INNOVATION AND THE GREAT DIVERGENCE

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Abstract: The Great Divergence of GDP per capita between the leading regions of Europe and China occurred around 1700 as a period of positive growth in Britain and the Netherlands coincided with a period of negative growth in the Yangzi Delta. The positive trend in northwest Europe was a continuation of a process that began in the fourteenth century, while the negative trend in the Yangzi Delta continued a pattern of alternating periods of growing and shrinking, but reaching lower levels of income. TFP growth was strongly positive in Britain after the Black Death, in the Netherlands during the Dutch Golden Age and again in Britain from the mid-seventeenth century. Although TFP growth was positive in China during the Northern Song dynasty, it was predominantly negative during the Ming and Qing dynasties, in the Yangzi Delta as well as in China as a whole.

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I. INTRODUCTION

When Pomeranz (2000) coined the term "Great Divergence" to describe the emerging gap in productivity and living standards between Europe and Asia, there was very little agreement about either the timing or the causes of the divergence. For much of the twentieth century, many economic historians treated the Industrial Revolution as just the culmination of a process of gradual improvement, beginning in the late middle ages and continuing throughout the early modern period (Weber, 1930; Landes 1969; North and Thomas,1971). On this view, as Europe transformed its institutions and accumulated capital, Asia stagnated and began to fall behind. Technological progress during the Industrial Revolution was seen as accelerating this process of divergence, rather than initiating it. Pomeranz (2000) questioned what he saw as the Eurocentric bias of this account, claiming that as late as 1800, the Yangzi Delta region of China was as developed as Britain and the Netherlands, the richest parts of Europe. Other parts of Asia were also characterised as equally developed at the end of the eighteenth century. This chimed with the work of Frank (1998) and other economic historians working in California, and became known as the California School.

However, despite the fundamentally quantitative nature of the revisionist claims being made, this work was not generally based on systematic analysis of data. Whilst this was understandable given the past focus of quantitative economic history on the modern period, and particularly the period since the mid-nineteenth century, the new century has seen much progress in the extension of the quantitative approach both back in time and across space to cover Asia as well as Europe. This paper draws on the new sources of data that have been uncovered to provide a quantitative assessment of both the timing of the Great Divergence and its causes. In particular, we use historical national accounting to establish the path of GDP per capita in regions of Europe and Asia, and growth accounting to assess the role of technology in explaining GDP per capita growth.

This paper argues that the revisionist authors of the California School were right to point to regional variation in economic performance in both Europe and Asia. We find that the Yangzi Delta, the richest region if China during the Ming and Qing dynasties, remained broadly on a par with Britain and the Netherlands in the richest northwest region of Europe until the start of the eighteenth century. However, the California School went too far in claiming parity of economic performance between the two continents until the nineteenth century. The historical national accounting data presented here suggest that the Great Divergence dates from the eighteenth rather than the nineteenth century, a view that has recently been endorsed by Pomeranz (2011; 2017). However, this is obviously a lot later than suggested in the traditional view, where Europe was seen as forging ahead since at least 1500, if not as early as 1300.

In addition, growth accounting is used to assess the contributions of factor inputs and the efficiency with which those inputs were used. Those inputs include the growth of the labour force, increased labour effort, investment in both human capital and physical capital and the growth of total factor productivity (TFP). Obtained as a residual, TFP growth is a measure of changes in the efficiency with which inputs are utilised. It has often been equated with technological progress, but includes other innovations, including organisational changes such as the introduction of the factory system. TFP growth was positive in China during the Northern Song dynasty, when China was the world's richest nation, but predominantly negative during the Ming and Qing dynasties in the Yangzi Delta as well as in China as a whole. In northwest Europe, by contrast, TFP growth was strongly positive in Britain after the Back Death, in the

Netherlands during the Dutch Golden Age, and in Britain again continuously from the mid-seventeenth century. Different paths of innovation were critical for the Great Divergence.

2. PATTERNS OF ECONOMIC GROWTH IN EUROPE AND ASIA, 1000-1870

Until recently, most accounts of economic growth before 1870 were largely qualitative. That changed with Maddison's (2001), *The World Economy: A Millennial Perspective*, published shortly after Pomeranz's (2000) *The Great Divergence*. Although Maddison's (2001) dataset was a major breakthrough for quantification of long run economic growth, it contained a large amount of "guesstimation" or "controlled conjectures", with a number of observations set at or close to $400 in 1990 international prices. This is equivalent to most people living at "bare bones subsistence", or the World Bank poverty level of $1 per day, with a small rich elite on top. Furthermore, Maddison provides his conjectural estimates only for a small number of years.

Stimulated by Maddison's work, economic historians have recently begun to produce estimates of per capita income in a national accounting framework, based on contemporary data, and a firmer picture has begun to emerge of the contours of long run growth and development in both Europe and Asia. This is possible because medieval and early modern Europe and Asia were much more literate and numerate than is often thought, and left behind a wealth of data in documents such as government accounts, customs accounts, poll tax returns, parish registers, city records, trading company records, hospital and educational establishment records, manorial accounts, probate inventories, farm accounts, tithe files and other records of religious institutions. With a national accounting framework and careful cross-checking, it is possible to reconstruct population and GDP back to the medieval period, sometimes at decadal or even annual frequency.

2.1 Europe's Little Divergence

For some European countries, abundant quantitative information has survived, so that historical national accounts can be constructed directly on a sectoral basis in great detail. Britain and Holland have very rich data, with historical national accountants able to build on decades of detailed data processing by generations of scholars as well as well-stocked archives (Broadberry, Campbell, Klein et al., 2015; van Zanden and van Leeuwen, 2012). For other countries, where information is more limited, or where there has been less processing of existing data, Malanima (2011), Álvarez-Nogal and Prados de la Escosura (2013) and others have developed a short-cut method for reconstructing GDP, building on pioneering work by Crafts (1985) and Wrigley (1985). In the short-cut method, the economy is first divided between agriculture and non-agriculture. In the agricultural sector, output is estimated via a demand function, making use of data on population, real wages and the relative price of food, together with elasticities derived from later periods and the more recent experience of other less developed economies. In Allen's (2000: 13-14) notation:

$$Q^A = rcN \tag{1}$$

where Q^A is real agricultural output, r is the ratio of production to consumption, c is consumption per head and N is population. Real agricultural consumption per head is assumed to be a function of its own price in real terms (P^A/P), the price of non-agricultural goods and services in real terms (P^{NA}/P), and real income per head (y). Assuming a log-linear specification, we have:

$$\ln c = \alpha_0 + \alpha_1 \ln(P^A / P) + \alpha_2 \ln(P^{NA} / P) + \beta \ln y \tag{2}$$

where α_1 and α_2 are the own-price and cross-price elasticities of demand, β is the income elasticity of demand and α_0 is a constant. Consumer theory requires that the own-price, cross-price and income elasticities should sum to zero, which sets tight constraints on the plausible values, particularly given the accumulated evidence on elasticities in developing countries (Deaton and Muellbauer, 1980: 15-16, 60-82).

For the non-agricultural sector, output is assumed to have moved in line with the urban population, but with some allowance made for rural industry and the phenomenon of agro-towns. This approach began with Wrigley (1985), and has recently been combined with the demand approach to agriculture to provide indirect estimates of GDP in a number of European countries during the early modern period (Malanima, 2011; Álvarez-Nogal and Prados de la Escosura, 2013; Schön and Krantz, 2012). With the path of agricultural output (Q^A) derived using equations (1) and (2), overall output (Q) is derived as:

$$Q = \frac{Q^A}{1-\left(Q^{NA}/Q\right)} \qquad (3)$$

where the share of non-agricultural output in total output (Q^{NA}/Q) is proxied by the urbanisation rate. The approach can be made less crude by making an allowance for higher productivity in the non-agricultural sector, so that (Q^{NA}/Q) increases more than proportionally with the urbanisation rate.

The new estimates of GDP per capita based on historical national accounting data for four key economies in northwest and Mediterranean Europe are presented in Figure 1 for the period 1000-1870. Although these data were constructed on an annual basis, they are provided here at decadal frequency from 1270 onwards. In Mediterranean Europe, Italy and Spain experienced long-term stagnation between 1300 and 1800, as bursts of episodic growth alternated with period of negative growth, or shrinking. In northwest Europe, by contrast, Britain and the Netherlands experienced trend long run growth from the mid-fourteenth century, as short bursts of episodic growth were interspersed with longer periods of stagnation, avoiding periods of substantial shrinking (Broadberry and Wallis, 2017).

The reversal of fortunes between northwest and Mediterranean Europe occurred in two phases. The first turning point came with the Black Death in 1348. Before then, per capita incomes were substantially higher in Italy and Spain than in Britain and the Netherlands. Although Italy, Britain and the Netherlands all received a positive boost to per capita incomes following the collapse of population beginning in the mid-fourteenth century, only Britain and the Netherlands remained permanently richer as population recovered. A second turning point occurred around 1500, as new trade opportunities opened up between Europe and Asia via trade routes around the south of Africa, and between Europe and the Americas via the Atlantic Ocean. The Netherlands first caught up with Italy then forged ahead during its Golden Age, while Britain experienced a further growth episode from the mid-seventeenth century.

Second-generation estimates of GDP per capita are now also available for other European countries, including France, Sweden, Poland, Portugal and Germany (Ridolfi and Nuvolari, 2022; Schön and Kranz, 2012; Krantz, 2017; Malinowski and van Zanden, 2017; Palma and Reis, 2019; Pfister, 2022). These estimates are shown in Figure 2 and confirm the picture of no trend growth between 1300 and 1800 outside northwest Europe, which forged ahead of the rest of the European continent from around 1500, led initially by the Netherlands, then by Britain.

2.2 Asia's Little Divergence

Data are available for some Asian economies for some time periods, but there has been relatively little work so far processing this material. Much work remains to be done on the Chinese data, but it is now possible to produce decadal estimates of GDP from the output side for China as a whole reaching back to the Northern Song dynasty apart from gaps during dynastic changes and for the Yangzi Delta back to the beginning of the Ming dynasty (Broadberry, Guan and Li, 2018; 2021; Zhai, 2023). Indian data are less abundant, and it has so far only been possible to produce decadal estimates back to 1800 and benchmarks every half century between 1600 and 1800 (Broadberry, Custodis and Gupta, 2015). Apart from Abū ’l-Fazl’s [1595] remarkable document, *The Ā’ īn–i-Akbarī*, most of the information about India comes from the records of the European East India Companies and the British Raj. Japan also has a wealth of data, but at this stage the estimates are available only for a handful of benchmark years before the Meiji restoration of 1868 (Bassino, Broadberry, Fukao et al., 2019).

The second generation GDP per capita estimates for Asia are set out in Figure 3. They suggest that China was the leading Asian economy during the Song dynasty, but was overtaken by Japan during the eighteenth century, while India declined through the seventeenth and eighteenth centuries. This has led to the suggestion of an Asian Little Divergence occurring at about the same time as the European Little Divergence. However, care must be taken here about the timing of the Asian Little Divergence because of differences in the size of the countries being compared. The population of Japan in 1600 was 17 million, at a time when the Chinese population was 160 million (Bassino, Broadberry, Fukao et al., 2019; Maddison, 2010). A more appropriate comparator for Japan would be the Yangzi Delta, widely regarded as China’s richest region. Measured against the Yangzi Delta, the reversal of fortunes between China and Japan was delayed until after the Meiji restoration rather than during the eighteenth century.

Figure 4 compares Zhai’s (2023) estimates of GDP per capita for the Yangzi Delta with alternative estimates from Broadberry, Guan and Li (2021) and Broadberry and Guan (2022). Broadberry Guan and Li (2018, 2021) made the first attempt to provide estimates of GDP per capita in the leading region of China over a substantial period of time, derived by assuming that the ratio between the Yangzi Delta and China as a whole in the 1820s remained constant over time. The ratio for the 1820s was obtained from a comparative study by Li and van Zanden (2012), who found per capita incomes in the Yangzi Delta to be around half of the level in the Netherlands in the 1820s. This suggests a per capita GDP figure of around $1,050 for the Yangzi Delta, in 1990 international dollars, or about 75 percent higher than in China as a whole. Applying the ratio between the Yangzi Delta and China as a whole in the 1820s to Chinese GDP per capita from Broadberry, Guan and Li (henceforth BGL) for earlier years produces a quantification of the leading Chinese region in the same units as the other countries in Figure 3. This does not have to mean that the Yangzi Delta was always the leading region, but rather that there was always a region that was proportionally as far above the Chinese average as the Yangzi region in the 1820s.

Broadberry and Guan (2022) provide estimates of Chinese GDP per capita for four benchmark years, broken down into seven macro regions during the Ming and Qing dynasties, establishing that East Central China was the richest macro region. However, this region still contained around a third of China's population, so data are also provided for the Yangzi Delta, the core of East Central China, widely seen as the richest part of China since the Ming. With a population of around 20 million in 1600, about the same as France, the Yangzi Delta is more comparable in size to a European nation state. For the Northern Song dynasty, although it is not possible to derive a full regional breakdown, data are provided for Kaifeng Fu, the region containing the capital city. Broadberry and Guan's (2022) benchmark estimates are broadly consistent with the time series projections of Broadberry Guan and Li (2021), which hold constant the ratio between GDP per capita in China's leading region and the empire as a whole.

Zhai's (2023) reconstruction of GDP per capita from the output side uses a similar methodology to Broadberry, Guan and Li (2018; 2021) but applied at the regional level using local sources such as gazetteers. Zhai's results are broadly consistent with the BGL and B&G estimates over the period 1400-1870. For the rest of the paper we will focus on Zhai's (2023) estimates for the Yangzi Delta during the Ming and Qing dynasties, combined with Broadberry and Guan's (2022) benchmark estimate for Kaifeng Fu during the Northern Song dynasty.

2.3 The Great Divergence

Figure 5 plots the new GDP per capita estimates for the leading regions of Europe from Figure 1 together with the series for the leading regions of China from Figure 4, to provide a focus on the Great Divergence. Kaifeng Fu was substantially richer than Italy and Britain in the eleventh century. When it itis next possible to make a comparison between the leading regions of China and Europe at the beginning of the Ming dynasty, the Yangzi Delta was on a par with Italy, which was then the richest European region. Although the Netherlands forged ahead during the sixteenth century, the Yangzi delta closed the gap by the mid-seventeenth century, and also remained ahead of Britain, the larger northwest European economy. From the end of the seventeenth century, however, GDP per capita in the Yangzi Delta began a long decline coinciding with the transition to modern economic growth in northwest Europe. The Great Divergence can thus be seen as beginning around 1700. These trends can be seen more clearly comparing the leading regions of China with the leading regions of Europe one at a time in Figure 6.

Figure 6A shows the comparative positions of Britain and the leading regions of China. During the Northern Song dynasty, Britain was a backwater of Europe, with GDP per capita less than half the level of Kaifeng Fu, the region around the capital city, Kaifeng. Britain improved its position during the second half of the fourteenth century following the Black Death, which reduced population by around half. This left many of those who survived with more land and capital, with even the landless benefitting from higher wages as factor proportions changed in favour of labour. Although the gap between the two economies narrowed during the sixteenth and early seventeenth centuries as GDP per capita declined in the Yangzi delta and remained on a plateau in Britain, overtaking was delayed until the very end of the seventeenth century, as the Yangzi Delta experienced a sharp increase in GDP per capita during the Ming-Qing transition. This occurred as a result of the sharp population decline resulting from the dynastic struggle. The critical juncture thus occurred around 1700 as Britain made the transition to modern economic growth, with population and GDP per capita both growing at the same time, while GDP resumed its secular decline in the Yangzi Delta as the cultivated land area failed to keep up with the resumption of population growth.

Turning to the comparison between the Netherlands and the leading regions of China in Figure 6B, we see that although the Netherlands did forge ahead of the Yangzi Delta briefly during its Golden Age, the Yangzi Delta very nearly caught up again during the Ming-Qing transition, so that the critical juncture is again seen to be delayed until the end of the seventeenth century. In Figure 6C, we can see the relationship between Italy and the leading regions of China. Since Italy was the leading region of Europe in the eleventh century, the substantial gap between Kaifeng Fu and Italy confirms that Kaifeng Fu was the richest region in Eurasia, and most likely in the world. Although the Yangzi Delta fell behind Italy during the eighteenth century, it should be borne in mind that by this time, Italy had long since lost its position as the European leader, and was now part of the poorer European periphery.

It is reassuring that the historical national accounting evidence suggests the eighteenth century as the beginning of the Great Divergence, since this seems to be the new consensus that is emerging from both California School authors such as Pomeranz (2011; 2017) and from economic historians using other quantitative indicators such as real wages and urbanization rates (Broadberry and Gupta, 2006; Allen, Bassino, Ma et al., 2011). It seems that the California School authors were right to point to the importance of regional variation within both Asia and Europe, but a bit too optimistic about the performance of the richest parts of Asia during the eighteenth century.

2.4 Dynamics of the Great Divergence

Settling the timing of the Great Divergence does not mean that what happened earlier can be disregarded in seeking to understand its origins. It is important to also examine the dynamics of the income process. Using annual estimates of GDP per capita reaching back to the thirteenth or fourteenth century for a number of countries, a radically new picture of the Industrial Revolution has appeared. Northwestern Europe forged ahead of the rest of Europe and also diverged from Asia not by growing faster during periods of positive growth, but rather by reducing the frequency and rate of shrinking during periods of negative growth (Broadberry and Wallis, 2017). Indeed, the period of improved long-run economic performance actually took place at a time when the average rate of growing during periods of positive growth was slowing down. This process of avoiding growth reversals in northwestern Europe can be traced back to the growth episode following the Black Death of the mid-fourteenth century. In this sense, the origins of the Great Divergence are still to be found in the late medieval period, as earlier generations of economic historians argued, even though at this stage northwestern Europe had not forged ahead of the rest of Europe or Asia.

Explaining the Industrial Revolution has more in common with solving the problem of development today than is usually acknowledged. Getting growth going in the first place, the traditional focus of analysis, is only part of the story. Just as important is ensuring that periods of positive growth are not followed by periods of negative growth, or shrinking (Broadberry and Wallis, 2017). This has been highlighted in the case of developing economies today by Easterly, Kramer, Pritchett et al. (1993) and Pritchett (2000). For the transition to modern economic growth in northwest Europe, it means paying as much attention to the absence of negative trend growth after the Black Death as to the innovations that started episodes of positive growth during the eighteenth century. For the decline of China and India, it requires paying more attention to the increasing frequency and rate of shrinking from the eighteenth century.

3. GROWTH ACCOUNTING AND THE GREAT DIVERGENCE

3.1 Growth accounting

Armed with the estimates of economic growth before 1870 from the previous section, this paper now turns to explanation. Growth accounting begins with a production function to assess whether economic growth came from the use of more factor inputs or from the more effective use of existing inputs (Solow, 1957). In the simplest formulation, aggregate output (Y) is produced using inputs of capital (K) and labour (L) and A is a measure of efficiency or total factor productivity (TFP):

$$Y = AF(K, L) \tag{4}$$

The growth rate of output ($\Delta Y/Y$) can be related to the growth rates of the inputs of capital ($\Delta K/K$) and labour ($\Delta L/L$) and the growth rate of TFP ($\Delta A/A$).

$$\Delta Y/Y = \alpha\, \Delta K/K + \beta \Delta L/L + \Delta A/A \tag{5}$$

The weights α and β reflect the relative importance of inputs in the production process, measured by their shares in the costs of production. For labour this is the share of wages in the value of output, while for capital it is the share of profits. The growth accounting equation can also be written in intensive rather than extensive form, to show how the growth of per capita output can be explained by the growth of capital per capita (capital deepening) or total factor productivity growth:

$$\Delta y/y = \alpha\, \Delta k/k + \Delta A/A \qquad (6)$$

where the growth of output per capita (Δy/y) is equal to the growth of output minus the growth of labour, and the growth of capital per capita (Δk/k) is the growth of capital minus the growth of labour.

The framework can be adapted to include human capital (H) and land (R) as additional factor inputs. This results in the extensive form growth accounting equation:

$$\Delta Y/Y = \alpha\, \Delta K/K + \beta \Delta L/L + \gamma \Delta H/H + \theta \Delta R/R + \Delta A/A \qquad (7)$$

where the weights γ and θ reflect the relative importance of human capital and land in the production process. The intensive form growth accounting equation then becomes:

$$\Delta y/y = \alpha\, \Delta k/k + \gamma \Delta h/h + \theta \Delta r/r + \Delta A/A \qquad (8)$$

where the growth of labour quality (Δh/h) is equal to the growth of human capital minus the growth of labour, and the growth of land per capita (Δr/r) is the growth of farmland minus the growth of labour.

The labour input is measured not just by the number of workers (usually assumed to grow in line with population), but must also take into account the number of days worked per person per year and the quality of the labour force. In economic history, these aspects are usually discussed under the headings “industrious revolution” and “human capital” (de Vries, 1994; Baten and van Zanden, 2008). The capital input is ideally measured by fixed capital excluding dwellings, although this is one of the most difficult series to obtain from historical sources (Feinstein, 1978; 1988). Measures of farmland are usually restricted to the arable acreage, as it is much harder to obtain reliable estimates of the amount of land used for grazing livestock. With independent measures of the growth of output, labour, capital and land, total factor productivity growth is derived as a residual. As noted earlier, although this is often used as an indicator of technological change, here it is taken to be a broader measure of innovation, including organisational change.

3.2 Accounting for British growth

Part A of Table 1 presents the results of the growth accounting exercise in extensive form using equation (7) to account for the growth of GDP in Britain. The labour force is assumed to move in line with population from Broadberry, Campbell, Klein et al. (2015) and allowance is also made for changes in the average number of days worked per person per year from Humphries and Weisdorf (2019). The stock of human capital is measured by the average years of education per person from de Pleijt (2018) multiplied by the population. The capital stock from Broadberry and de Pleijt (2021) is measured by fixed capital excluding dwellings. The land variable is the cultivated acreage from Broadberry, Campbell, Klein et al. (2015). For most of the period, the factor input weights are 40 per cent for labour (population and annual days worked), 20 per cent for human capital, 20 per cent for fixed capital and 20 per cent for land, but from the 1830s onwards the split between fixed capital and land is adjusted to 30 per cent for capital and 10 per cent for land. This reflects the roughly equal shares of fixed capital and land in national wealth at current prices until the nineteenth century in Broadberry and de Pleijt (2021) and the changing factor shares during the modern period in Crafts (2021: 312).

Note that the last two columns of Table 1A (TFI growth and TFP growth) add up to the first column (GDP growth). The main result is that output growth was driven predominantly by the growth of inputs, with TFP growth playing a relatively minor role. Input growth was in turn driven primarily by population growth, which declined after the arrival of the Black Death before recovering from the 1450s. The population decline caused by the Black Death wiped out one-third of the population within three years and more than half the population within a century of its arrival in 1348, affecting not only the supply of labour and the stock of human capital, but also the amount of land that could be cultivated by the smaller workforce and the incentives to accumulate capital. Annual days worked per capita declined during the dramatic population collapse between the 1340s and the 1400s, but then increased in line with the industrious revolution, so that the more modest episodes of population decline in the first half of the fifteenth century and the second half of the seventeenth century were offset by an increase in days worked per capita. As population recovered from the 1450s, inputs of land, fixed capital and human capital all grew and days worked per capita increased. Capital growth became noticeably more important from the 1830s, while relatively little growth of farmland was possible beyond recovery from the post-Black Death decline.

Part B of Table 1 presents the results of growth accounting in intensive form for Britain, using equation (8) to show how the growth of GDP per capita can be explained by work intensity, human and physical capital deepening, changes in the land-labour ratio and growing efficiency. Again, the last two columns (TFI per capita growth and TFP growth) add up to the first column (GDP per capita growth). The main result from Table 1B is that TFP growth was as important a driver of growth in GDP per capita as the contribution of per capita total factor inputs, accounting for around half of the positive GDP per capita growth. Nevertheless, the contribution of factor inputs was not unimportant, and developments can again be split into two periods, covering the Black Death years and the subsequent period of population recovery. TFI per capita growth after the Black Death was driven by the effects of population decline, as survivors had extra land, capital and education opportunities and also more leisure as days worked per person declined. With the recovery of population from the 1450s, human capital per capita continued to grow, albeit at a declining rate as most of the population became literate. Note that the capital-labour ratio grew relatively little until after the 1830s, while the land-labour ratio drifted downwards as population increased. Increasing the quantity and quality of labour thus played an important role, together with innovation, in driving the British transition to modern economic growth.

3.3 Accounting for Dutch growth

For the case of Holland, van Zanden and van Leeuwen (2012) report the results of a growth accounting exercise in extensive form using population, human capital, fixed capital and land as the factor inputs to explain the growth of GDP. Since they provide the growth rates for all series and also the factor shares, it is possible to reproduce their results in extensive form and extend the exercise to the intensive form to account for the growth of GDP per capita. The results are reported in Table 2 using their factor shares. These are also the factor shares used in the British case for the nineteenth century, with a smaller share of non-labour incomes accruing as a return to land (10 per cent) and a larger share to fixed capital (30 per cent). This seems reasonable given the earlier structural shift of the Dutch economy away from agriculture and reliance on grain imports (de Vries and van der Woude, 1997: 198-210).

Beginning with the extensive growth accounts in Table 2A, total factor input growth was the main driver of GDP growth over the period 1540-1800, as in the British case. Again, as in the British case, population growth was the main driver of TFI growth. Turning to the intensive growth accounts in Table 2B, however, we see a much stronger role for TFP growth in explaining GDP per capita growth, particularly during the Dutch Golden Age, 1540-1620. Nevertheless, as in the British case, factor inputs also had a significant role to play. Human capital deepening was the most important driver of TFI per capita from 1620 onwards, while fixed capital deepening was more important during the Dutch Golden Age. The land-labour ratio made a mainly negative contribution to GDP per capita growth.

3.4 Accounting for Chinese growth

So far growth accounting has been used to explain the path of GDP per capita in northwest Europe, but for an understanding of the Great Divergence it is also necessary to explain the path of GDP per capita in China. We begin with China as a whole, before also presenting growth accounts for the Yangzi Delta. Data on China's GDP and the inputs of land (the cultivated area) and labour (population) are available from Broadberry, Guan and Li (2018; 2021). Although there are currently no estimates of fixed capital for China, it is possible to make the Kaldorian assumption that the capital-output ratio remained constant over time. Kaldor (1963) established this as a "stylised fact" of economic growth on the basis of data for the nineteenth and twentieth centuries, but Broadberry and de Pleijt (2021) have shown that it also holds for Britain between the fourteenth and nineteenth centuries. Human capital has been proxied by the number of book titles available at decadal frequency from McDermott (2005) for the period 1131-1566 and van Leeuwen and Xu (2021) for the period after 1550.

Results of growth accounting for China using these variables and covering the period 980-1840 are reported in Table 3. The extensive growth accounts in Table 3A show that GDP growth was driven mainly by total factor input growth, particularly population growth. This is very much in line with the results for Britain and Holland. However, in the case of China, TFP growth was always small in magnitude and predominantly negative. As a result, when we turn to the intensive growth accounts in Table 3B, TFP growth also rarely boosted GDP per capita growth and then only by a small amount. Since land per capita was declining and other inputs were barely keeping up with population growth, apart from a period of strong human capital deepening during the Ming dynasty, GDP per capita also trended down over the period as a whole. The Qing period 1690-1840 was particularly disastrous for China, with sharply declining factor inputs per capita amplified by negative TFP growth.

3.5 Accounting for Yangzi Delta growth

We have shown earlier that the Yangzi Delta was the leading region of China during the Ming and Qing dynasties. For this period, we can also conduct growth accounting for the Yangzi Delta using data from Zhai (2023). The extensive growth accounts in Table 4A show that GDP growth was driven primarily by the growth of total factor input in the Yangzi Delta as well as in China as a whole. Trends in the labour force played an important role as population first increased during the Ming dynasty, then declined sharply during the Ming-Qing transition before increasing again during the Qing dynasty. However, these developments in the quantity of labour were reinforced by similar trends in the quality of labour, as the growth of human capital was strongly positive apart from during the Ming-Qing transition. The growth of cultivated land was only weakly positive. As in China as a whole, TFP growth was negative over the 1400s-1840s period as a whole, with positive TFP growth restricted to a short period during the Ming-Qing transition.

The intensive growth accounts in Table 4A show that GDP per capita growth was negative over the 1400s-1840s period as a whole, and this was driven largely by the predominantly negative TFP growth. Again, as in China as a whole, the trend in land per capita was predominantly negative as the cultivated area could not be expanded sufficiently to keep up with population trends apart from during the catastrophic collapse of the Ming-Qing transition.

3.6 Accounting for the Great Divergence

McCloskey (1981: 108) wrote "ingenuity rather than abstention governed the industrial revolution". Although growth accounts in extensive form over the very long run show that output growth in northwest Europe was driven largely by total factor input growth rather than by TFP growth, this does not mean that investment/savings (or abstention) was more important than innovation (or ingenuity) in the Great Divergence. Rather, McCloskey's vision is confirmed using the growth accounts in intensive form. GDP per capita growth in northwest Europe, which underpinned the rise in living standards, was driven as much by TFP growth as by physical and human capital deepening. Just as northwest Europe made the transition to modern economic growth from around 1700, in China, and in particular in the Yangzi Delta, GDP per capita trended down as the land-labour ratio fell, human and fixed capital deepening slowed down and even turned negative while TFP growth was also slightly negative.

4. INNOVATION IN NORTHWEST EUROPE AND CHINA

The key drivers of the Great Divergence in the eighteenth century were the transition to modern economic growth in northwest Europe at the same time as a period of negative per capita. income growth or shrinking in Qing dynasty China. However, northwest Europe and China, including the Yangzi Delta, had been on different paths of innovation and technology since at least the Song dynasty (Needham, 1981; Lin, 1995). This shows up in the different paths of total factor productivity growth in the two continents.

4.1 Innovation in northwest Europe and China, c. 980-1400

In China, TFP growth was positive during the Northern Song dynasty. This is consistent with Chinese technological advances across a wide range of industries at this time (von Glahn, 2016: 245-249; Lin, 1995: 270). Indeed, a number of innovations that are often seen as crucial to the emergence of modern economic growth in Industrial Revolution Britain can be seen to have already appeared in Song dynasty China. In iron, the coke smelting of iron was widespread in the eleventh century, while in textiles, the spinning wheel had been introduced by the thirteenth century and central power sources subsequently applied to the spinning of yarns (Hartwell, 1962; Mokyr 1990: 212). The Chinese shipbuilding industry was producing ocean-going junks that were much larger and more seaworthy than the best European ships well before 1400 (Mokyr, 1990: 215). While genuine porcelain had first appeared during the Tang Dynasty, improvements led to it being exported in large quantities during the Song Dynasty (Mokyr, 1990: 218; Elvin, 1973: 285; von Glahn, 2016: 247-248).

There were also innovations in Chinese agriculture at this time, including seed drills, weeding rakes and the deep-tooth harrow (Mokyr, 1990: 209). Improvements in water control allowed the draining and irrigation of lands, permitting the expansion of rice cultivation in the south, while the introduction of new varieties of quick-ripening Champa rice permitted rapid population growth. This resulted in population growth outstripping the growth of other factor inputs, leading to negative per capita total factor input growth offsetting the positive TFP growth. The net outcome was negative growth of GDP per capita between 980 and 1120 (Table 3).

In Britain, there was strongly positive growth of GDP per capita between the 1340s and the 1400s which was largely explained by the growth of per capita inputs, as population collapsed with the arrival of the Black Death, leaving survivors with more land and capital, and better educational opportunities (Broadberry, 2021; Broadberry and de Pleijt, 2021). However, there was also positive TFP growth, arising from innovations including shifts from arable to pastoral farming, and from exporting raw wool to manufacturing cloth (Broadberry, Campbell, Klein et al., 2015: 115-118, 144-146).

4.2 Innovation in northwest Europe and China, c. 1400-1620

The Netherlands experienced an episode of rapid growth of GDP per capita during the Dutch Golden Age, driven by total factor productivity growth (Table 2). This reflected significant improvements of Dutch technology and organisation in a number of areas, including fishing, shipbuilding, land reclamation, water control and agriculture (Maddison, 2001; de Vries and van der Woude, 1997). In fishing, during the fifteenth century the Dutch developed a new type of factory ship, the herring buss, which permitted crews to gut, clean, salt and barrel herring while at sea (de Vries and van der Woude, 1997: 243-254). The Dutch merchant shipbuilding industry developed into the largest and most technically advanced in Europe between the 1460s and 1600s, culminating in the development of the fluitschip, which created a tube-like hull that maximised loading space within the constraints imposed on depth by the shallow waters off the Dutch and Baltic coasts, on breadth by northern harbours and tolls based on length and breadth as measured at the level of the deck (de Vries and van der Woude, 1997: 355-357).

Innovation in the control of water played a major role in the development of Dutch agriculture (Maddison, 2001: 78). Settlers in the middle ages occupied mounds and turned them into polders by building dykes to keep off flood waters and as their skills in hydraulic management improved, large areas of new land were reclaimed. By the beginning of the sixteenth century, water management and engineering were entrusted to professionals, with farming communities raising taxes to provide funds for water boards. Windmills were used as a power source for pumps which were used to control canal waters (de Vries and van der Woude: 27-32). Within this context, Dutch agriculture developed a high degree of specialisation, concentrating on the production of high value added meat and dairy produce. Grain was imported using the profits from the export of livestock products. The structural shift from low value added arable to high value added livestock farming was another source of TFP growth.

Neither Britain nor China exhibited significant TFP growth during the period c. 1400-1620. This is not normally seen as surprising in the case of Britain, which is widely viewed as a backwater of Europe at this time. In the case of China, by contrast, this is known as the Needham puzzle, after the historian of Chinese science and technology who highlighted the achievements of the Song dynasty and wondered why China did not go on to achieve a full-fledged scientific and industrial revolution (Needham, 1981; Lin, 1995). Lin (1995: 276) argues that China was predominant in technological invention based on experience during pre-modern times, but did not shift from the experience-based process of invention to the experiment-cum-science-based innovation that came to dominate the modern world. He sees this as a result of China's bureaucratic system combined with its imperial and ideological unification, which effectively blocked the growth of modern science (Lin, 1995: 281-285).

4.3 Innovation in northwest Europe and China, c. 1620-1870

Substantial growth of GDP per capita in Britain from the mid-seventeenth century was driven to a large extent by TFP growth. Indeed, from the 1690s to the 1830s, TFP growth accounted for almost all of the GDP per capita growth as accelerating population growth slowed down the growth of per capita human capital and fixed capital (Table 1B). Crafts (1985) pointed to the importance of rapid TFP growth in the modernising sectors that contained the great innovations of the Industrial Revolution, such as the steam engine, the spinning jenny, the water frame and coke-smelted iron (Allen, 2009: 135).

The steam engine was developed for pumping and winding operations in mines, but soon spread to manufacturing, driving bellows in iron furnaces and forges, spinning and weaving machinery in cotton textiles (von Tunzelmann, 1978). As it developed further, it spread more widely across the whole economy. In services, steam power drove ships at sea and locomotives on railways, while in agriculture, steam powered machinery began to appear. Steam power can therefore be seen as an early example of a General Purpose Technology (Crafts, 2004). The mechanisation of cotton textiles turned Britain from a net importer to a net exporter of yarn and cloth and led to a dramatic shift of competitive advantage between Britain and India (Broadberry and Gupta, 2009). Mechanisation affected all stages of the production process beginning with preparation of the raw cotton with a carding engine, through its spinning into yarn with the spinning jenny, the water frame or the mule, followed by the weaving of the yarn into cloth with the power loom and the finishing process with roller printing (Timmins, 1996: 34-54). The resulting increase in productivity led to dramatic falls in the real price of cotton yarn and cloth (Harley, 1998). Technological progress was also rapid in the British iron industry during the Industrial Revolution, where the combination of coke-smelting to replace charcoal-smelting and the use of steam engines rather than water wheels to power bellows in the blast furnace and tilt-hammers and rolling mills in the forge, freed the industry from the "tyranny of wood and water" (Musson, 1978: 98-99; Hyde, 1977).

China experienced a burst of positive GDP per capita growth and TFP growth during the early decades of the Qing dynasty with the substantial territorial expansion leading to the growth of the market (Table 3). However, this this was not sustained from the 1690s, after which China experienced substantial negative growth of both GDP per capita and TFP. The rapid population growth of the Qing Dynasty led to a decline in land per capita which could not be offset by rising grain yields, putting downward pressure on agricultural output per capita. This is broadly consistent with the view of involution advocated by Huang (2002). Recent work by Bernhofen, Eberhardt and Morgan (2016) finds that internal grain markets were becoming less integrated during the Qing Dynasty, consistent with a less efficient use of resources, or negative TFP growth. Under these circumstances, GDP per capita was bound to fall, with negative TFP growth playing a significant role.

5. CONCLUSIONS

This paper seeks to establish the role of innovation in the Great Divergence of GDP per capita between Europe and Asia. The first step involves establishing the quantitative dimensions of the Great Divergence by tracking the paths of GDP per capita over the period 1000-1870 in the two continents, taking account of regional variation. The Great Divergence of GDP per capita between the leading regions of Europe and China occurred around 1700 as a period of positive growth in Britain and the Netherlands coincided with a period of negative growth in the Yangzi Delta. However, it is also instructive to note the trends in the two continents in the centuries preceding the divergence. The positive trend in northwest Europe was a continuation of a process that began after the arrival of the Black Death in the mid-fourteenth century. In most parts of Europe, as population declined by 50 per cent or more, Malthusian gains in living standards were followed by a reversal of per capita growth, or shrinking, as population growth returned. By contrast, the gains were consolidated in Britain and the Netherlands and provided a permanently higher level of per capita income from which the next growth phase occurred. As a result, there was a reversal of fortunes between northwest Europe and the Mediterranean region. Adding other European economies to the picture confirms the finding that between 1300 and 1800, positive trend growth of per capita incomes was restricted to northwest Europe.

The negative trend in GDP per capita in China as a whole and also in the Yangzi Delta from around 1700 was a return to a pattern of decline from the period of China's global per capita income leadership during the Northern Song and Ming dynasties. However, the strongly negative trend in the Yangzi Delta, from the beginning of the eighteenth century represents not just a falling behind Britain and the Netherlands, the leading European economies, but also a decline relative to the poorer regions of Europe, where GDP per capita remained on a plateau before picking up in the nineteenth century.

The second step in the paper seeks to establish the role of innovation in the Great Divergence by using growth accounting to assess the contribution of TFP growth to GDP per capita growth in the leading regions of Europe and Asia. Although the growth of GDP over the very long run in northwest Europe was driven primarily by the growth of the factors of production (population, days worked per person, human capital, physical capital and land), the growth of GDP per capita was driven as much by TFP growth. TFP growth was strongly positive in Britain after the Back Death, in the Netherlands during the Dutch Golden Age and again in Britain from the mid-seventeenth century. TFP growth was positive in China during the Northern Song dynasty, when China was the world's leading economy, but was predominantly negative during the Ming and Qing dynasties, in the Yangzi Delta as well as in China as a whole.

TABLE 1: Accounting for British growth, 1340s to 1860s (% per annum)

A. Accounting for growth of GDP

	GDP	Population	Work days p.c.	Human capital	Capital	Land	TFI	TFP
1340s - 1400s	-0.73	-0.51	-0.17	-0.10	-0.08	-0.11	-0.98	0.25
1400s - 1450s	-0.21	-0.05	0.11	0.19	-0.09	-0.02	0.14	-0.35
1450s - 1640s	0.50	0.21	0.10	0.26	0.10	0.01	0.69	-0.19
1640s - 1690s	0.84	-0.02	0.17	0.09	0.10	0.00	0.34	0.49
1690s - 1830s	1.08	0.30	0.08	0.17	0.19	0.05	0.78	0.31
1830s - 1860s	2.28	0.47	0.06	0.53	0.57	0.00	1.92	0.36

B. Accounting for growth of British GDP per capita

	GDP p.c.	Work days p.c.	Human capital p.c.	Capital p.c.	Land p.c.	TFI p.c.	TFP
1340s - 1400s	0.54	-0.17	0.15	0.17	0.14	0.30	0.25
1400s - 1450s	-0.08	0.11	0.22	-0.06	0.01	0.28	-0.35
1450s - 1640s	-0.03	0.10	0.16	0.00	-0.09	0.16	-0.19
1640s - 1690s	0.88	0.17	0.10	0.11	0.01	0.39	0.49
1690s - 1830s	0.34	0.08	0.02	0.04	-0.10	0.03	0.31
1830s - 1860s	1.11	0.06	0.30	0.34	-0.23	0.75	0.36

Sources and notes: GDP, population and land from Broadberry, Campbell, Klein et al. (2015). Work days from Humphries and Weisdorf (2019). Human capital from de Pleijt (2018). Capital from Broadberry and de Pleijt (2021).Weights for 1340s-1830s: 0.4 for labour and work effort, 0.2 for human capital, 0.2 for capital and 0.2 for land. Weights for 1830s-1860s: 0.4 for labour and work effort, 0.2 for human capital, 0.3 for capital and 0.1 for land.

TABLE 2: Accounting for Dutch growth, 1540-1800 (% per annum)

A. Accounting for growth of GDP

	GDP	Popu-lation	Human capital	Fixed capital	Land	TFI	TFP
1540-1620	1.92	1.05	1.17	1.56	0.17	1.14	0.78
1620-1665	-0.18	0.68	1.28	0.75	0.17	0.77	-0.95
1665-1720	0.08	-0.04	0.56	-0.26	0.03	0.02	0.06
1720-1800	0.04	0.68	-0.10	0.22	0.07	0.33	-0.29

B. Accounting for growth of GDP per capita

	GDP p.c.	Human capital p.c.	Fixed capital p.c.	Land p.c.	TFI p.c.	TFP
1540-1620	0.87	0.12	0.51	-0.88	0.09	0.78
1620-1665	-0.86	0.60	0.07	-0.51	0.09	-0.95
1665-1720	0.12	0.60	-0.22	0.07	0.06	0.06
1720-1800	-0.64	-0.78	-0.46	-0.61	-0.36	-0.29

Sources and notes: Derived from van Zanden and van Leeuwen (2012: 126). Weights are 0.4 for labour, 0.2 for human capital, 0.3 for capital and 0.1 for land.

TABLE 3: Accounting for Chinese growth, 980-1840 (% per annum)

A. Accounting for growth of GDP

	GDP	Popu-lation	Human capital	Fixed capital	Land	TFI	TFP
980-1120	0.78	0.87	0.00	0.78	0.72	0.65	0.13
1120-1400	-0.18	-0.20	0.01	-0.18	-0.21	-0.15	-0.03
1400-1620	0.35	0.32	1.33	0.35	0.31	0.53	-0.18
1620-1690	0.20	-0.01	-0.22	0.20	0.07	0.01	0.19
1690-1840	0.40	0.70	0.45	0.40	0.27	0.51	-0.10

B. Accounting for growth of GDP per capita

	GDP p.c.	Human capital p.c.	Fixed capital p.c.	Land p.c.	TFI p.c.	TFP
980-1120	-0.09	-0.87	-0.09	-0.15	-0.22	0.13
1120-1400	0.02	0.21	0.02	-0.01	0.04	-0.03
1400-1620	0.03	1.01	0.03	-0.01	0.21	-0.18
1620-1690	0.20	-0.21	0.20	0.08	0.02	0.19
1690-1840	-0.30	-0.25	-0.30	-0.43	-0.20	-0.10

Sources and notes: GDP, labour and land from Broadberry, Guan and Li (2018; 2021). Human capital from McDermott (2005) and van Leeuwen and Xu (2022). Fixed capital assumed to grow in line with output, as proposed by Kaldor (1963).Weights are 0.4 for labour, 0.2 for human capital, 0.2 for fixed capital and 0.2 for land.

TABLE 4: Accounting for Yangzi Delta growth, 1400s-1840s (% per annum)

A. Accounting for growth of GDP

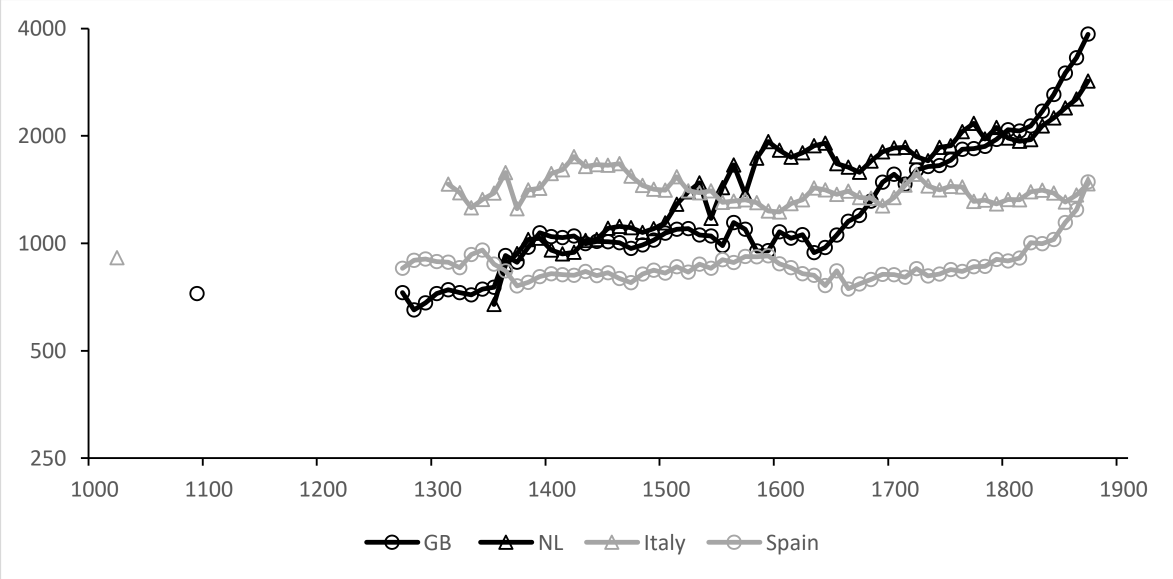
	GDP	Population	Human capital	Fixed capital	Land	TFI	TFP
1400s-1620s	0.21	0.35	1.33	0.21	0.05	0.46	-0.25
1620s-1690s	-0.15	-0.48	-0.22	-0.15	0.05	-0.25	0.11
1690s-1840s	0.17	0.40	0.45	0.17	0.06	0.29	-0.13

B. Accounting for growth of GDP per capita

	GDP p.c.	Human capital p.c.	Fixed capital p.c.	Land p.c.	TFI p.c.	TFP
1400s-1620s	-0.14	0.98	-0.14	-0.31	0.11	-0.25
1620s-1690s	0.33	0.26	0.33	0.53	0.22	0.11
1690s-1840s	-0.23	0.06	-0.23	-0.33	-0.10	-0.13

Sources and notes: GDP, labour and land from Zhai (2023). Human capital from McDermott (2005) and van Leeuwen and Xu (2022). Fixed capital assumed to grow in line with output, as proposed by Kaldor (1963). Weights are 0.4 for labour, 0.2 for human capital, 0.2 for fixed capital and 0.2 for land.

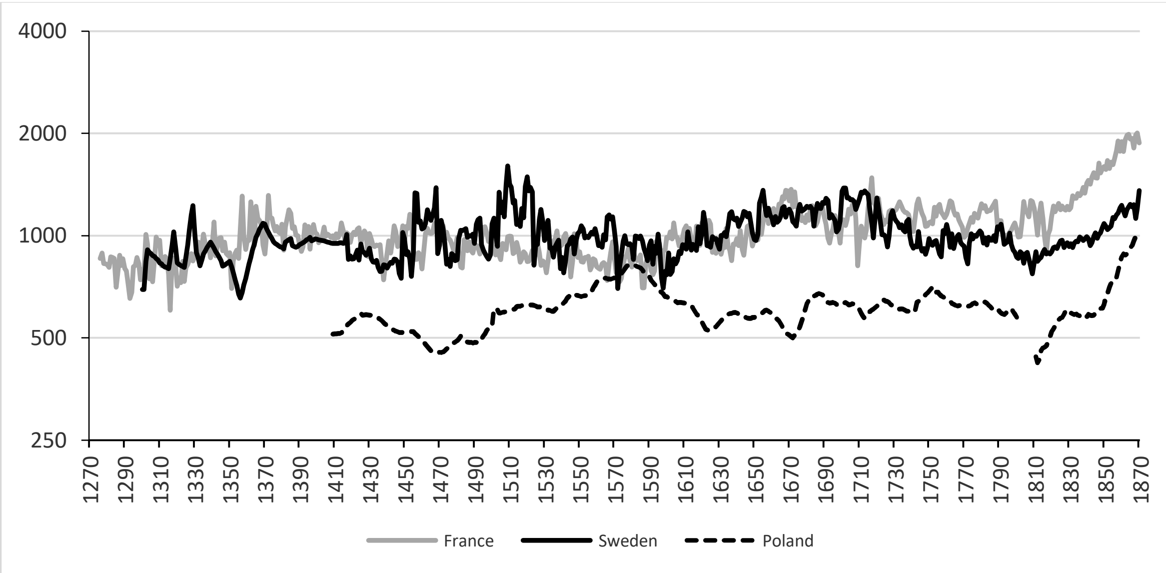
FIGURE 1: GDP per capita in northwestern and Mediterranean Europe, 1270-1870 (1990 international dollars)



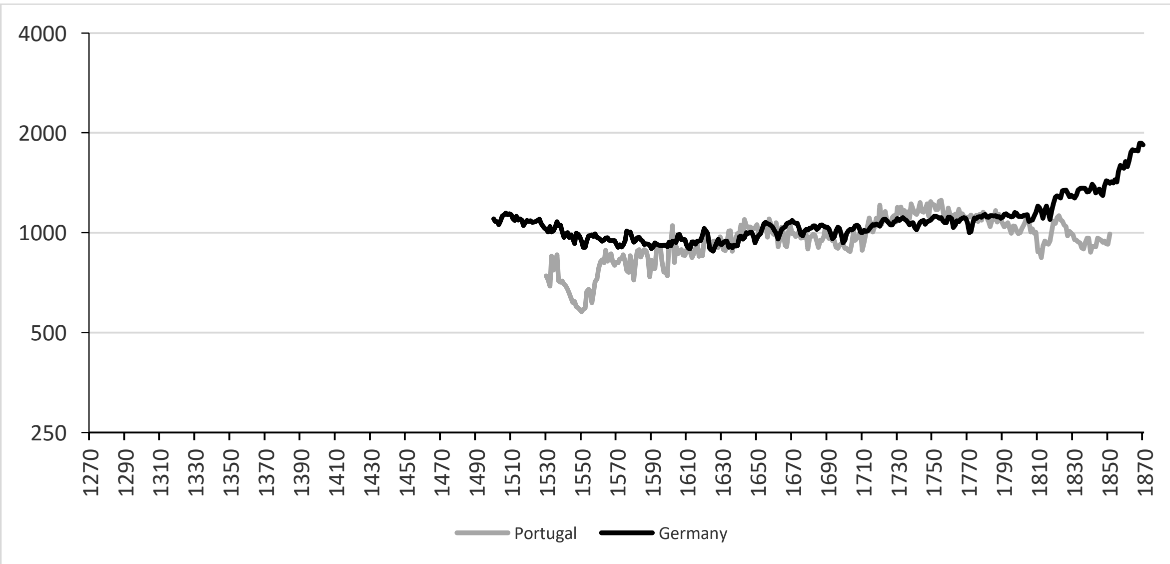
Sources: Great Britain: Broadberry et al. (2015). Netherlands: van Zanden and van Leeuwen (2012). Italy: Malanima (2002; 2011). Spain: Álvarez-Nogal and Prados de la Escosura (2013).

FIGURE 2: Real GDP per capita in other parts of Europe, 1270-1870 (1990 international dollars, log scale)

A. France, Sweden and Poland

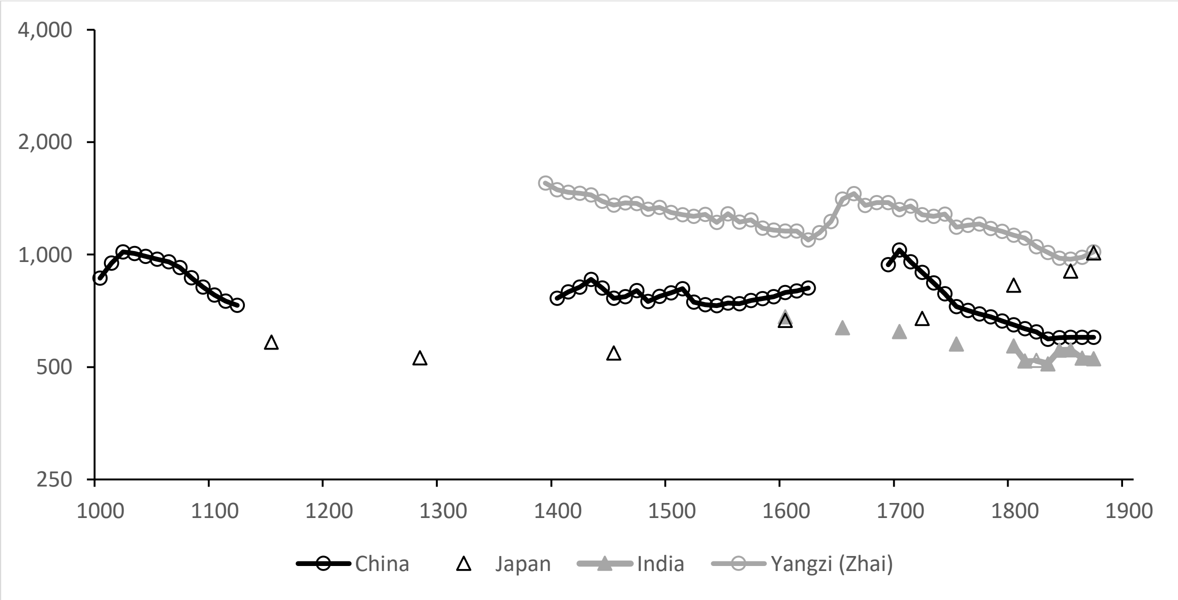


B. Portugal and Germany



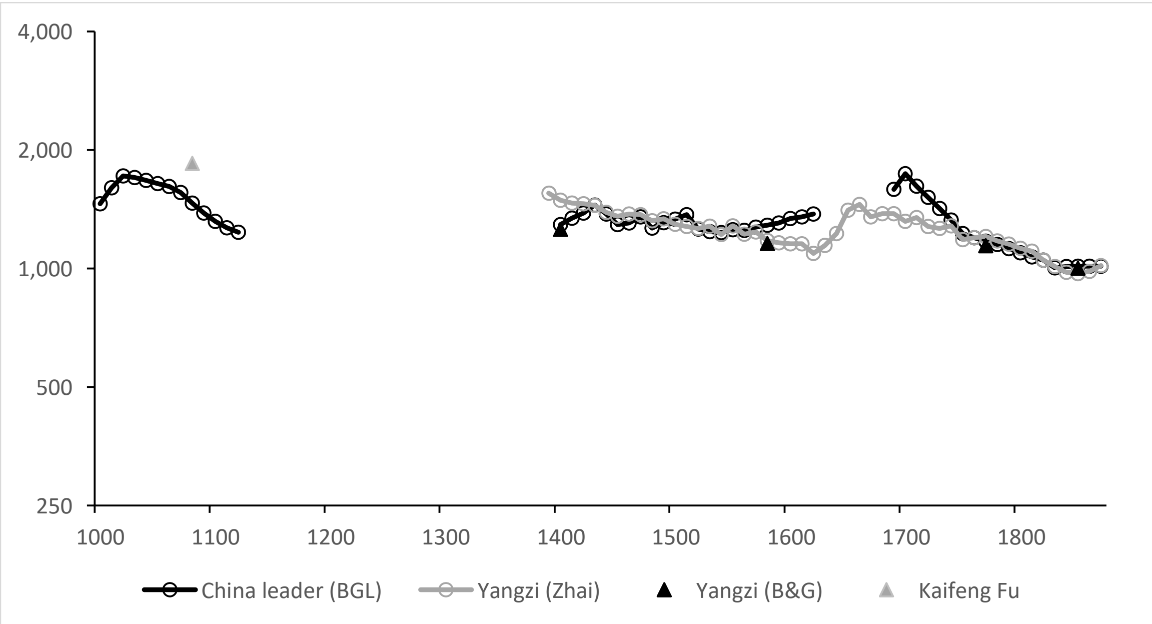
Sources: France: Ridolfi and Nuvolari (2022). Sweden: Krantz (2017), Schön and Krantz (2012). Poland: Malinowski and van Zanden (2017). Portugal: Palma and Reis (2019). Germany: Pfister (2022).

FIGURE 3: GDP per capita in Asia, 1000-1870 (1990 international dollars)



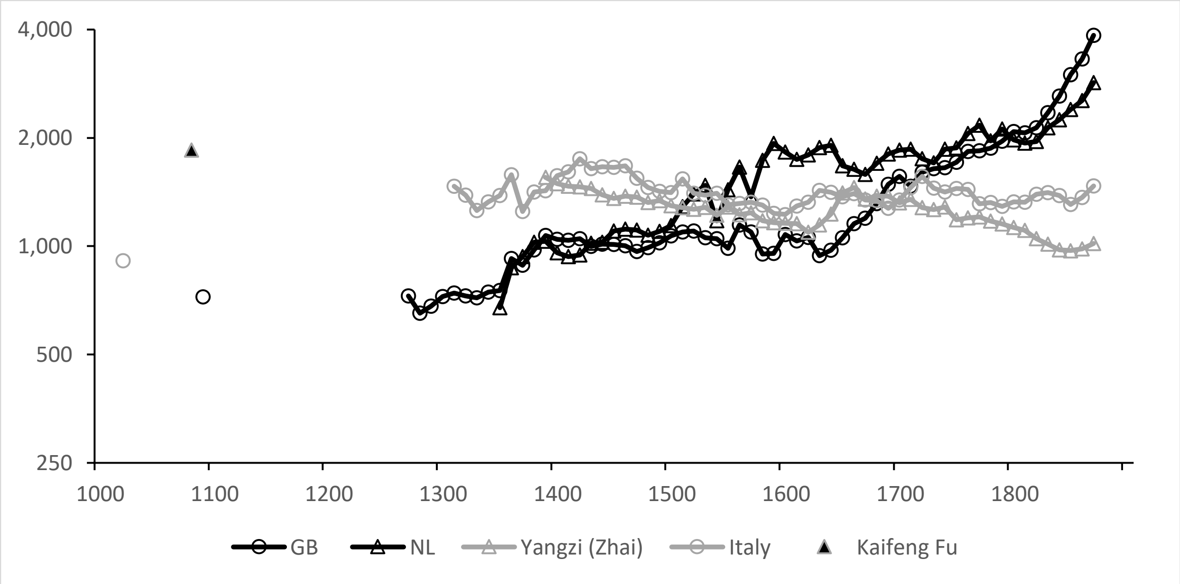
Sources: China: Broadberry, Guan and Li (2021). Japan: Bassino et al. (2015). India: Broadberry, Custodis and Gupta (2015). Yangzi: Zhai (2023).

FIGURE 4: GDP per capita in China's leading regions, 1270-1870 (1990 international dollars)



Sources: China leader (BGL): Broadberry, Guan and Li (2021). Yangzi (Zhai): Zhai (2023).Yangzi (B&G) and Kaifeng Fu: Broadberry and Guan (2022).

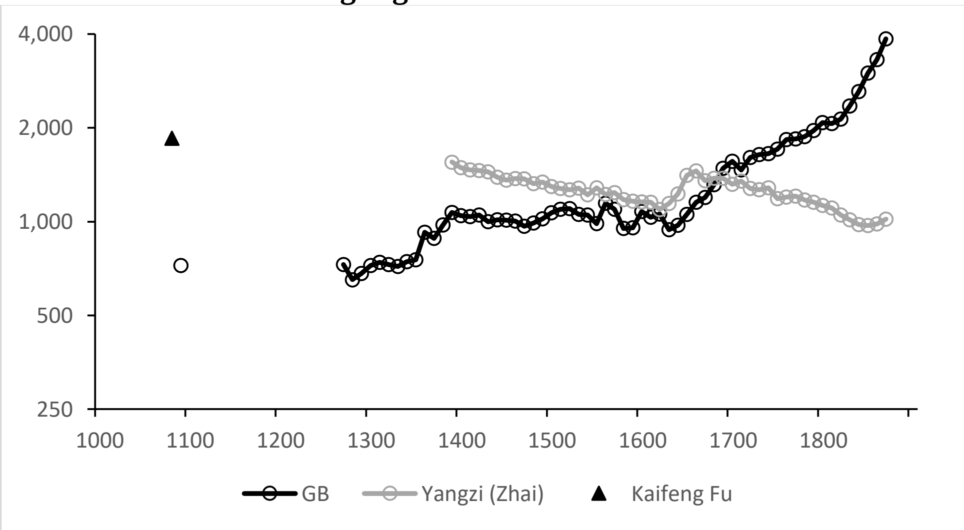
FIGURE 5: GDP per capita in the leading regions of China and Europe, 1000-1870 (1990 international dollars)



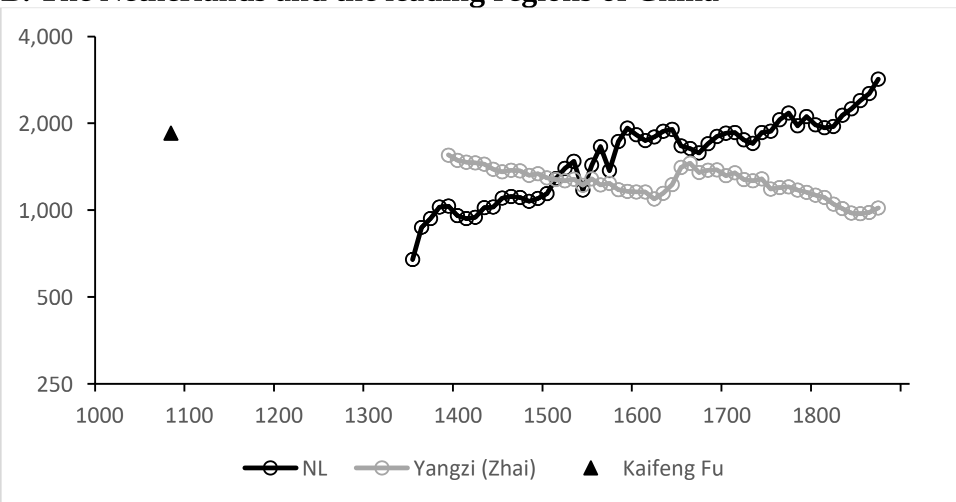
Sources: Great Britain: Broadberry, Campbell, Klein et al. (2015). Netherlands: van Zanden and van Leeuwen (2012). Yangzi: Zhai (2023). Italy: Malanima (2011). Kaifeng Fu: Broadberry and Guan (2022).

FIGURE 6: GDP per capita in the leading regions of China and Europe, 1000-1870 (1990 international dollars)

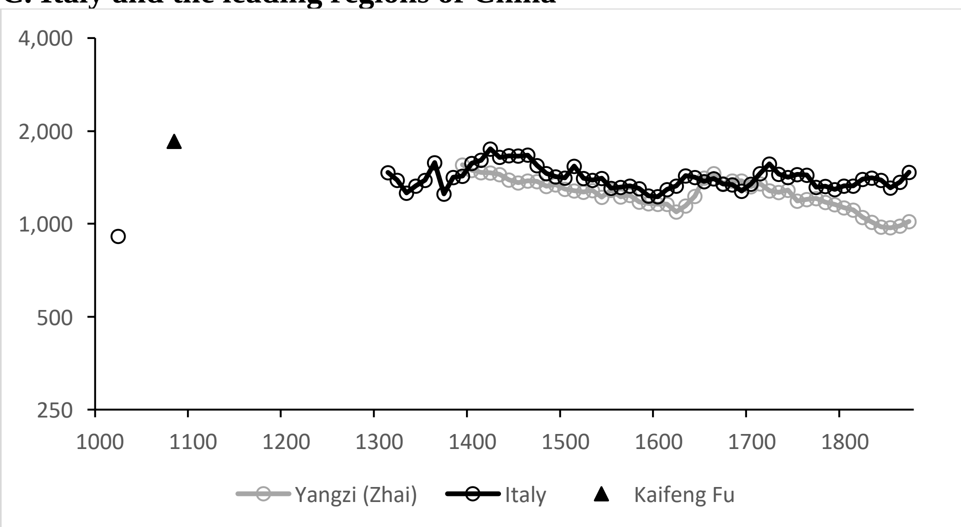
A. Britain and the leading regions of China



B. The Netherlands and the leading regions of China



C. Italy and the leading regions of China



Sources: Great Britain: Broadberry, Campbell, Klein et al. (2015). Netherlands: van Zanden and van Leeuwen (2012). Yangzi: Zhai (2023). Italy: Malanima (2011). Kaifeng Fu: Broadberry and Guan (2022).

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