes, presents a new definition of the “onset of an Industrial Revolution”. Section 6 (pp. 44 – 48) presents a discussion, summary and conclusion.

2. Song China – Kuznets’ Modern Economic Growth

In Section 3, I will introduce a definition of the Industrial Revolution that is based on 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. My focus 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

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9 Some scholars have proposed answers to this question. 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 and tend to have relatively little interest in issues directly related to economic growth. 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 strong links to the West. 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 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.
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.10 His 1922 article, “A general view of the Tang and Song periods” became the starting point for ensuing debates in Japan about Song China.11 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 (曾我部靜雄), Sudō Yoshiyuki (周藤吉之) and others spent a lifetime studying Song China.12 With differences of opinion regarding details, a consensus emerged in Japan as to the important qualitative features of the Tang-Song transition.13 The traditional view of a changeless and stagnant China prior to the arrival of the Westerners has been discarded by Japanese Sinologists.14 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.15

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,

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10 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.
11 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).
13 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 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.
14 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.
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.16

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.””17

Despite this fundamental change of view in historiography of Song China, even some notable comparative historians have missed the new found importance of Song 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.18 Among social scientists and most notably economic historians and economists in the West the traditional view of economic stagnation in Song China remains strong.19 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 –


18 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.

19 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. One important exception is Guanglin William Liu (劉光臨).
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.20 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.”21 More recently, some economic growth experts have come to acknowledge the economic growth of Song China, including Angus Maddison, Stephen L. Parente and Edward C. Prescott.22

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.23 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.24 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.25

20 Elvin (1973), Part Two and p. 203.
22 These scholars’ estimates of Song China per capita GDP growth will be presented in what follows.
23 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.
24 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.
25 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.
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 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 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.\(^{26}\) 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.\(^{27}\) 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

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\(^{26}\) 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.

\(^{27}\) 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.
constant. No serious argument has been made that they exhibited a long run decline during this period.\textsuperscript{28} This reasoning suggests that in the 12\textsuperscript{th} 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.\textsuperscript{29}

\begin{center}
\textbf{Maddison’s Estimates of Chinese and European GDP per capita (1990 $)}
\end{center}

\begin{tabular}{|c|c|c|}
\hline
 & 960 AD & 1300 AD \\
\hline
China & 450 & 600 \\
Europe & 422 & 576 \\
\hline
\end{tabular}

Table 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.\textsuperscript{30}

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\textsuperscript{28} The one major deviation to these long-run trends was the period after the arrival of the plague in the mid-13\textsuperscript{th} 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.

\textsuperscript{29} See Maddison (2007b), Table 1.3, p. 29.

\textsuperscript{30} 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 12\textsuperscript{th} and 13\textsuperscript{th} 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-20\textsuperscript{th} 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.
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.

In the centuries preceding and during the Song Dynasty, China was the world leader in science and technology.31 Joel Mokyr, Joseph Needham and Nathan Sivin, all eminent historians of science and technology, hold this view.32 Needham contends that during this period the flow of inventions across Eurasia was mostly from China to the West.33

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

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.

31 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.

32 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

33 See Needham (1969), pp. 15 – 16. See also Mokyr (1990), pp. 31, 40 and 44.
equivalent to Cavalieri’s Principle. Even before the Song Dynasty, Chinese 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.

**Chinese depiction of “Pascal’s Theorem” from the 13th century**

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34 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 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 (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.

35 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.
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.\footnote{Note that the West was relatively advanced in mechanics and dynamics. See Needham (1969), pp. 17 – 20; Needham (1981), pp. 10 – 12, 15 – 22.}

**Drawing of Su Song’s water powered mechanical clock/observatory (1088)**
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.37

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.38 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.39

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38 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.
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.\textsuperscript{40}

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.\textsuperscript{41}

Paper was first produced in China in the 2nd century BC, possibly earlier.\textsuperscript{42} 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.\textsuperscript{43} 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.\textsuperscript{44} It is widely held that Chinese paper produced from the 12th to 14th centuries is generally of better quality than that of previous periods.\textsuperscript{45} 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

\textsuperscript{40} See Needham (1971), pp. 562 – 563.
\textsuperscript{41} 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.
\textsuperscript{42} 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, “zhī (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.
\textsuperscript{45} 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.46

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.47

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.48

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.49 In the mid-11th century, moveable type printing was discovered in China by an engraver, Bi Sheng (畢昇).50 Multi-colored woodblock printing appeared around the early 12th century.49

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49 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.
50 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.\textsuperscript{51} 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.\textsuperscript{52} Unlike paper, it appears likely that printing was independently discovered in the West, and in other countries.\textsuperscript{53}

Initially, Chinese printing spread regionally within the Far East. In Japan, printing first appeared around the late 8\textsuperscript{th} century, but of poor quality. The first known printings of complete books in Japan appeared around the 10\textsuperscript{th} century. In Korea, printing began around the 11\textsuperscript{th} century.\textsuperscript{54} Printing appeared in Persia around the late 13\textsuperscript{th} century and in Europe around the late 14\textsuperscript{th} century. Not until the mid-15\textsuperscript{th} century, when Johann Gutenberg’s moveable type printing was invented, did printing have a notable impact in Europe.\textsuperscript{55}

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

\begin{quote}
\begin{center}
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.
\end{center}
\end{quote}

\textsuperscript{51} See Needham (1985), pp. 277 – 280. In China multi-colored printing of decorations on silk was known by the 2\textsuperscript{nd} century AD. See Whitfield and Farrer (1990), pp. 111 – 112.


\textsuperscript{53} 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-14\textsuperscript{th} 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.


\textsuperscript{55} 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 9\textsuperscript{th} century. During the Song Dynasty and the Yuan Dynasty (1279 – 1368) its use gradually spread and printing techniques improved. In the 13\textsuperscript{th} 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 17\textsuperscript{th} century. See Needham (1985), pp. 96 – 100, 293.
over one millennium, woodblock printing by six centuries and moveable type printing by four centuries.\textsuperscript{56}

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.\textsuperscript{57} 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.\textsuperscript{58} 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.

\textit{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.\textsuperscript{59}

\textsuperscript{56} See Needham (1985), p. 3.
\textsuperscript{57} See Needham (1986), pp. 356, 514.
\textsuperscript{58} See Shiba (1970b), p. iii.
\textsuperscript{59} 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

In what follows, I shall present evidence that Song China experienced unprecedented income growth, population growth, agricultural productivity growth, industrial expansion, urbanization and the emergence of a middle class as well as other indicators of economic growth.

- Population

Population in China experienced an unprecedented increase during the Song Dynasty. Table 1 below presents estimates of China’s population from year 1 to 1300.60

60 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. short run 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). I finally provide a conservative estimate of 125 million for the year 1300. This latter figure is conservative in the sense that some argue it may have dropped. There is one important point that Maddison (1997, 2007b) appears to have missed. Most if not almost all of the
Table 1

<table>
<thead>
<tr>
<th>Year (A.D.)</th>
<th>Population (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>800</td>
<td>50</td>
</tr>
<tr>
<td>1000</td>
<td>55</td>
</tr>
<tr>
<td>1100</td>
<td>120</td>
</tr>
<tr>
<td>1200</td>
<td>125</td>
</tr>
<tr>
<td>1300</td>
<td>125</td>
</tr>
</tbody>
</table>

Table 2 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 unprecedented doubling during the eleventh century. Thereafter the growth rate of total population decreased considerably and stabilized around the late-twelfth and thirteenth centuries. Observe that not only did China’s total population experience unprecedented growth during Song China, but it appears that after this growth the total population growth rate decreased considerably. It is important to note that this type of “S” curve pattern of total population is what usually occurs when a country goes through a demographic transition.\(^{61}\)

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.\(^{62}\)

population gains of the Song Dynasty were realized during the eleventh 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. 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 the total population of China should experience 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.

\(^{61}\) 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.

\(^{62}\) See Hartwell (1966), p. 34 for the figures reported in Tables 1 and 3. Note that for the year 1 AD, I
China’s Iron Output Per-Capita and Population

<table>
<thead>
<tr>
<th>Year</th>
<th>Iron Output Per-capita (pounds per-capita)</th>
<th>Population (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.22</td>
<td>59.6</td>
</tr>
<tr>
<td>806</td>
<td>0.5</td>
<td>54</td>
</tr>
<tr>
<td>998</td>
<td>1.2</td>
<td>54</td>
</tr>
<tr>
<td>1064</td>
<td>2.9</td>
<td>62</td>
</tr>
<tr>
<td>1078</td>
<td>3.1</td>
<td>81</td>
</tr>
</tbody>
</table>

Table 1

Table 1 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 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.63

China’s Growth Rate of Iron Output Per-Capita

<table>
<thead>
<tr>
<th>Period</th>
<th>Per-century growth rate of iron output per-capita (pounds per-capita)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – 800</td>
<td>11%</td>
</tr>
<tr>
<td>800 – 1000</td>
<td>55%</td>
</tr>
<tr>
<td>1000 – 1100</td>
<td>160%</td>
</tr>
</tbody>
</table>

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. Note that many scholars have expressed doubts regarding the reliability of Hartwell’s estimates. A brief discussion here is appropriate. Hartwell’s iron output estimates are based on tax records.

63 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.
Table 2

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 increase in the growth rate continues to an unprecedented level. 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 3 indicates that China’s rate of growth in this important sector was about ten times that of Western Europe’s in their respective periods.

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

<table>
<thead>
<tr>
<th>Region</th>
<th>Century</th>
<th>Percentage Increase (during the century)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>11th</td>
<td>250 %</td>
</tr>
<tr>
<td>Western Europe</td>
<td>18th</td>
<td>26 %</td>
</tr>
</tbody>
</table>

Table 3

One of the striking features of Song China is its technological creativity. According to the eminent scholar of the history of science in China, Joseph Needham, “Whenever one follows up any specific piece of scientific or technological history in Chinese literature, it is always at the Sung dynasty that one finds the major focal point. This is as true for the applied as for the pure sciences. Improvements in hydraulic engineering, as well as its intensified use, are to be noted, such as lock-gates and new surveying instruments. In bridge-building the use of the ingenious transverse shear-wall and the caisson were introduced. … Shipbuilding took great strides, the sternpost rudder, which had probably been invented some time before, became general, and sea-going junks of considerable size were built. Treadmill-driven paddle-wheel ships, again not new, became more general.”64 The Song China’s technological progress has also gained the note of eminent historians of technology in the West. As Joel Mokyr notes, “In the centuries before 1400, the Chinese developed an amazing technological

64 Needham (1954), p. 134. It should be noted that in a publication over thirty years later, regarding this view, Needham commented that “all our discoveries since then have confirmed this judgment” – see Needham (1986), p. 278.
During the Song Dynasty, China was in competition with several countries including Xi Xia, Liao and the Mongols. Wars were not uncommon. However, government demand for military weapons is not responsible for the increase in iron output during the 11th century. After a war with the Liao, a major peace treaty was signed in 1004. 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 (See Wong, p. 21). An increase in demand for weapons can not therefore explain the striking growth in the iron industry during the 11th century. Also cite Nap-yin Lau’s peace accord article.

Another important factor to consider in long-run economic growth is the rate of technological innovation. There is broad consensus among economists that the onset of modern economic growth was accompanied by an increase in the pace of technological innovation. At least during the early phases of modern economic growth, the shift in product and resources employed away from agricultural activities toward industrial activities is associated with an increase in the pace of technological innovation. Among historians of China, it is generally agreed that Song China was a period remarkable technological progress. During this period, China was the world’s technological leader. The figures based on data of significant inventions reported in Table 3 indicate that during the 1000 – 1250 period the rate of technological innovation doubled relative to the previous two and a half centuries.

<table>
<thead>
<tr>
<th>Period</th>
<th>Innovations Per Century</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 – 750</td>
<td>5</td>
</tr>
<tr>
<td>750 – 1000</td>
<td>8</td>
</tr>
</tbody>
</table>


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. 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. Note the same sources and methods are also used in constructing the innovation rates in Table 5.
China is a major part of the world’s long-run development. Currently, the Chinese constitute about one fifth of the world’s population. However, in the middle of the Song Dynasty, the Chinese exceeded a quarter of humanity. Most Western scholars are unfamiliar with Song China. Yet, as Eric L. Jones points out, “There are no grounds for ignoring it simply because it was a long time ago…” 67 The economic past is data for theories to confront. Recently, however, long-run growth and development economists have begun to bring Song China into their analysis.

According to the late Angus Maddison, regarding China during the Song Dynasty, “it seems likely that there was an increase in per capita income” … and “there was clearly an increase in the pace of population growth”. 68 Maddison provides rough estimates on China’s long-run economic performance:

<table>
<thead>
<tr>
<th>China’s GDP per capita (1990 $) and Population (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>GDP per capita</td>
</tr>
<tr>
<td>Population</td>
</tr>
</tbody>
</table>

It is worth pointing out here that according to Kuznets, the distinctive features of modern economic growth are the extremely high rates of increase in the rate of population growth and the rate of per-capita product growth. 70 The issue of what is meant by “extremely high” in the context of Song China is discussed subsequently.

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69 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.
Nevertheless, it is clear that, according to estimates by Maddison, China’s growth rates of GDP per capita and population both experienced unprecedented increases during the Song Dynasty.

Currently, the Chinese constitute about one fifth of the world’s population. However, in the middle of the Song Dynasty, the Chinese totaled nearly one third of humanity. Two notable examples are Maddison (2007b) and Parente and Prescott (2000).

Many economic historians and some growth economists have explicitly stated or at least made statements strongly suggesting the view that Song China experienced economic growth.

Western trained economic historians and economists of long-run economic growth who have considered Song China, the view that China experienced economic growth is not a matter of controversy (see Jones (1988), pp. 35-6; Maddison (2007), pp. 23-30; Mokyr (1990), Ch. 9; and Parente and Prescott (2000), pp. 17-18, 136.). Much of the literature on the Song Dynasty is in studies done by Marxist historians in Japan and China. Western trained historians are beginning to take an interest in Song China but their numbers are small and they have had little impact on economic history or economic growth and development in the West. I can not name a single expert on the Song Dynasty in any economic department in the West or in any economic history department in Europe. Nor can I name a single paper on Song China published in the top five economics journals or in the top few economic history journals. While experts of the Ming-Qing period are beginning to take interest in these subjects, little research exists regarding the Song Dynasty. In my view, the reason economic historians and economists in the West do not view China during the Song Dynasty as an episode of the onset of the Industrial Revolution is that they are not sufficiently aware of the data. Any reasonable view of China’s experience during the Song Dynasty will include considerable increases in the growth rates of both output per-capita and population.71 Despite this, the traditional view maintains that England was the first country to experience the onset of the Industrial Revolution. Although the traditional view is widely held throughout academia in the West, the view that Song China experienced the onset of the Industrial Revolution will eventually be the

71 It is worth pointing out here that according to Kuznets “The distinctive features of modern economic growth are the extremely high rates of increase in the rate of population growth and the rate of per-capita product growth,” see p. 1, Kuznets (1973). The issue of what is meant by “extremely high” in the context of Song China is discussed subsequently.
predominant one, at least 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.

Second, no direct evidence exists to establish that China’s output per-capita increased during the Song Dynasty. There was no concept of national income and product accounts and thus no measurement of it during the Song Dynasty. Without such data recorded during the Song Dynasty we have no direct means of calculating total output. Nonetheless, beyond strong evidence of growth in some key economic sectors, we know a lot about economic growth and many of the features that are closely associated with it. Indeed, the characteristics Kuznets identified and used to define modern economic growth provide one summary of our knowledge of this social phenomenon. It is extremely unlikely that all of Kuznets’ features of MEG were in force in China during the Song Dynasty except for increases in per capita product. Furthermore, there are other indicators that point in the direction of growth of per-capita output. For example, that MEG is associated with increases in productivity derived from improvements in the quality of inputs rather than quantity. This is most often associated with improvements in production technology or changes in the nature of the organization of production. These two features were common throughout Song China.

China’s increase in the rate of technological innovation during the Song Dynasty is well established. In agriculture we can note the widespread use of double-cropping rice, use of improved farming tools, more extensive use of fertilizers, better selection of crop seeds and improved irrigation systems. Paper production was improved with the development of woodblock printing around the 9th century. In the mid-11th century moveable type printing appeared. (Mention the increased use of water power in paper production). These innovations played an important role in the publication and dissemination of books and manuals describing various technological aspects of agricultural production, botany, medicine and science. They also played a role in the appearance of the government’s official gazette, the world’s first national newspaper. There was a widespread shift in industrial fuel from charcoal to coal in northern China during the Song Dynasty. Maritime shipping witnessed technological innovations such as

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3. Industrial Revolution – Two Types

In this section, I contend that there are two types of Industrial Revolution – one non-science based and one science based. First, the concept of the Industrial Revolution will be given a clear foundation. Kuznets’ definition of “modern economic growth” will be used as a point of departure. His (1966) comparative study of the economic growth of nations will be examined and expanded to include China during the Song Dynasty (960 – 1279) (Song China hereafter). 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 and one science based. Lastly, I state my definitions of the two types of Industrial Revolution, which are based on this reformulation.

My analysis is innovative in the integration of the Song China episode into Kuznets’ multi-country comparative study of modern economic growth. A brief description of Kuznets’ framework will be an instructive detour at this stage. Most importantly, a distinction between Kuznets’ conceptual framework and his measured framework is highlighted. With this distinction in mind, consideration of both 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 and one science based.

Like social and economic historians before him, Kuznets tried to divide human history into useful periods for the purpose of analysis – i.e. a periodization system. 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. Kuznets was particularly interested in what he called the “modern economic epoch,” defined as the period 1750 – 1950. According to Kuznets, “the epochal innovation that distinguishes the modern economic epoch is the extended application of science to problems of economic production,” (see Kuznets (1966), p. 9). Kuznets also calls this epoch the “scientific epoch.” He then provides considerable discussion to the role of science in the modern economy.

Kuznets’ definition of science is given below:

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74 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 argued were needed. See Kuznets (1966), pp. 31 – 32.

75 This rough outline of Kuznets study is based on my reading of Kuznets (1966), pp. 1 – 12.

76 Kuznets argued such an epoch should cover an extended period, well over a century. See Kuznets (1966), p. 2.

77 Kuznets’ definition of science lacks a degree of objectivity regarding the predictive capacity of
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.

With his conceptual framework – the modern economic epoch – as his guide, Kuznets set out to measure features of this period. In particular, he performed a multi-country comparison, designed to highlight features of this epoch, using a group of countries during the 1750 – 1950 period. Here however, Kuznets’ analysis was largely quantitative. He identified important similarities and used them to define the term “modern economic growth.” Being the synthesis of a largely quantitative comparison, the abstract notion of science was not used in his definition of “modern economic growth,” which was qualitative and described relatively observable features of the economy. (See the end of Section 2 – page 18 – for a brief version of Kuznets’ definition of modern economic growth.)

The key point here is that Kuznets established a conceptual “modern economic epoch” or “scientific epoch”, which is characterized by the widespread application of science to economic problems. He went on to measure prices and quantities of this epoch with a resulting definition of “modern economic growth.” These two concepts are based on distinct phenomena – one, the application of science and the other, patterns in observed economic variables. The issue that immediately arises is the relationship of these two concepts. The coincidence in timing of these two concepts is virtually perfect with one major exception – England.

Kuznets observed that the process of modern economic growth as he measured it did not coincide with the beginning of the widespread application of science to the English economy. Modern economic growth as Kuznets measured it began in England around 1750. However, the extended application of science did not begin in England until about 1850. 78 Some of the science came from England while some came from science usually associated with notions of modern science, which usually includes the mathematization of concepts (for China’s case see Needam (1981), p. 9). This apparent deficiency is mitigated by his description of a key aspect of the application of science to problems of economic production – science based technologies. Kuznets also provides the following definition of 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.” He goes on to comment, “Ignoring the weighty problems hidden behind these definitions, 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.

78 It should be noted that this view is widely held among economic historians and historians of science and technology. See Landes (2006), p. 16; Mokyr (2002), p. 34; Polanyi (1962), p. 182. 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
other countries, such as France and Germany. But it was the extended application of science in England that was the distinguishing feature. Kuznets stated explicitly, “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.”

After noting his reservations, Kuznets dated his modern economic epoch, based on the extended application of science, as beginning around 1750 – in direct contradiction of England’s data. In effect, Kuznets identified his conceptual framework with his measured framework even though there was a century difference in the timing of their beginning. Despite the absence of the extended application of science to the economy in England from 1750 – 1850, Kuznets justifies his choice by appealing to England’s “intellectual and cultural milieu” of the time. Given the subsequent observations of all other countries widely applying science to problems of production, this judgment seems reasonable and has been accepted by many scholars.

This situation changes dramatically with the introduction of new data. It is not uncommon for well established theories and judgments to experience major reevaluations and reformulations when new observations appear that contradict established opinion. I argue that this is indeed one such case in the social sciences. In the previous section I argued that Song China experienced modern economic growth as Kuznets measured it. Kuznets did not evaluate the data from Song China. According to Kuznets, the distinctive quantitative features of modern economic 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.” 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. In short, during the 1750 to 1850 period, science had no significant effect on England’s aggregate economy and it did not experience a widespread application, although there was one development – the steam engine. It is from the mid-nineteenth century that science begins to play a considerable role in England’s economy.

See Kuznets (1966), pp. 10 – 11.

Arguably the most famous such example in science is Newton’s theory of gravity. Given the data of the time, Newton’s theory did a remarkable job at predicting movements of physical bodies. Over time, as measurement gradually improved, new evidence clearly revealed some slight differences between Newton’s predictions and observations – such as in the orbit of Mercury around the Sun. Although Newton’s theory was supported by almost all of the evidence and proved to be a remarkably useful predictive theory for many applications, these slight deviations from Newton’s theory of gravity paved the way for its overthrow and the widespread acceptance of theory of general relativity.
growth, i.e. the increase in the growth rates of both population and per capita product, did not occur before 1750.\footnote{See Kuznets (1966), p. 20.} Other scholars who have focused on the data from Western Europe and its offshoots have also come to this conclusion. However, with the introduction of the Song China data we see that this view is untenable. China experienced considerable growth in per capita product and population during the three centuries spanning 1000 to 1300 AD. Furthermore, China constituted about a fifth of the world’s population at the time, not an observation to be lightly dismissed.

A comparison between Song China and England (1750 – 1850) shows that both of these episodes fit Kuznets’ measured framework – modern economic growth. However, the clear absence of the extended application of science to the economy in the Song China episode strongly suggests that Kuznets’ judgment was incorrect.\footnote{A comment about the concept of “science” is warranted here. Scholars have long struggled with the key elements of the distinction between “science” based and “non-science” based technologies. Like all definitions of “science”, that of Kuznets faces problems by examples in the “grey area.” Its use here is not a litmus test for a grand classification system of technologies. The sole purpose here is to provide a meaningful distinction between the two types of economic growth observed in the data – one non-science based and one science based. In this respect, the definition performs quite well as the difference between these two types of economic growth appears rather stark. Landes suggests a similar view regarding the lack of science in the Song China economy. See Landes (2006), p. 6.} In particular, we should not identify his conceptual framework with his measured framework. It appears that what we are actually observing is not a transition to the extended application of science, but rather two different types of modern economic growth – one non-science based, one science based. In the Song China episode, the observation is clear – modern economic growth as Kuznets measured it without the extended application of science.\footnote{Indeed, modern science, which includes the mathematization of theories and concepts, was largely non-existent in Song China.} The England episode is more complicated. We can see that England (1750 – 1850) also experienced modern economic growth as Kuznets measured it without the extended application of science. In sharp contrast with Song China and England (1750 – 1850), the extended application of science to the economy appears in England (1850 – 1950). It seems that England (1850 – 1950) can be identified as a distinct type of modern economic growth – one that neither Song China nor England (1750 – 1850) experienced.

In my view, we are actually observing two different types of modern economic growth. The first type lacks the extended application of science, while the second is accompanied by the extended application of science. Based on this observation, I define the two types of the Industrial Revolution as follows.

**Definition:**

**Industrial Revolution**
Type 1 – “modern economic growth” as Kuznets defined the term without the extended application of science to problems of economic production.

Type 2 – “modern economic growth” as Kuznets defined the term with the extended application of science to problems of economic production.

In short, I argue there are two types of the Industrial Revolution, one non-science based and one science based. Hereafter, I shall use the following terms interchangeably.

**Terminology:**

- Type 1 Industrial Revolution = non-science based Industrial Revolution
- Type 2 Industrial Revolution = science based Industrial Revolution

This reformulation of Kuznets’ modern economic growth seems natural, at least in my view. Science or proto-science has been around for many, many centuries – millennia in some cases. It seems a strong case can be made that the foundation for the application of science to the economy is the social process “modern economic growth” and the changes associated with it. This description is clearly consistent with the evidence. Indeed Kuznets comments, “The Industrial Revolution of the late eighteenth century in Great Britain was associated with gradual improvements in trade, finance, and agriculture that provided the base for the initial technological developments. It was only later that scientific progress itself became dominant.”

Modern economic growth provides an environment that encourages the application of science to the economy. England made the transition from a Type 1 to a Type 2 Industrial Revolution in the mid-nineteenth century. However, as the Song China episode clearly establishes, a country need not make the transition to a Type 2 Industrial Revolution, i.e. it can experience a non-scientific Industrial Revolution.

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86 See Kuznets (1966), p. 11, ft. 3.
87 The focus of this research is on the onset of a Type 1 Industrial Revolution. Cases of Type 2 Industrial Revolution are not relevant to this focus. A brief comment about the Type 2 Industrial Revolution cases in Kuznets (1966) should be noted. England (1850 – 1950) is one such episode. However, this is actually a transition from a Type 1 to a Type 2 Industrial Revolution. The fundamental question here is why the extended application of science in the economy began – a question unrelated to the onset of a Type 1 Industrial Revolution. All other episodes of Type 2 Industrial Revolution considered in Kuznets (1966) are cases of spread, as opposed to onset – a distinction that is explained in detail in the following section, where it is argued that Type 2 episodes have a different cause.
**Section 3 Summary:** I argue that there are two types of Industrial Revolution. Type 1 Industrial Revolution (or non-science based Industrial Revolution) is defined to be “modern economic growth” as Kuznets defined the term *without* the extended application of science to problems of economic production. Type 2 Industrial Revolution (or science based Industrial Revolution) is defined to be “modern economic growth” as Kuznets defined the term *with* the extended application of science to problems of economic production. I argue that Song China and England (1750 – 1850) are both episodes of a Type 1 Industrial Revolution. England made a transition to a Type 2 Industrial Revolution, but Song China did not. (See Figures 1 & 2 below)

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 the Industrial Revolution is not completely novel. There exists a large literature on the economic growth of Europe that makes essentially the same 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.88

In this literature the definitions of the first and second Industrial Revolutions are usually dominated by particular technologies or sectors, although they also often 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.89 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

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89 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).
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.90

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.91 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 led to the inexpensive production 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. There is a large consensus that the technologies of the second Industrial Revolution are science-based. Roughly speaking, my two types of Industrial Revolution correspond to the well-established first and second Industrial Revolution. Seen in this light, this extension seems not only much less controversial, but also quite natural.

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.”92 He goes on to say, “Pre-modern water transport was close to a similar ceiling of efficiency.”93

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

90 See Mokyr (1998), p. 1. In my view this description can be equally applied to Song China.
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.  

These observations suggest that essentially both 1300 China and 1850 England had developed and applied technologies from Type 1 modern 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,” 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 Type 1 Industrial Revolution. 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 a non-science based Industrial Revolution” with the objective of finding its cause. There are strong grounds for arguing that the comparison between Song China and England (1750 – 1850) is superior to other comparisons made with England. As argued in the previous section, they are the same social phenomenon – non-science based (or Type 1) Industrial Revolutions. Basic scientific principles dictate that when the goal is to discover fundamental characteristics of a phenomenon, comparisons with the same phenomenon are superior to those that compare different phenomena.  

Furthermore,
this comparison is superior to others in that these two episodes have the same cause. When the ultimate goal is to identify cause, episodes with the same cause are strictly preferred. To develop this argument my use of the term “onset” needs to be explained.

Regarding either type of Industrial Revolution, by my definition, “onset” occurs when either appears in a nation which has no contact with a country experiencing an Industrial Revolution (Type 1 or Type 2). In other words, an Industrial Revolution begins without the stimulus of contact with a country experiencing either type of Industrial Revolution. The reason for explicit definition regarding the nature of a country’s transition to Industrial Revolution 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 an Industrial Revolution is the state, which includes all the people and resources under the government’s jurisdiction. Hereafter, the state or nation is taken to be the unit of observation. An Industrial Revolution 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 an Industrial Revolution through a chain of contact countries leading back to the Case 0 country. The cause of the spread must almost certainly be related to contact with another country that has contracted an Industrial Revolution. But what about the Case 0 nation? Since there was no such contact, the cause of the onset of an Industrial Revolution 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 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.

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 an Industrial Revolution and that at that time 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

\[\text{our knowledge. Comparisons and natural experiments to discover the cause are different than the issue at hand – discovering its defining characteristics.}\]

\[\text{96} \text{ Strictly speaking, Kuznets argued this for the case of his “modern economic growth.” See Kuznets (1951). I adopt this view for my definition of both a Type 1 and a Type 2 Industrial Revolution, which are based on Kuznets’ definition of “modern economic growth.”}\]

\[\text{97} \text{ Kuznets called the Case 0 nation the “pioneer” country to distinguish it from the countries to which modern economic growth spread, which he called “follower” countries. See Kuznets (1966), p. 497.}\]

\[\text{98} \text{ In principle, there will always be the possibility of spontaneous onset of an Industrial Revolution in a country just as another country experiencing Industrial Revolution comes into contact with it. While acknowledging this logical possibility, it is extremely unlikely given world events from 1750.}\]
that was experiencing an Industrial Revolution. In particular, I argue that Song China experienced the onset of an Industrial Revolution (Type 1 in particular). 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 Industrial Revolution for over two centuries with no consensus as to its defining characteristics, when it started 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. 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 an Industrial Revolution?” Comparisons between England and other countries that subsequently experienced an Industrial Revolution 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 an Industrial Revolution and those that experienced the spread, has not generated a consensus as to what caused England’s Industrial Revolution. The comparison between Song China and England (1750 – 1850) offers a superior comparison. These two episodes are the same social phenomenon – a non-science based Industrial Revolution. In addition, 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 are the same social phenomenon

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99 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.

100 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.
and have the same cause.

5. Embryonic stage & onset of the Type 1 Industrial Revolution

My goal is to define the “onset of a non-science based (Type 1) Industrial 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 a non-science based Industrial Revolution.

It will be useful to review the previous arguments. My premise is that there are two types of Industrial Revolution, one non-science based and one science based. I have argued that both China during the Song Dynasty (960 – 1279) (Song China hereafter) and England (1750 – 1850) are episodes of modern economic growth, as Kuznets defined the term, without the extended application of science to problems of economic production (non-science based Industrial Revolution). Furthermore, the onset of an Industrial Revolution and the spread of an Industrial Revolution are different social phenomena in that they have different causes. The onset occurs when an Industrial Revolution appears in a nation which has no contact with another country experiencing an Industrial Revolution. This is in contrast to the situation where an Industrial Revolution spreads through social contact among nations. Since the spread is almost surely related to social contact with a country experiencing an Industrial Revolution. This is in contrast to the situation where an Industrial Revolution spreads through social contact among nations. Since both Song China and England (1750 – 1850) are episodes of a non-science based Industrial Revolution 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 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 a non-science based Industrial Revolution.

Scholars have long believed that the only episode of the onset of an Industrial Revolution 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 been studying a single episode of the onset of a non-science based Industrial Revolution with little fundamental progress. For the first time, we can compare two cases. In my view the Song China episode contains important information that has not yet been 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 a non-science based Industrial Revolution 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 other definitions of the Industrial Revolution – 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 a non-science based Industrial Revolution and aims to discover commonalities. New common characteristics preceding “modern economic growth” as Kuznets defined the term are identified, allowing us to define the onset of a non-science based Industrial Revolution 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 a non-science based Industrial Revolution as the “Embryonic stage.”

My comparison reveals a metamorphosis during a period preceding a non-science based Industrial Revolution and continuing into it which sheds the structures of a self-sufficient agrarian economy and lays the foundation for a non-science based Industrial Revolution. 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 a non-science based Industrial Revolution.

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 common 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 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.\textsuperscript{101} 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 modern 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 these developments were uneven over time and space, the general trend of an

\textsuperscript{101} 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.
increasing number of rural towns is clear. These urban centers increasingly engaged in commercial activities.\(^{102}\) 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. 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.\(^{103}\)

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 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.104

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 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.105

- 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

increasing number of travelers. 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.106

**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.107 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.108

- **England**

**Phase IV – Development of markets and supporting organizations**

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106 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); Landes (1969), pp. 46 – 7.


Summary, Discussion and Conclusion

The goal of this study is to define the “onset of a non-science based Industrial Revolution” with the objective of finding its cause. In developing this question I have argued that there are two types of Industrial Revolution – one non-science based and one science based. For most readers, the most difficult aspect of my analysis to accept is the role of technology in economic growth advanced here. The apparent contradiction with the well established foundation of economic growth – the dominant influence of technology – will likely be difficult to accept at first glance. In addition, the important distinction between “onset” and “spread” of economic growth will likely be greatly under appreciated. Before summing up, two preliminary comments are in order.

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. Essentially, I argue that there are two types of economic growth. Type 1 (non-science based) takes place when science and scientific technologies are not in widespread use but all other factors of technology are at work. Type 2 (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 stripped from one type of economic growth. Yet in this type of non-science based economic growth (Type 1) 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 growth as fundamentally different from 20th century economic growth in the West in anything other than the widespread application of science and scientific technologies to the economy. Lastly, it should be noted that there is very little controversy that this type of economic growth (non-science based) has been clearly identified in the data – the first century of economic growth in England, and, as I shall argue, also China during the Song Dynasty (960 – 1279) (Song China hereafter).

Secondly, a similar comment should be made about different kinds of economic growth.
growth observed in the data, which are distinguished by features other than science. It must be emphasized that my argument addresses only one very specific kind of economic growth – its onset. This argument is silent regarding all other kinds of economic growth. The meaning of “onset” needs elaboration.

Let me begin by describing a well established distinction between two kinds of economic growth. Over the last several decades, there has been significant research on the economic growth of nations since the Second World War. The main lesson drawn from this research is that technology, broadly defined, is the engine of economic growth. Kuznets spoke of this as the “stock of useful knowledge”. 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 which are not using their existing technologies efficiently or have not 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 drastically different.

In this spirit, this study makes a distinction by separating and isolating the “onset” of economic growth from all other kinds of long-run economic growth, including the spread of economic growth, frontier growth, miracles and disasters. 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. The “onset” of economic growth occurred in England but subsequently spread via contact to other countries throughout the world. Frontier growth, miracles and disasters all occurred either after or concurrently with the spread of economic growth. The basis for the view that the “onset” is a different type of economic growth, sufficient enough to warrant a new, distinct type of economic growth, is that the “onset” of economic

109 Specifically, in terms of modern growth theory by technology I mean human capital and total factor productivity.
110 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.
growth has a different cause than that of the “spread” (this was discussed in detail in Section 4 and will be reviewed below). Thus, I argue that when the ultimate goal is to discover the cause of the “onset”, we should separate the “onset” cases from other cases in our analysis. The main contribution of this study is to identify one specific, distinct type of economic growth whose importance has not yet been sufficiently recognized – the onset of a non-science based Industrial Revolution. Next, I shall present a summary, a discussion of the significance of the Song China comparison with England (1750 – 1850) and of the role of science and technology in an Industrial Revolution and a conclusion.

Summary

I contend that there are two types of the Industrial Revolution – one non-science based (Type 1), one science based (Type 2). 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 conceptual and one measured. He started with the conceptual framework. He argued 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 conceptual 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 measured framework – “modern economic growth”, which he defined to be an increase in per capita product, accompanied by an increase in population and changes in the industrial structure.\footnote{See Section 3, page x, for a more detailed presentation of Kuznets’ definition and for his definition in full see Kuznets (1966), p. 1.} 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 conceptual (modern economic epoch) and one measured (modern economic growth). According to Kuznets, these two frameworks coincided with one exception – England. His conceptual framework, the modern economic epoch (based on the extended application of science to problems of economic production), was identified as the period 1850 – 1950, while his measured
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, the extended application of science was clearly absent.\(^{112}\) 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’ conceptual and measured frameworks are distinct and should not be identified with each other. Song China and England (1750 – 1850) both experienced “modern economic growth” 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”.\(^{113}\) Rather, I contend that we are actually observing two different types of “modern economic growth” – one non-science based, one science based.

With this distinction in mind, I define two types of the Industrial Revolution. The first type, the “non-science based Industrial Revolution”, is taken to be “modern economic growth” as Kuznets defined the term without the extended application of science to problems of economic production. I shall use the terms “Type 1 Industrial Revolution” and “non-science based Industrial Revolution” synonymously. The second type, the “science based Industrial Revolution”, is taken to be “modern economic growth” as Kuznets defined the term with the extended application of science to problems of economic production. I shall use the terms “Type 2 Industrial Revolution” and “science based Industrial Revolution” synonymously. Thus, we have two episodes of the non-science based Industrial Revolution, Song China and England (1750 – 1850), while England (1850 – 1950) and the other cases in Kuznets’ study are identified as the science based Industrial Revolution. The cases of Song China and England (1750 – 1850) are the focus of subsequent analysis (See Figures 1 & 2.

\(^{112}\) 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, page y.

\(^{113}\) 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 Section 3, pp. x – y. Eric L. Jones has made related arguments – see Jones (1988)). Second, if one views the Song China 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.
This study aims to define the “onset of a non-science based Industrial Revolution.” Definitions are relative to a purpose. The eventual goal of this line of inquiry is discover the cause of the onset of a non-science based Industrial Revolution. Therefore, causation is a fundamental factor in any such definition. I argue that the two episodes of the onset of a non-science based Industrial Revolution experienced by Song China and England (1750 – 1850) very likely had the same cause. To follow this argument, the clear distinction between the onset and the spread must be understood. The onset occurs when either type of Industrial Revolution appears in a nation which has no contact with another country experiencing either type of Industrial Revolution. This is in contrast to the situation where either type Industrial Revolution spreads through social contact among nations. Since the spread is almost surely related to social contact with a country experiencing one type of the Industrial Revolution and the onset is not, these social phenomena must have different causes. I argue that Song China and England (1750 – 1850) are both onset cases and therefore very likely have the same cause – one that can be better revealed by a comparison of onsets.

Finally, I compare Song China and England (1750 – 1850), in order to expand Kuznets’ definition of “modern economic growth” to include common features that precede its onset. In my comparison, preceding both episodes I identify a common stage, which I 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 credit. I argue that the appearance of the Embryonic stage is the turning point for the onset of the non-science based Industrial Revolution. I complete the analysis by defining the “onset of the non-science based Industrial Revolution” as an episode of the non-science based Industrial Revolution, which is immediately preceded by the Embryonic stage.

**Conclusion**

When confronting the question "What caused the onset of modern economic growth?", I conclude by arguing the most important question that needs to be addressed is: "What caused the urbanization of the countryside?" – which is the first phase of the Embryonic stage. This needs to be addressed in the case of both China and England beginning about 760 and 1660 respectively.
England

Phenomena

Embryonic Stage

Type 2: Industrial Revolution

Type 1: Industrial Revolution

Self-Sufficient Agrarian Economy

1650 1750 1850 1950 Year

Figure 1

Song China

Phenomena

Embryonic Stage

Type 1: Industrial Revolution

Self-Sufficient Agrarian Economy

750 1000 1100 1200 1300 Year

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
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