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Alexander Klein
School of Economics, University of Kent

Tim Leunig
London School of Economics

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Alexander Klein
School of Economics, University of Kent
a.klien-474@kent.ac.uk

Tim Leunig
London School of Economics
t.leunig@lse.ac.uk

Abstract

Gibrat's Law states that the growth of towns and cities is independent of their initial size. We show that the Industrial Revolution was revolutionary enough to violate this law for 1761-1801, 1801-1891, and all decades within. Small places grew more slowly throughout this period. Larger towns, in contrast, typically grew faster, but only if they were in core Industrial Revolution Counties. In line with economic theory, towns grew disproportionately when agglomeration economies exceeded urban disamenities, allowing wage rises that induced workers to migrate to the town. This only occurred in places characterised by new, mechanised industries and mining.

Keywords: Gibrat's law, city-size distribution, industrial revolution
JEL Codes: N93; R12

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Introduction

The historiography of the English Industrial Revolution has undergone something of a revolution itself in the last thirty years or so. The initial picture was one of revolution, economically, socially and politically. In this characterisation the old order, based on land, was swept away and replaced by a new order, based on steam, mines, factories and railways. That shift was accompanied by social and political change, with inventors and entrepreneurs becoming rich enough to challenge the landed gentry, while the urban masses – and fear of the urban masses – became impossible to ignore. The last thirty years have seen a sustained and successful challenge to the idea that the Industrial Revolution was revolutionary. Rates of economic growth are now seen as much slower than had hitherto been claimed, and the geographic extent of the Industrial Revolution is more limited.

Yet for all the validity of the challenge, there is no denying the massive and unprecedented rise in population. The population of England grew from 1761 onwards, rising from 6.1m in 1761 to 8.7m in 1801, 16.7m in 1851 and 27.1m by 1891 (Wrigley and Schofield, 1981, p. 529 & Census for relevant years). This article looks at whether that rise should be seen as disruptive and “revolutionary” or whether it should be seen as something steadier, and more predictable.

To do this, this article looks specifically at whether Gibrat’s Law is violated. Gibrat's Law states that the growth of cities is independent of their initial size. If it holds, then population growth across places is reasonably even, at least in the sense that initial size cannot predict the likely growth rate of a place. If it is violated, we will see some places shoot ahead, and some left behind, according to their initial sizes. If so, that would help historians understand how England successfully came to accommodate a population that grew so rapidly, without resorting to mass-emigration, or succumbing to hunger and even starvation.

Empirical support for Gibrat's Law is mixed, with studies finding it more likely to hold for larger towns and/or over longer periods. This article formally tests the hypothesis that the quadrupling of the English population, in a period characterised by huge shifts in the economic structure, would be sufficient to violate Gibrat's Law. The obverse is by no means a straw man: the Industrial Revolution was not, by modern standards, a period of rapid economic development.

We find that this hypothesis clearly and unambiguously holds: Gibrat's Law was violated between 1761 and 1891. This is true for all individual decades, and for all longer periods. It is true for England as a whole, for counties central to the Industrial Revolution, and for those that it largely bypassed. In each case, the relationship between initial size and growth is U shaped, with low growth for places of a small to medium size consistently statistically significantly below average growth rates. In addition, larger places in Industrial Revolution counties generally grew statistically more quickly than is compatible with Gibrat's Law. In short, the combination of massive population growth and the Industrial Revolution was sufficient to cause repeated, extensive, violations of Gibrat's Law.

The structure of the paper is as follows: the second section sets out the basics of population growth in this era, the third section discusses relevant literature relating to Gibrat's Law, the fourth section describes the data, section five looks at whether Gibrat's Law holds, while section six places this finding in context. Section seven concludes.

Population in the era of the Industrial Revolution

The single most important fact is that England contained 21m more people in 1891 than in 1761 – its population had grown more than four-fold. These people could not be accommodated on new land, for even in 1761 England was a nation wholly under cultivation.

Unlike the United States in this era, there was no extensive margin, no prairies or plains waiting to be settled. Nor could they remain on existing land: England could not support 27m people given the agricultural production frontier in this era. The only alternatives to urbanisation and industrialisation were starvation or emigration.

As a result, England became an urban nation, based on industry and trade. The discovery of extensive coal deposits made this feasible. Coal powered the factories that produced the goods, and the trains and ships that exported them around the world – and brought back the grain and other foodstuffs needed to feed the nation's ever larger population. Towns and cities grew, often dramatically.

This matters not only to economic historians, but to political and social historians as well. Towns were and are different to the countryside. Social bonds are different, and politics are different as well. Cities are places of social change, upheaval and sometimes revolution. The Peterloo Massacre, the 1842 General Strike and the Chartist movement were very much urban phenomena. The 1832 Great Reform Act enfranchised towns and cities, changing the relationship between land and parliament forever. It is notable that the Corn Laws – which kept out foreign wheat to the benefit of landowners – were passed prior to the Great Reform Act, and repealed after it. The franchise mattered, and urban voters had very different priorities to those who lived in the countryside. For these reasons, political historians care about urban growth, and, by extension, about whether Gibrat's Law holds.

English towns did not grow equally quickly. The new industries were based on coal. Coal is heavy and so expensive to move. As a result places near to coalfields often became major centres not just of mining, but also of industry. The nineteenth century also witnessed a transport revolution, in which steam trains and steamships lowered the costs of moving goods around England and the world. This in turn allowed industry to be geographically

concentrated. Free-trade policies and international peace supported these trends. This led to a concentration of production across nations, increasing England's share of total manufacturing output (Crafts and Leunig, 2005). The biggest exception to the pattern of free trade was of course the US, but even here free trade within the US led to manufacturing becoming concentrated in the Northern manufacturing belt (Klein and Crafts, 2012).

Trains also allowed food to be brought into cities from much further away, much more cheaply, eliminating one constraint on city size. Steamships did the same for international foodstuffs, to the particular benefit of coastal towns. The decline in domestic (i.e. household) production of goods such as clothing or furniture offered greatest advantage to those who lived in towns, given that they had better access to shops. Finally, the arrival of the railway meant that people were able to migrate from one part of the country much more easily than they could have done before, and for the first time in human history opened up the prospect of regular contact with family left behind. Taken as a whole, the English migrated rather than commuted (O'Rourke and Williamson, 1999, 2004). This was understandable given the costs of commuting relative to wages, particularly in the pre-railway era (Cameron and Muellbauer, 1998).

Taken as a whole the importance of coal, railways, trade and so on meant that we can imagine a wide range of outcomes. This is particularly true in an era with no planning controls, and next to no zoning rules. It is possible that towns that were already large would grow dramatically, while villages remained as villages. This would be a clear violation of Gibrat's Law. Alternatively, growth could happen in ways that were predictable by (say) the location of previously unimportant coal deposits, but which would offer no relationship with prior population. That would be compatible with Gibrat's Law.

There was certainly much heterogeneity in population growth at the level of the individual place. While population as a whole tripled between 1801 and 1891, this was not true for all places. For example, Bath, the thirteenth largest town in England in 1801, grew by only 50% in these ninety years. Even more extreme is the cathedral city of Salisbury in Wiltshire, which grew by just 6% in total in 90 years, or one additional family a year. Some cities, such as Oxford and Cambridge, grew in line with the national average. The textile towns, such as Oldham and Preston, and trading cities such as Liverpool and Manchester, grew seven-fold or more, transforming the previous agricultural backwater of Lancashire into one of the most populous and urban counties of England. There were even more dramatic rises elsewhere, particularly in new mining communities. For example, the iron mining town of Dalton-on-Furness grew 32-fold. Even more spectacularly, the discovery of coal in Seaham transformed a sleepy coastal village of 144 people on a "dreary coast" (Byron, 1830, p. 258) into a major colliery and port town of almost 14,000 people. The railway also had significant effects. Swindon grew 20-fold, and Crewe almost 50-fold, both having 33,000 people by the end of this period. The indirect effects of the railways were large as well: the seaside resorts of Brighton and Torquay grew 16-fold.

In short, England in 1891 looked different to England in 1801. There were far more people, and they were in different places. The population was more urban, and more northern. England's rates of population growth were far higher than those experienced in other European countries, particularly in the first half of the nineteenth century (Alter and Clark, p. 53). This in turn led to internationally unprecedented rates of urbanisation. As early as 1840 around half the English population was to be found in urban areas, sixty years before the same could be said for France, Germany or the United States (Crafts, 1985, pp. 57-59, Atack and Passell, 1994 p. 239).

These towns and cities were growing in an era before many of the things that make city living easy had been invented. Nineteenth century English towns and cities were heated with smoky coal, leading to awful air quality. Streets were filled with manure-producing horse-drawn carts and buses. Sewerage and refuse removal systems were at best erratic and sometimes non-existent, especially earlier in the period. Slums were common, fresh food was not. Conditions were improving – brick built houses and paved roads were common by mid-century. Urban centres in the industrial revolution were described as "not so much towns as barracks: not the refuge of a civilisation, but the barracks of an industry" (Hammond and Hammond, 1917, 39). Despite this, many of those with strong positions in the labour market chose to migrate to cities, demonstrating via revealed preference that they perceived that higher wages compensated for the problems of urban life (Hammond and Hammond, 1917; Humphries and Leunig, 2009). Towns and cities had both advantages and disadvantages – something that we shall return to later. Gibrat's Law is important in this context: if large cities are simply unbearable to live in, then the largest cities will grow much more slowly, and Gibrat's Law will be violated.

Literature survey

Gibrat first put forward his "law" in his 1931 book, *Les Inégalités économiques*. It states that growth rates are independent of initial size, and can be applied to either places or firms. Surveys can be found in Gabaix and Ioannides (2004) for places and Sutton (1997) for firms. Some studies confirm Gibrat's Law, and some do not. Most look at the United States. Ioannides and Overman (2003), Eeckhout (2004), and Gonzáles-Val (2010) find that Gibrat's Law broadly holds, while Black and Henderson (2003), Garmestani et al. (2007), Glaeser et al. (2011), and Michaels et al. (2012) find departures from it. Some common results stand out. Gibrat's Law appears more likely to hold in the long run, and for larger places. Thus

Gonzáles-Val (2010) and Glaeser et al. (2011) point out that even though Gibrat's Law seems to hold in the long-run – such as the period 1900-2000 in the former and 1790-1990 in the latter – there are decades when that is not so. Michaels et al. (2012) find that Gibrat's Law is violated for intermediate-size places, while Eeckhout (2004) and Garmestani et al. (2007) suggest that Gibrat's Law is less likely to hold for small places. Studies examining other countries also find mixed results, with good evidence that smaller places are more likely to violate Gibrat's Law. Examples include Guerin-Paca (1995) for France, Eaton and Eckstein (1997) for France and Japan, Soo (2007) for Malaysia, and Bosker et al. (2008) for West Germany.

The literature also finds that economic shocks can lead to the violation of Gibrat's Law. Bosker et al. (2008), for example, examine the effect of the Second World War on the growth of German cities. They find that Gibrat's Law holds before but not after the war, suggesting that the disruption caused by the war and its aftermath had a substantial impact on West Germany's urban system. The literature also covers long run shocks such as the movement from an agrarian to an industrial economy (Glaeser et al., 2011, Michaels et al 2012), or the later movement from an industrial to a service based economy (Black and Henderson, 2003). This literature again suggests that Gibrat's Law can be violated in these circumstances. This paper is related most closely to this body of literature.

Data Description

Great Britain undertook the first census in 1801, and has had decennial censuses ever since. From 1811 onwards the census reports the population in a place both at the census date, and as per the previous census. It is thus straightforward to make decade on decade comparisons.

It is not straightforward, in contrast, to make comparisons over a longer period, because the definitions of places change from one census to the next. At various times in the nineteenth century, for example, England had "Ancient Counties", "Administrative Counties" and "Registration Counties". We are, however, extremely fortunate that Wrigley and co-authors have done the detailed work to produce consistent place level population time series from 1801-1891, and we are extremely grateful to them for allowing us to use their data.[1] We aggregated their generally parish level data into recognisable towns, for example by merging the separate parishes that make up cities such as Norwich, or London.

The period prior to 1801 is more problematic. There were no censuses for these years, and we have instead to rely on population data at the level of the "hundred" (Wrigley, 2011, table A2.7). This was an administrative unit, dating back to Saxon times, larger than a parish, and smaller than a county. In an agrarian era it would usually include clusters of villages, or a small town and its surrounding villages. Thus, for example, the county of Cornwall contains 12 hundreds, while the 1801 census records that it has 205 separate places, mostly small villages. A Cornwall hundred therefore contains an average of 17 separate places, typical for hundreds across England. We aggregate the hundreds that made up London, Leeds, Liverpool and Manchester; although for simplicity we continue to refer to hundreds throughout. We need to be careful in interpreting the pre-1801 results, therefore, since hundreds agglomerate places of different sizes within a single unit. The hundreds remain constant over the period 1761-1801, allowing us to perform the analysis for the period as a whole, as well as for individual decades. We cannot, however, join the pre- and post- 1801 periods, as the data sources are just too different.

[1] E.A. Wrigley, G.H. Newton, A.E.M. Satchell, and L Shaw-Taylor, 1801 to 1891 Census Report of England and Wales: Parish and Registration District Population dataset (2009), funded by ESRC grants RES 000-23-0131 and RES-000-23-1579. Details of the methodology used are given in Wrigley (2011).

The descriptive statistics are as follows. There are 598 places for which we have data for the period 1761-1801. 511 grew over this period, 87 did not. The 87 are generally smaller, and contain 10.8% of the total initial population. The unweighted average growth rate is 0.65% per year, the median 0.41%, and the standard deviation 0.007. The distribution of growth rates is given graphically in appendix one. The top quarter of hundreds by initial size grew by 0.64%, the smallest quarter by 0.72%, while those in between grew by 0.41%. The largest proportionate gain was the smallest hundred, Newcastle-under-Lyme, in the Staffordshire Potteries District, while the largest gain in absolute terms was London, which grew by 442,442 people.

There are 10,672 places in our data set for the period 1801-1891. The mean place contained 809 people in 1801 and 2,535 in 1891. 7,569 places grew, 3,103 did not. Again, the places that did not grow were typically smaller at the start of the period: they accounted for 29% of the places and 13% of the initial population. The (unweighted) average growth rate was 0.37% per year, the median was 0.23% and the standard deviation of 0.007. The distribution of growth rates is again given graphically in appendix one. Larger places grew notably faster than smaller places. The largest quarter of places (with an initial population of 611 people or more) grew at 0.63% per year, while the smallest quarter grew at 0.26% per year, and those in between by 0.29%. The fastest growth rate was in Middlesbrough, which grew from 352 people in 1802 to 75,107 in 1891, an annual growth rate of 6.1%. The largest absolute gain was again London, which grew from 1m to 5m people in this period, followed by Manchester, Liverpool, Birmingham, Leeds and Sheffield, which grew by between a quarter and three-quarters of a million people.

City Growth

We now investigate Gibrat's Law using non-parametric regression analysis. We use the methodology pioneered by Ioannides and Overman (2003), and used since by Eeckhout (2004) and Gonzáles-Val (2010). The regression equation has the following specification:

$$g_i = m(S_i) + \varepsilon_i \quad (1)$$

where g_i is the standardized growth rate of place i (defined as $(P_{it}/P_{it-1} - P_{Et}/P_{Et-1})/ \sigma(P_{it}/P_{it-1})$, where P indicates population, i a specific place, E England as a whole, t the end date, t-1 the prior date, and σ the weighted standard deviation for all places), S_i is the log of the population of place i at the start of the period and m is a functional relationship. We use relative size as a robustness check: the results stand. We do not assume any specific relationship between g_i and S_i. Instead, we use the local average around S smoothed with a symmetrical, continuous and weighted kernel. We follow Ioannides and Overman (2003) and use the Nadaraya-Watson method in which

$$\hat{m}(s) = \frac{n^{-1}\sum_{i=1}^{n} K_h(s-S_i)g_i}{n^{-1}\sum_{i=1}^{n} K_h(s-S_i)} \quad (2)$$

where K_h is the Epachenikov kernel. The bandwidth h was calculated using the Silverman (1986) rule. We again follow Ioannides and Overman (2003) and use 99-percent confidence intervals, calculated using the lpoly command in Stata 13. Using 95 or 90 confidence intervals does not change the results materially.

Gibrat's Law states that growth is independent of initial size. Since the growth rates are normalized, Gibrat's Law can be said to hold if the estimated kernel is not statistically different from zero. Conversely, if the estimated kernel is statistically different to zero, we can say that Gibrat's Law does not hold.

The long run is much more important than the short run, and for that reason we first present our two long run findings, for 1760-1801 and 1801-1891. In each case the population is divided into 100 size categories, each equal in log size. There is no reason to expect that all size categories will have towns within them: in particular, London is much bigger than Manchester, so there will be a range of size categories between Manchester and London that have no observations.

There are four logical possibilities for each size class. If the upper confidence interval is below zero, Gibrat's Law is violated because places are growing too slowly. If the upper confidence interval is above zero, and the lower confidence interval below zero, Gibrat's Law is not violated. If the lower confidence interval is above zero, Gibrat's Law is violated because growth is too rapid. Finally, there will be some size classes that have too few observations to allow confidence intervals to be assessed. London falls into this category, for example.

The results are given in figures 1 and 2. These and all subsequent figures, give the line of best fit and the 1% confidence intervals. The figures all use a common scale for the Y axis, but the X axis scale varies according to the relevant maximum population. Because there is only one place the size of London, and because it is much larger than other places, there is never an estimate for London. For that reason the right hand side of the graph is frequently blank.

The results are clear: Gibrat’s Law is violated. In both cases there is a U shape relationship between initial population and growth. The relationship is more pronounced for the earlier period. In this period Gibrat's Law is violated in both directions, with substantial size classes that grow at rates incompatible with Gibrat's Law. The principal violations occur for hundreds containing 3,600-18,300, and more than 75,000 people. Since there were typically 17 places per hundred, this implies that Gibrat’s Law was violated for places with

populations of around 200-1,100, or above 4,400 people. Far more people lived in the former category: the size classes that grew too slowly contained 53% of the population, while the size classes that grow too quickly contain only 5%. Of the remainder, 32% live in places of a size that does not violate Gibrat's Law, while the remaining 10% live in places for which we are unable to provide an estimate.

For the post 1801 period the violations overwhelmingly consist of medium sized places that grow too slowly. There are no substantial size categories that grow too quickly. Gibrat's Law is violated for places with 50-1,600 people, with smaller violations before, and small non-violations within that range. To modern eyes, places with 1,600 people or fewer are villages, of little economic importance. This was not true for 1801. 42% of people lived in places in the size categories that grew so slowly as to violate Gibrat's Law, while a further 3% lived in places that grew so fast that they violated Gibrat's Law. A further 34% lived in places for which Gibrat's Law was not violated. The remaining 21% lived in places for which no estimate is possible, principally London.

These two periods present a similar picture. Above all, Gibrat's Law is unambiguously and extensively violated. Around a half of the population lived in places of sizes that violate Gibrat's Law, a third in places of sizes than conform, and the remainder in places for which no assessment is possible. The largest violations consist of growth that is too slow: small and medium sized places that are bypassed by the overall trends. For sure, some initially small places like Crewe and Swindon grew spectacularly, but taken as a whole small to medium sized places grew less quickly than the nation as a whole. They were outpaced by both the tiny and the large. In contrast, fewer size classes grew so quickly as to violate Gibrat's Law.

We can go further, in three dimensions. First, for the period after 1801 we can test Gibrat's Law for counties most and least affected by the Industrial Revolution. (Sample sizes preclude

doing this for the earlier period). Second, we can look at the pre- and post-railway parts of the nineteenth century. Third, we can look at individual decades, to see whether short term events were more likely to cause more extensive violations, or whether there were decades in which urban development was more even.

We follow Crafts in dividing England into "Industrial Revolution" and "non-Industrial Revolution" counties, according to the share of employment in modern industrial sectors (Crafts 1985, Table 1.1, pp. 4-5). Industrial Revolution counties are those with 29.6% or more of the male workforce in modern industries, while non-Industrial Revolution counties are those with 14% or fewer in these industries.[2] We exclude the nine counties (and London) that lie between these figures as they do not fit well into either group. In total, the Industrial Revolution counties contain 21% of the population in 1801, 25% in 1841, and 29% in 1891. Conversely, the non-Industrial Revolution counties contain 52% of the population in 1801, 45% in 1841, and 38% in 1891. We can see immediately that, as expected, growth rates were typically faster in Industrial Revolution counties than in non-Industrial Revolution counties.

Figures 3 and 4 give the results for industrial and non-Industrial Revolution counties respectively.

Again, we see that Gibrat's Law is violated in both cases. For the Industrial Revolution counties, the violation broadly covers places with sizes from around 45-300. For non-Industrial Revolution counties, the violation is much larger, covering places in the range 25-3,300. The proportion of the population contained in these ranges is strikingly different. Just fewer than 10% of people in Industrial Revolution counties lived in places of a size that violated Gibrat's Law. The equivalent figure for non-Industrial Revolution counties is 70%.

[2] 29.6% is obvious by inspection: there are no counties with between 22% and 29.6%, creating a natural break. 14% is less obvious and we used the extensive historiography of English counties in making this decision.

Furthermore, the confidence intervals are much tighter for the non-Industrial Revolution counties: this is partly because the sample size is larger, (see table 1, below), but partly reflects the consistency of experience of these places. The knowledge that a place was of small to medium size, and located in a non-Industrial Revolution county is a very strong predictor that its population will grow markedly more slowly than that of the nation as a whole.

We now turn to look at the pre- and post-railway eras, defined as 1801-1841 and 1841-1891. The results are summarised in Table 1, and given graphically in (online) appendix 2.

Table 1 about here

Gibrat's Law is violated in both periods, for the country as a whole, and for both sub-sections. Some notable patterns emerge. First, the U shaped pattern is again apparent. Second, the proportion of the population living in places of sizes that violate Gibrat's Law falls from 50% prior to the invention of the railway to 33% afterwards. Third, this change is driven overwhelmingly by a change in the Industrial Revolution counties. In the earlier period a quarter of them grow too slowly, and half grow too quickly. These proportions fall to a sixth and a third respectively in the later period. This change in turn is driven primarily by a shift in the distribution of the population across places of different sizes, rather than a shift in the range of places that violate Gibrat's Law. Fourth, there is little difference in the experience of non-Industrial Revolution counties across the two periods, where the vast majority of people remain in places that grow too slowly to comply with Gibrat's Law. It is notable, however, that the size range of places in non-Industrial Revolution counties that violate Gibrat's Law grows. Relatively large places (4,000-10,000) that had previously been big enough to avoid falling behind were now growing significantly more slowly than the nation as a whole.

We now turn to look at the individual decades, covering the period 1760-1891. There is no reason to expect that the results will be the same at decadal level as over a longer time period. As we noted earlier, the literature finds that Gibrat's Law is more likely to be violated in shorter periods (Gonzáles-Val, 2010, Glaeser et al., 2011). This is because a shorter period is more likely to contain a single event that will cause a violation, and because of the absence of the smoothing effect of a longer time period. Against that, it is possible that a smaller but persistent effect, decade on decade, may not be significant in any one decade, but could be significant over a longer time period.

Again for completeness we look at England as a whole, and (after 1801) at Industrial Revolution and non-Industrial Revolution counties separately. The results are summarised in table 2, with the full set of graphs given in the online appendix 2. Once more, the patterns are remarkably consistent, with all periods exhibiting a U shape to greater or lesser extent.

Table 2 about here

Table 2 establishes five facts. First, Gibrat’s Law is violated for a substantial proportion of the population in each decade, and for each set of counties under consideration. In well over half the rows of the table, a majority of the population lived in places of sizes that violated Gibrat's Law.

Second, industrial and non-Industrial Revolution counties behave very differently. Violations in Industrial Revolution counties are much more likely to involve places growing too quickly, than too slowly. In contrast violations in non-Industrial Revolution places always consist of places growing too slowly. Furthermore, the range of sizes for which Gibrat's Law is violated because growth is too low is much larger for non-Industrial Revolution counties. Substantial

market towns, with 5-10,000 people found themselves left behind, particularly around the middle of the 19th century.

Third, the proportion of people living in places that grew too slowly declines over time. This is true from 1841 onwards for Industrial Revolution counties, and from 1861 onwards for non-Industrial Revolution counties. It is not so much that the range of sizes that violate Gibrat's Law changes, but rather the proportion of the population living in places in these sizes falls. At one level this is an arithmetic requirement: given that these places are growing more slowly than the population as a whole, it follows that in later decades they will contain a lower share of the total population.

Fourth, the proportion of the population who live in Industrial Revolution counties in places of sizes that grow too quickly falls over time, but the pattern is somewhat more erratic. (We note parenthetically that the remarkably low figure for 1851-61 is anomalous. For this decade a significant proportion of the population grows at a rate that is almost, but not quite, too high to be in keeping with Gibrat's Law. We believe that little should be read into this particular figure.)

Fifth, the picture for England as a whole is not a simple average of the two subsections. This is most obviously true when we look at places where growth is too rapid to be compatible with Gibrat's Law. These places are extensive in Industrial Revolution counties, but given that these are numerically less important than non-Industrial Revolution counties, their statistical power is largely lost when the two subsections are combined.

These facts all add to our understanding of the Industrial Revolution. We have found that Gibrat's Law generally does not hold when we look either at longer periods, or at individual decades. That is an important finding: the Industrial Revolution was revolutionary in many

ways, and one aspect of that revolution was to revolutionise not just the size of English towns and cities, but to violate a law on city growth that has been found to hold in many circumstances.

Second, we have found that Gibrat's Law is violated for both Industrial Revolution and non-Industrial Revolution counties, albeit in very different ways. Non-Industrial Revolution counties were largely bypassed, and their populations did not grow in line with the nation as a whole. For sure, the Industrial Revolution had an effect even in these places. Trade and commerce became more firmly embedded in English life, as per Napoleon's jibe that England was "a nation of shopkeepers". Agriculture changed, with a growing importance of fresh, city-bound crops, such as dairy and fruit (Hunt and Pam, 1997). Port and seaside towns grew, and changed dramatically in nature. Sussex was never a core part of the Industrial Revolution, but Brighton, its leading seaside resort, was very much a creation of the railway. But for all this, people were voting with their feet, and leaving all but the largest towns in these counties.

Third, there is no discernible trend in the range of sizes for which Gibrat's Law was violated. England remained a nation of change throughout the nineteenth century. Population continued to grow dramatically, and towns evolved in ways that were not easy to predict ex ante. Table 2 gives a sense that the system was less turbulent as the nineteenth century wore on, but the overall picture remains one of long run and ongoing change.

Fourth, the proportion of people living in places for which Gibrat's Law was violated falls over time. Population continued to grow, but as the country developed and became more modern, patterns of development stabilised. New and extensive coal deposits were increasingly rare, and the disruptive influences of new towns became less frequent. England was beginning to settle down.

Finally, the proportion of the population of Industrial Revolution counties living in places of sizes that violate Gibrat's Law was lower than the equivalent in non-Industrial Revolution counties, particularly as the period wore on. This is perhaps the most surprising finding, and reminds us that the levels of outmigration from some areas were very high indeed. These places could not support the natural rate of population increase, and therefore migration was a requirement.

Understanding these findings

We have found that Gibrat's Law was violated in three distinct ways. First, small places (populations ~50-2,000) in England grew too slowly. Second, medium places (populations 2,000-8,000) in non-Industrial Revolution counties grew too slowly. Third, large places (say, 30,000 and up, but less tightly defined) in Industrial Revolution counties grew too quickly.

Many of the models that set out conditions under which Gibrat's Law holds have implausibly restrictive assumptions. Eaton and Eckstein (1997), for example, require zero discounting, Gabaix (1999) requires independent and identically distributed amenity or productivity shocks and Rossi-Hansberg and Wright (2007) require either no physical or human capital. None of these models can help us understand England in this era.

The models developed by Eeckhout (2004) and Córdoba (2008) are more useful. Both share a common trait: they model Gibrat's Law as an equilibrium condition between positive and negative externalities. In Eeckhout's (2004) model a city is characterized by a productivity parameter reflecting its technological position, which rises in the size of the city. On the other hand, city size also imposes a negative externality owing to the need for workers to commute. In this model, Gibrat's Law holds when the positive productivity externalities balance the negative commuting externality. Córdoba's 2008 model is similar. In this case city size raises

productivity because of informational spillovers, pecuniary externalities, and/or search and matching in local labour markets. Larger cities also create negative externalities, such as congestion costs, which reduce productivity. Again, Gibrat's Law is satisfied when positive and negative externalities balance.

These models can explain our violations of Gibrat's Law if four conditions hold. First, city sizes can change in response to economic incentives. Second, larger cities must impose costs on residents. Third, larger cities must offer productivity benefits. Fourth, they must do so disproportionately in Industrial Revolution industries. We will look at each in turn.

There are three reasons to believe that city sizes would have responded to incentives in this era, and one note of caution. First, as noted earlier, this was an era with almost no zoning or planning laws. Towns could expand in a manner predicted by market-based economic models. Second, there were no laws on migration or residency. People could and did migrate. Third, there was no tax wedge to blunt the working of the model. In a competitive market, a rise in workers' marginal revenue product will raise (gross) wages, but workers care about net wages. In this era virtually no workers would have paid income tax, and there was no widespread sales tax either. Again this suggests that a market clearing model will offer useful intuitions. Against this, workers rented rather than owned housing. Rents were set by the market, and there was a strong rent gradient from the city centre. Commuting was expensive, so most people lived near their place of work. This means that as a city grew, the benefits of higher labour productivity would have been manifest in higher gross and net of tax wages, but the workers would lose some of the gain to landlords, in the form of higher rent payments. Taken together, these facts lead us to expect that town sizes would respond to economic incentives, but that city sizes may have remained below their optimal level.

It is straightforward to show that large towns imposed monetary and non-monetary costs on workers. Life expectancy was as low as 25 in Manchester, 16 years short of the national average, a damning indictment of urban squalor (Szreter and Mooney, 1988, p. 93, table 3). Engels described cities as "social murder" (Voth 2004, 284). De Toqueville, visiting Manchester for the first time, noted that the smoke and pollution blotted out the sun. This was aesthetically unpleasant, and limited vitamin D production. This, along with poor diet, let to rickets and other physical deformities (Hunt, 2005, p. 26). The problem was so extensive that factory commissioner Dr Bisset Hawkins reported that: "most travellers are struck by the lowness of stature, the leanness and paleness which present themselves so commonly to the eye in Manchester." (Floud et al., 1990, p. 1). Williamson (1990) estimated urban disamenity premiums needed for potential migrants to consider moving to towns at three to seven per cent.

Against that, we also have strong evidence that larger cities were more productive. At one level we can deduce this: cities grew, despite the urban penalty. Firms could only pay the higher wages required if productivity was higher in cities. There is an extensive literature on the role of agglomeration economies in modern manufacturing in this era, most obviously in the textile industry. Alfred Marshall (1919, 1920) first identified "external economies of scale", noting that "The mysteries of the trade become no mysteries; but are as it were in the air". Broadberry and Marrison (2002) find econometric evidence to support this proposition: wages rise in the number of people in an occupation in a city, but not with firm size. Porter (1998) argues that larger cities are better at facilitating "cluster economies", whereby firms in related industries locate close together, raising the productivity of all. There is evidence for clustering in the textile industry. Worrall's Textile Directory lists large numbers of machinery makers, belt makers, suppliers of grease and tallow and so on, as well as cotton

manufacturers. Together, these advantages allowed small textile firms to remain competitive despite much higher labour costs than those in rival nations (Clark 1987, Leunig, 2003). This allowed the industry to persist even after the arrival of lower wage competition (Broadberry, Marrison and Leunig, 2009). To quote de Toqueville again, “From this foul drain the greatest stream of human industry flows out to fertilise the whole world. From this filthy sewer pure gold flows.” (1958, 107-8).

The productivity benefits of larger cities were very industry specific. Traditional, pre-mechanised, manufacturing is characterised by very limited internal and external economies of scale. Workshops were small, and could be widely scattered. Customers were largely local. Industries such as food manufacture, pin and lock makers, furriers, hat manufacturers, shoe makers, brick makers, cabinet makers, bookbinders, piano makers, builders, shop workers, insurance agents, clergy, dentists, waiters, domestic servants, and general labourers were not characterised by either internal or external economies of scale to any extent (Crafts, 1985, 5; Lee, 1979, 30-37).

Taken together, this conceptualisation of the costs and benefits of cities in different circumstances leads us to the following predictions. First, places specialising in traditional industries should not grow, since there is no gain to producers, and costs to workers. Second, that places with modern industries should grow much faster, as the benefits to producers will outweigh the costs to workers. These asymmetries will lead to substantial violations of Gibrat's Law.

This is, of course, what we find. Small places everywhere grow slowly. These places do not, on the whole, have modern industry, even when they are located in an Industrial Revolution county. They did not grow because the costs would have exceeded the benefits of doing so. The same is true for medium sized places in non-Industrial Revolution towns. Again, these

were not characterised by modern manufacturing, but were instead market towns and similar. Places of this size in Industrial Revolution counties grew at a faster rate, one compatible with Gibrat's Law. This set of places consisted of both market towns in Industrial Revolution counties, and fast growing modern manufacturing centres. Larger places in Industrial Revolution counties grew fastest of all. This group of places did not include conventional market towns, and instead consisted exclusively of fast growing towns characterised by modern industry. Without the slower growing market towns in the mix, they therefore violate Gibrat's Law from above.

Conclusion

The Industrial Revolution was revolutionary enough to cause extensive violations of Gibrat's Law. Population as a whole grew dramatically, but unevenly. We have always known that growth was uneven by county, but this article shows that it was also uneven by initial size. The towns that grew from almost nowhere, places such as Swindon, Crewe, and Middlesbrough, were very much the exceptions. Small places rarely broke through, and were much more likely to be left behind. Larger places in Industrial Revolution counties, in contrast, grew rapidly often becoming industrial powerhouses.

This exercise helps us in two ways. First, it is a useful example of how a market-based economy with few land controls and very low taxes responds to big structural changes. In these circumstances Gibrat's Law is broken in both the short and long runs. This was true for every decade 1761-1891, and for periods of 40 years or more.

Second, it forces us to think about the nature of different towns in this era. The basis of the economy in a small town was different to that in a large town, and the basis of the economy was different in large towns according to whether they were in an industrialising area or not.

When agglomeration economies are asymmetric across industry and therefore place, the models of Eeckhout and Córdoba predict what we find: places grow in a manner predictable by their initial size and location, thus violating Gibrat's Law.

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Table 1: Was Gibrat's Law violated before or after the invention of the railway?

	Initial population	% population in places: violation: growth too low	no violation	violation: growth too high	no estimate possible	principal downward violations size range	principal upward violations size range
				Pre-railway			
All counties	8,632,940	47	34	3	16	20-1,900	
IR counties	1,811,079	26	23	51	0	20-900	>6,000
non-IR counties	4,438,710	78	22	0	0	20-4,000	
				Post-railway			
All counties	15,043,400	33	41	0	26	55-2,200	
IR counties	3,791,721	16	50	34	0	20-1,400	>70,000
non-IR counties	6,821,493	81	19	0	0	20-10,000	

0 includes some figures that are less than 0.01%; there are no results between 0.01% and 0.5%

Population in industrial and non-industrial revolution counties do not add up to the total population because some counties are characterized as neither industrial nor non-industrial.

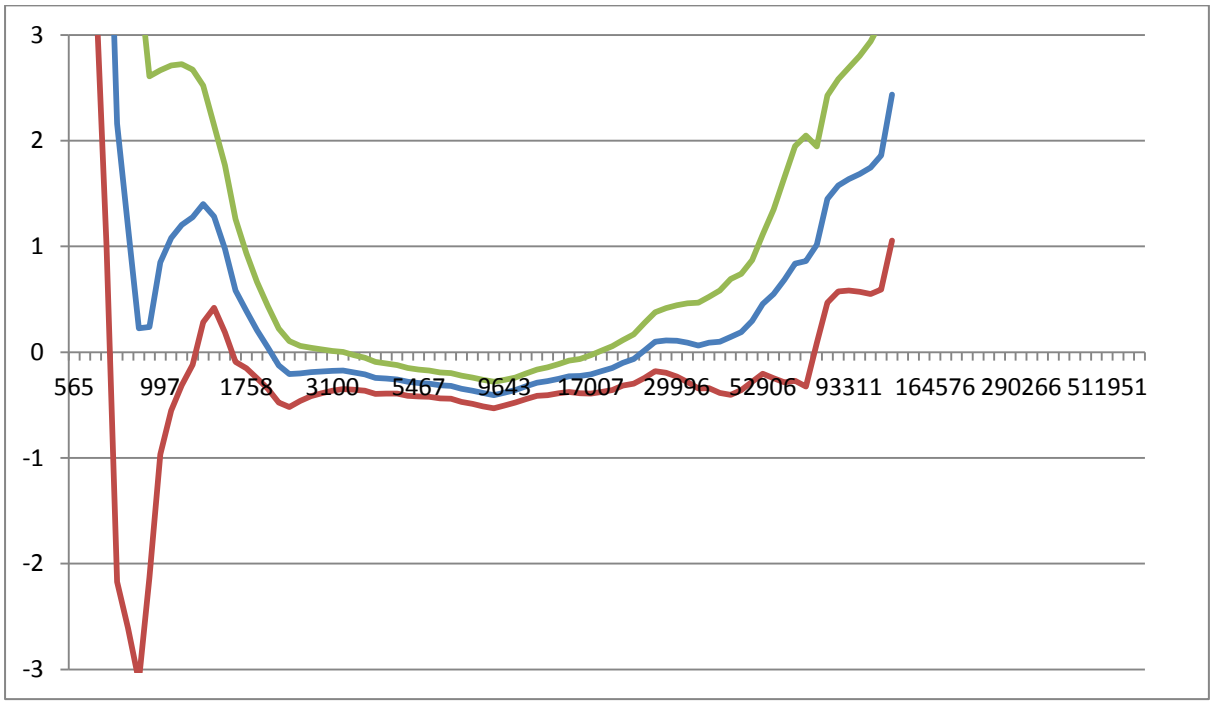
Table 2: Was Gibrat's Law violated? Results for individual decades

Decade	Initial population	% of population in places: Violation: growth too low	No violation	Violation: growth too high	no estimate possible	principal downward violations size range	principal upward violations size range
				All counties			
1761-71	6,310,340	48	37	5	10	4100-17000	<800, >75,000
1771-81	6,623,366	41	46	2	11	3500-13600	>85,000
1781-91	7,206,143	58	30	1	11	3100-24000	50,000-70,000, >180000
1791-1801	7,845,676	26	60	0	15	7700-16000	None
1801-11	8,632,940	42	43	0	16	60-1500	None
1811-21	9,817,885	50	32	3	15	75-2900	24,000-28,000
1821-31	11,405,928	47	32	5	17	40-2900	29,000-43,000
1831-41	13,198,112	42	36	5	17	55-2700	14,000-18,000 & 32,000-42,000
1841-51	15,043,400	50	23	6	21	70-6700	36,000-60,000
1851-61	16,948,659	40	35	3	22	70-4400	13,000-15,000
1861-71	18,654,135	29	41	7	23	50-2800	6,400-7,400, 20,000-22,000
1871-81	21,153,566	29	47	0	24	40-4000	None
1881-91	24,254,285	24	63	3	10	40-3300	15,600-18,000
				Industrial Revolution counties			
1801-11	1,811,079	18	20	62	0	60-600	>1300
1811-21	2,143,555	27	32	40	0	75-1300	3,600-8,000 & 16,000-40,000 & >70,000
1821-31	2,584,172	28	37	36	0	40-1700	>23,000
1831-41	3,176,562	32	29	39	0	15-3200	>34,000

1841-51	3,791,721	27	39	35	0	40-5200	31,000-100,000 & >230,000
1851-61	4,422,153	19	77	4	0	45-2300	38,000-60,000
1861-71	5,021,691	15	61	24	0	50-2000	5,300-15000, 200,000-400,000
1871-81	5,855,245	10	45	45	0	25-1500	3,800-80,000, 200,000-300,000
1881-91	7,048,067	10	63	27	0	30-2000	6,400-70,000
				Non-Industrial Revolution counties			
1801-11	4,438,710	77	23	0	0	50-3700	none
1811-21	4,915,111	78	22	0	0	50-5000	none
1821-31	5,603,537	82	18	0	0	30-6800	none
1831-41	6,242,233	76	24	0	0	40-6500	none
1841-51	6,821,493	78	22	0	0	60-8200	none
1851-61	7,291,218	80	20	0	0	60-12000	none
1861-71	7,503,443	70	30	0	0	30-8200	none
1871-81	8,088,941	67	33	0	0	40-8400	none
1881-91	8,597,210	57	43	0	0	30-6500	none

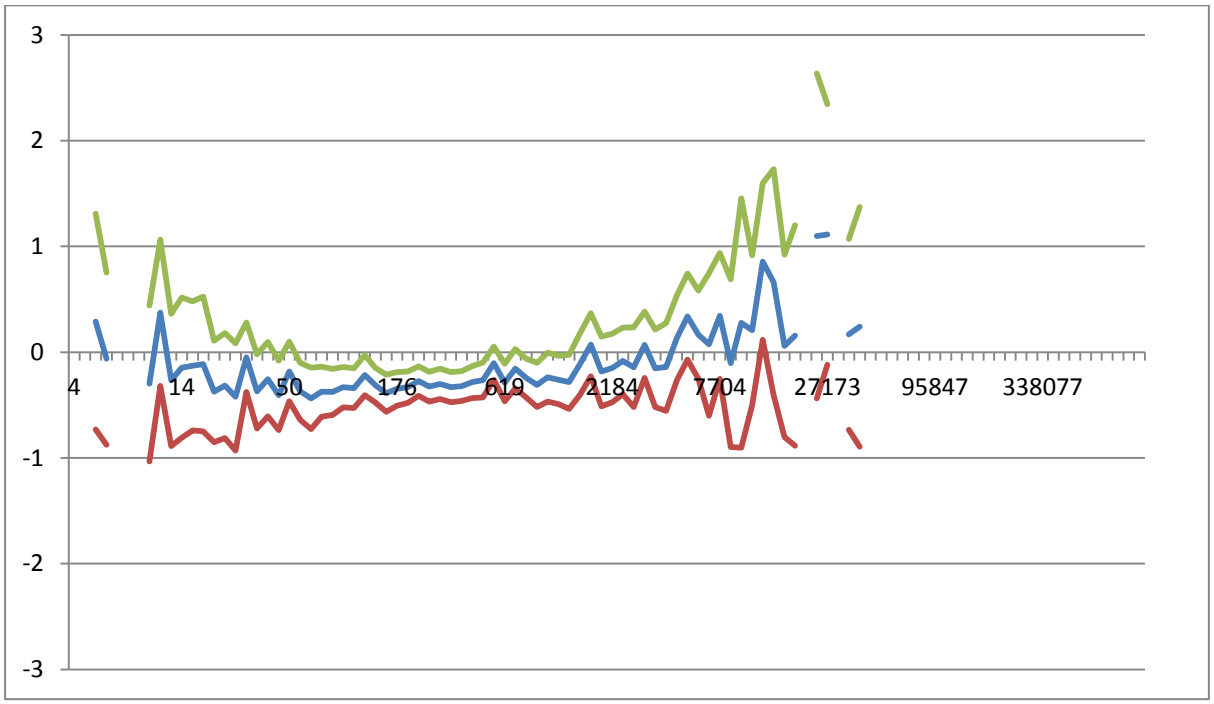
Figures 1-4 (all figures for main text)

Figure 1 1760-1801



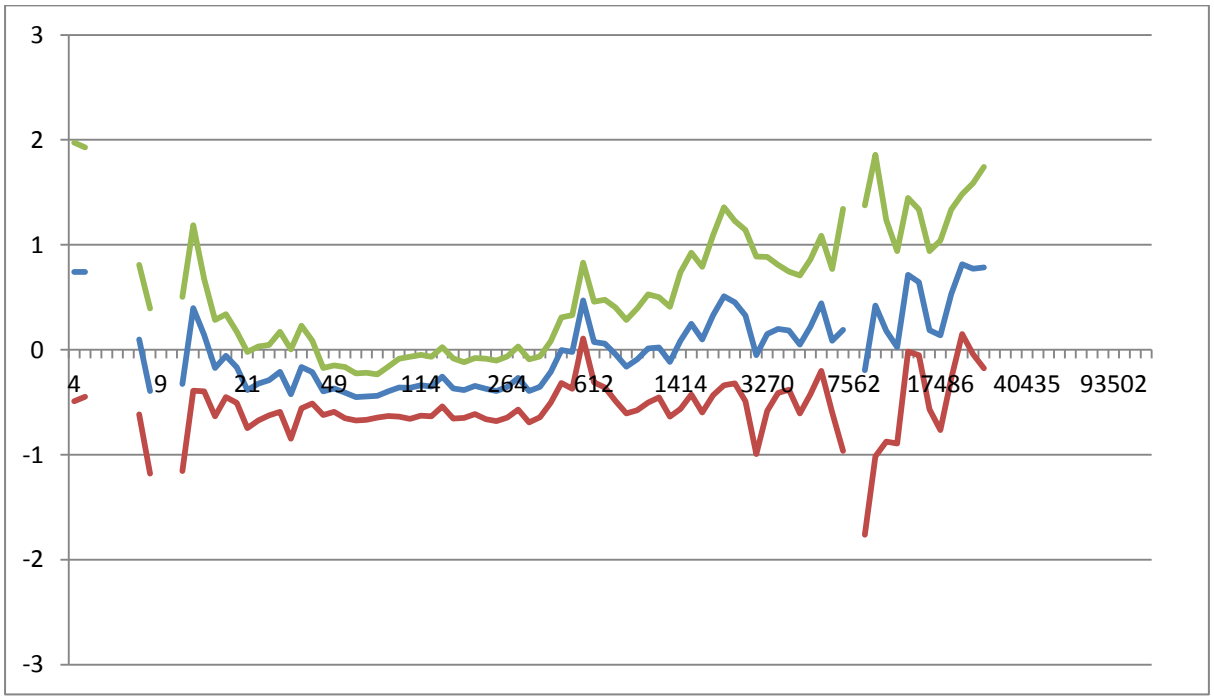
Notes to figure 1: Central estimate and 99% confidence intervals.

Figure 2 1801-1891



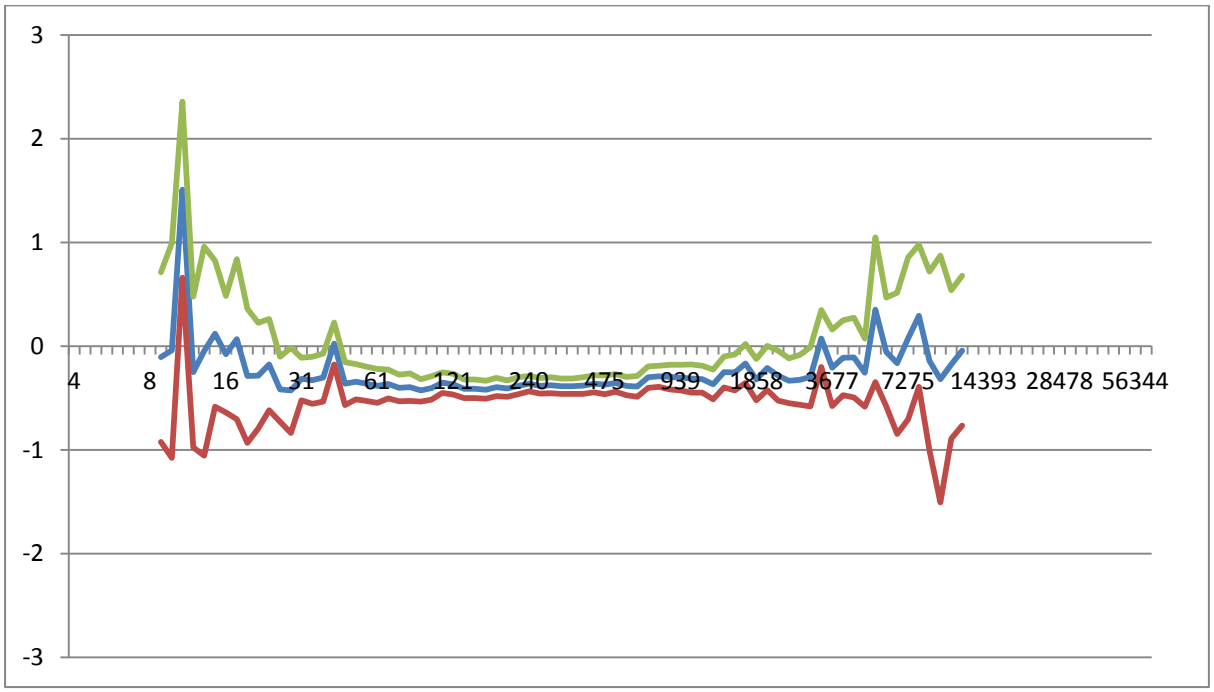
Notes to figure 2: As figure 1

Figure 3: Industrial Revolution counties, 1801-91



Notes to figure 3: As figure 1

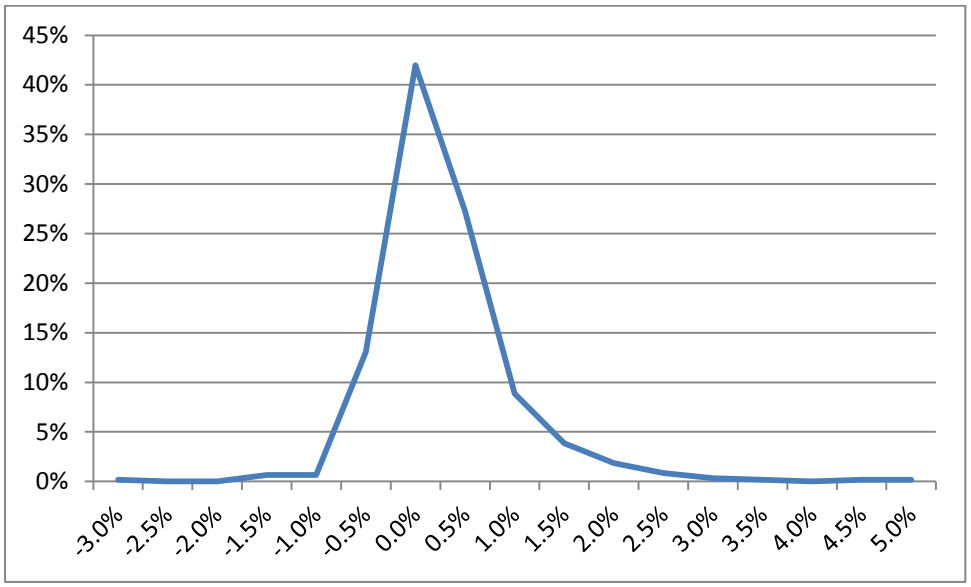
Figure 4: Non Industrial Revolution counties, 1801-1891



Notes to figure 4: As figure 1

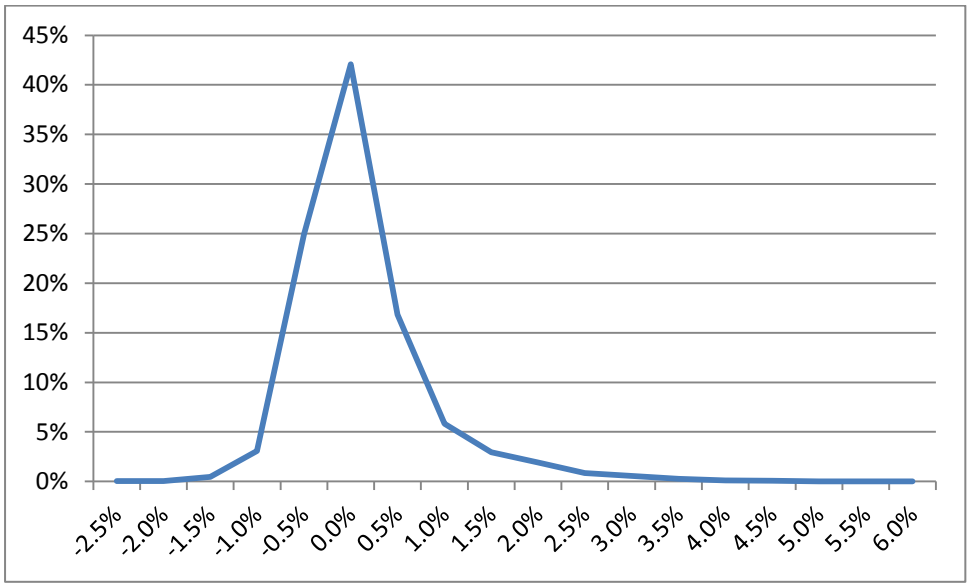
Appendix 1: the distribution of growth rates

Figure A1a: Distribution of annual average growth rates, 1761-1801



Notes: "-3.0%" means -3.0%=<x<2.5%, etc.

Figure A1b: Distribution of annual average growth rates, 1801-1891



Notes: as per figure A1a

Appendix 2: Growth rates by size of place

Notes

This appendix shows the central estimates and 99% confidence intervals.

The x-axis includes places of all sizes. The right hand section is often missing because there are so few large places. Where the largest place is of a unique size there is no reliable way to produce an estimate or confidence intervals. The largest place in non-industrial revolution counties is often of similar size to other places and therefore we are able to provide estimates and confidence intervals.

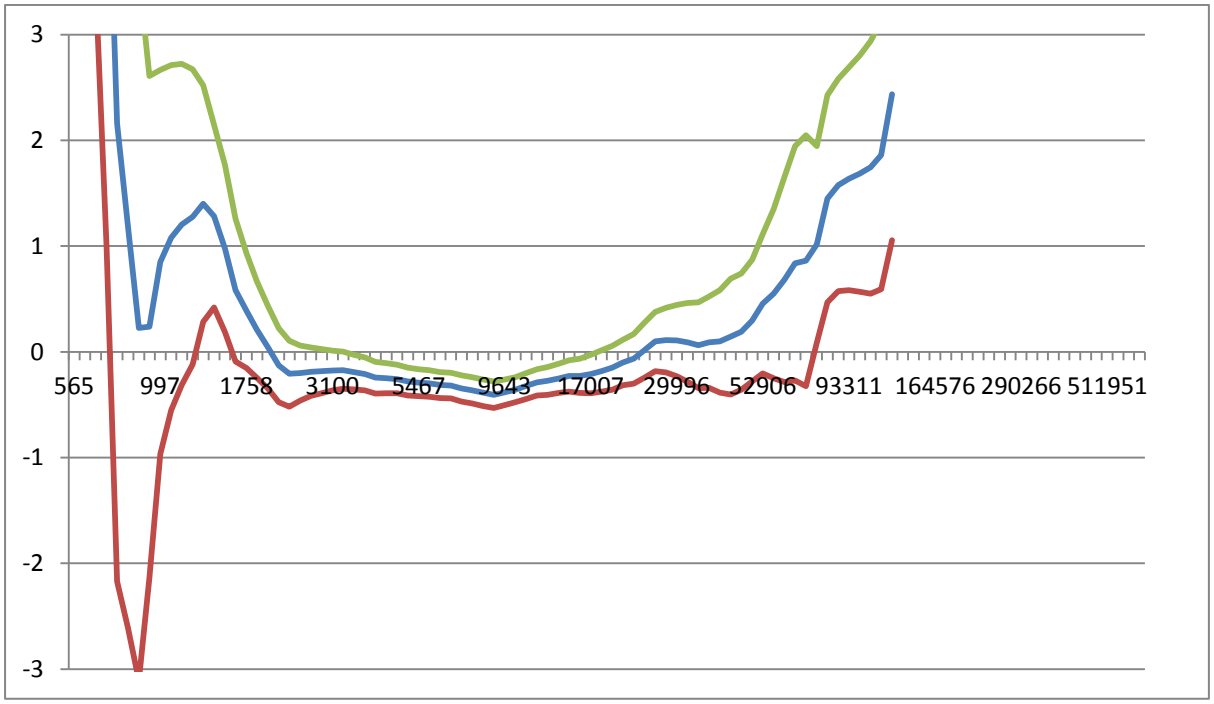
For consistency and visual clarity, the y-axis (standardised growth rates) range from -3 to +3 in each case.

Graphs are given as follows:

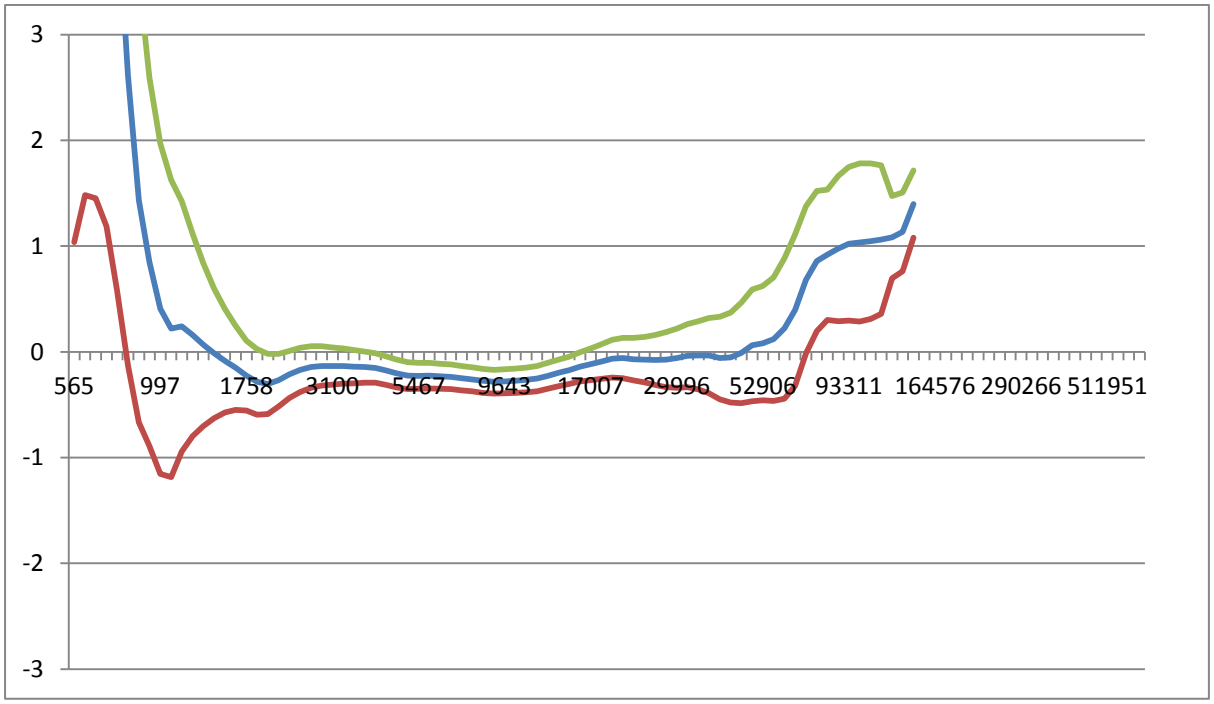
i) 1761-1801, England
ii) 1761-1771, England
iii) 1771-1781, England
iv) 1781-1791, England
v) 1791-1801, England
vi) 1801-1891, England
vii) 1801-1891, England: industrial revolution counties only
viii) 1801-1891, England: non- industrial revolution counties only
ix) 1801-1841, England
x) 1801-1841, England: industrial revolution counties only
xi) 1801-1841, England: non- industrial revolution counties only
xii) 1841-1891, England
xiii) 1841-1891, England: industrial revolution counties only
xiv) 1841-1891, England: non- industrial revolution counties only
xv) 1801-1811, England
xvi) 1801-1811, England: industrial revolution counties only
xvii) 1801-1811, England: non- industrial revolution counties only
xviii) 1811-1821, England
xix) 1811-1821, England: industrial revolution counties only
xx) 1811-1821, England: non- industrial revolution counties only
xxi) 1821-1831, England
xxii) 1821-1831, England: industrial revolution counties only
xxiii) 1821-1831, England: non- industrial revolution counties only
xxiv) 1831-1841, England
xxv) 1831-1841, England: industrial revolution counties only
xxvi) 1831-1841, England: non- industrial revolution counties only
xxvii) 1841-1851, England
xxviii) 1841-1851, England: industrial revolution counties only
xxix) 1841-1851, England: non- industrial revolution counties only
xxx) 1851-1861, England
xxxi) 1851-1861, England: industrial revolution counties only

xxxii) 1851-1861, England: non- industrial revolution counties only
xxxiii) 1861-1871, England
xxxiv) 1861-1871, England: industrial revolution counties only
xxxv) 1861-1871, England: non- industrial revolution counties only
xxxvi) 1871-1881, England
xxxvii) 1871-1881, England: industrial revolution counties only
xxxviii) 1871-1881, England: non- industrial revolution counties only
xxxix) 1881-1891, England
xl) 1881-1891, England: industrial revolution counties only
xli) 1881-1891, England: non- industrial revolution counties only

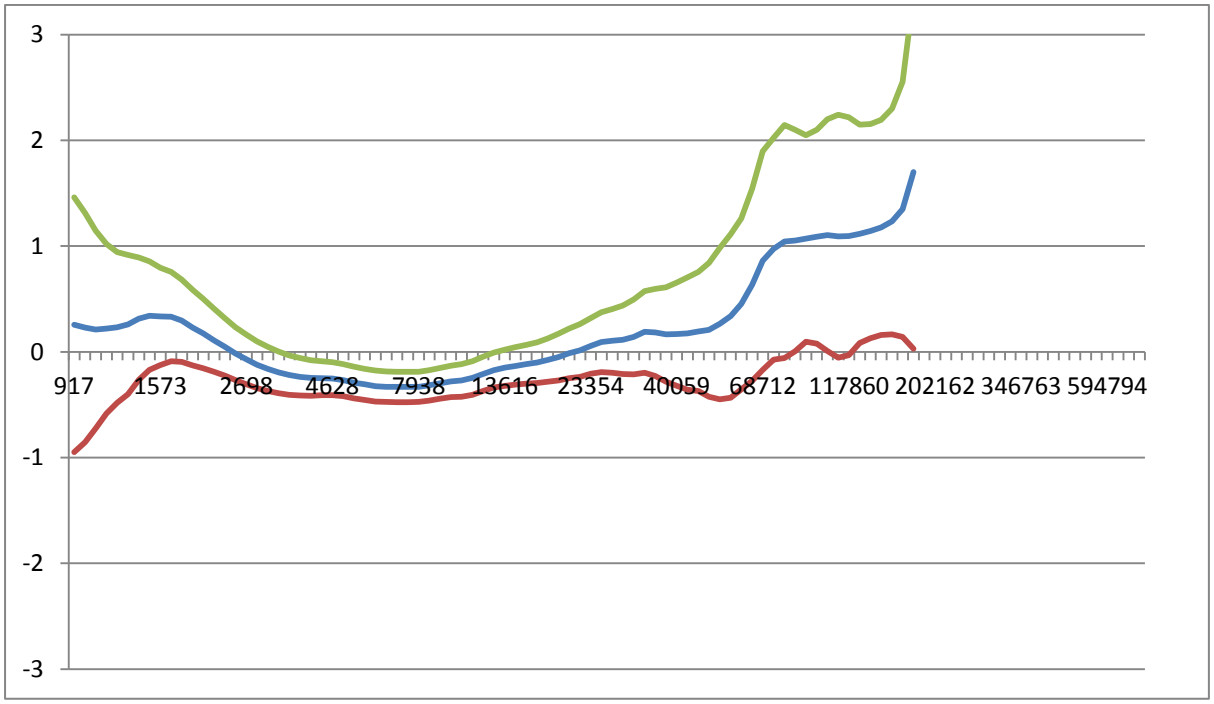
i) 1761-1801, England



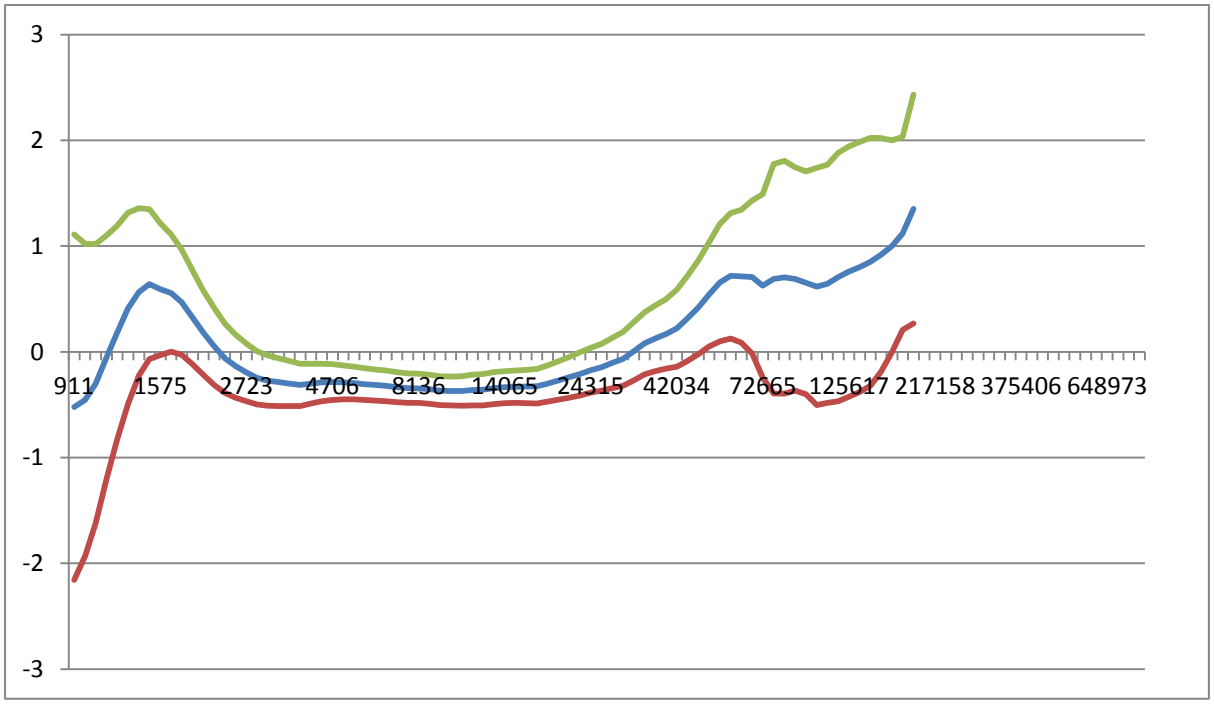
ii) 1761-1771, England



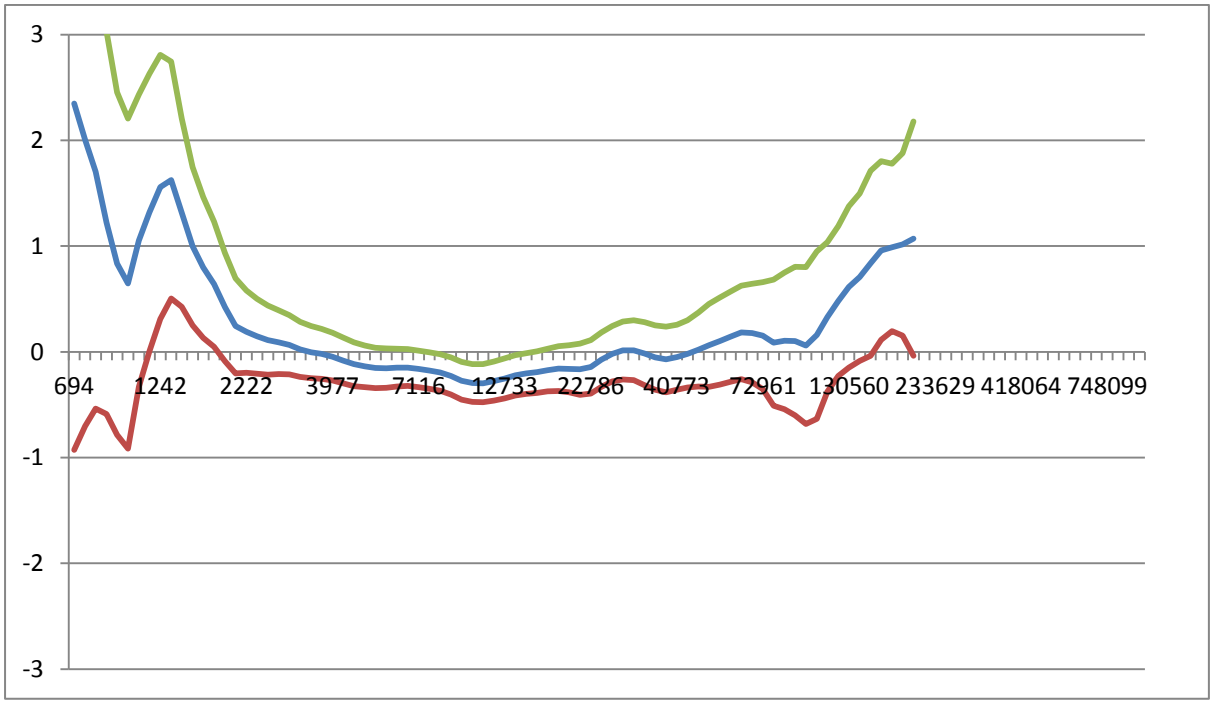
iii) 1771-1781, England



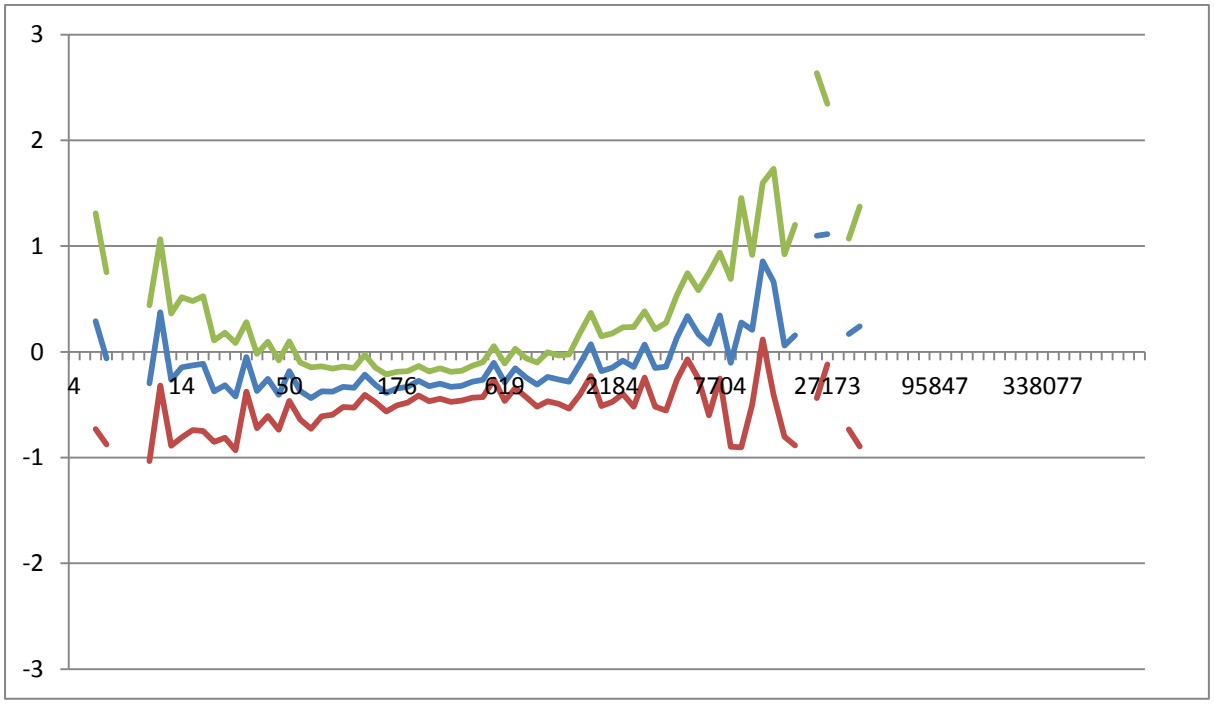
iv) 1781-1791, England



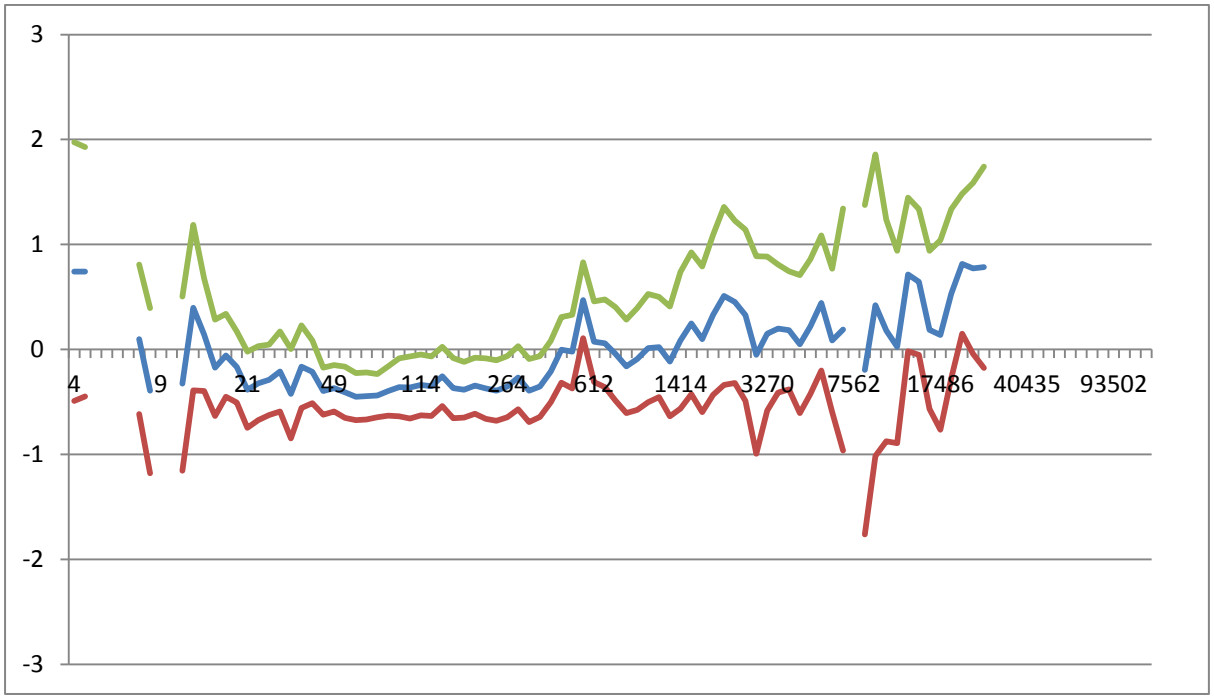
v) 1791-1801, England



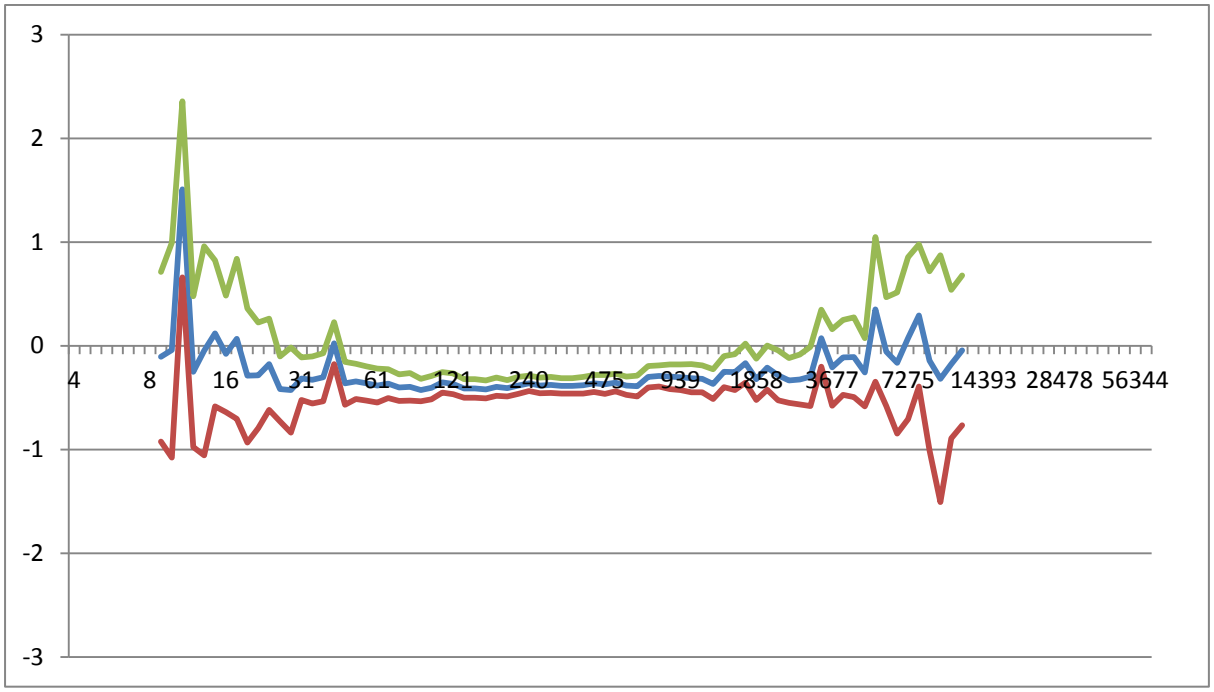
vi) 1801-1891, England



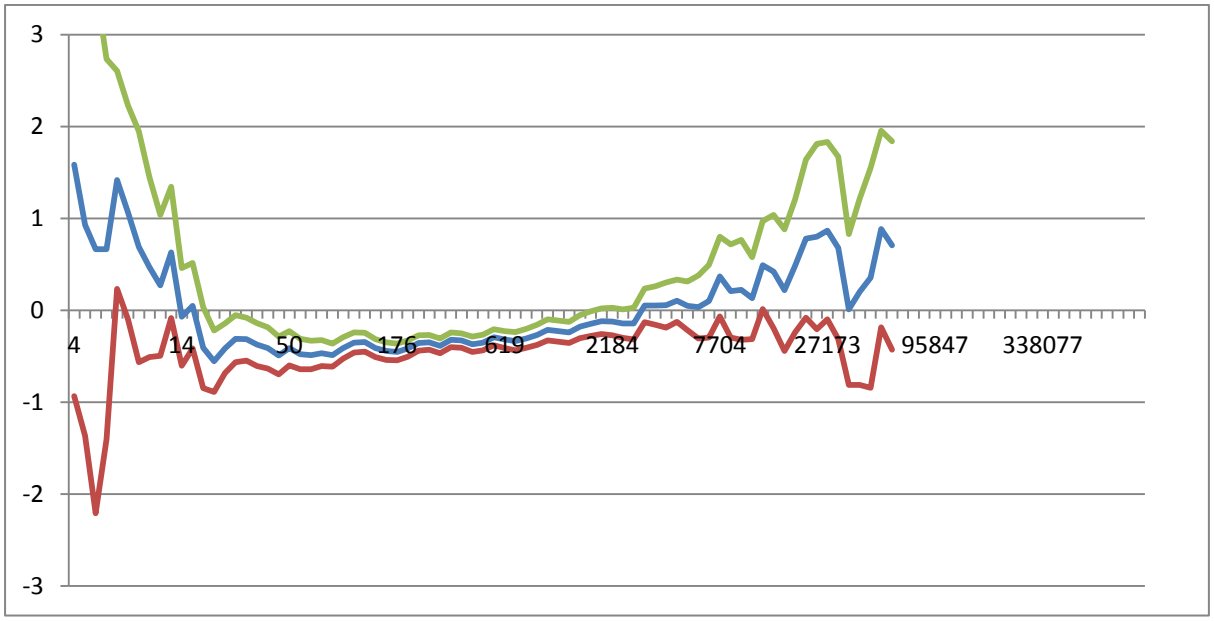
vii) 1801-1891, England: industrial revolution counties only



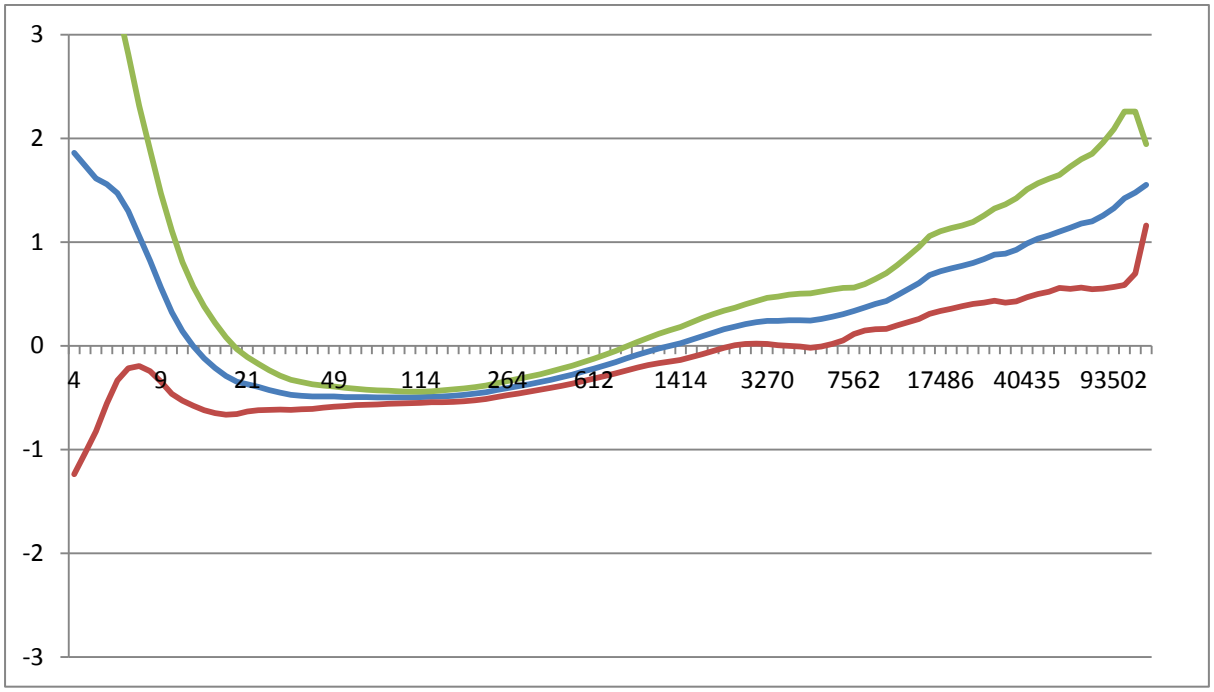
viii) 1801-1891, England: non- industrial revolution counties only



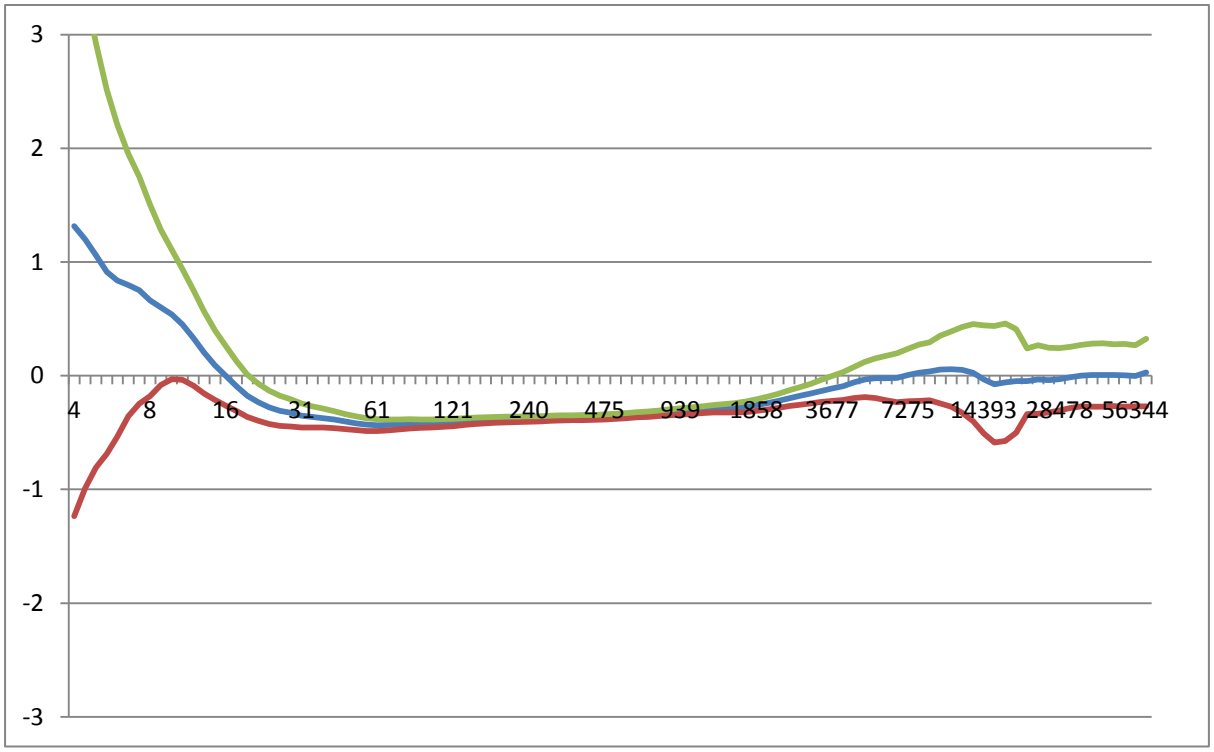
ix) 1801-1841, England



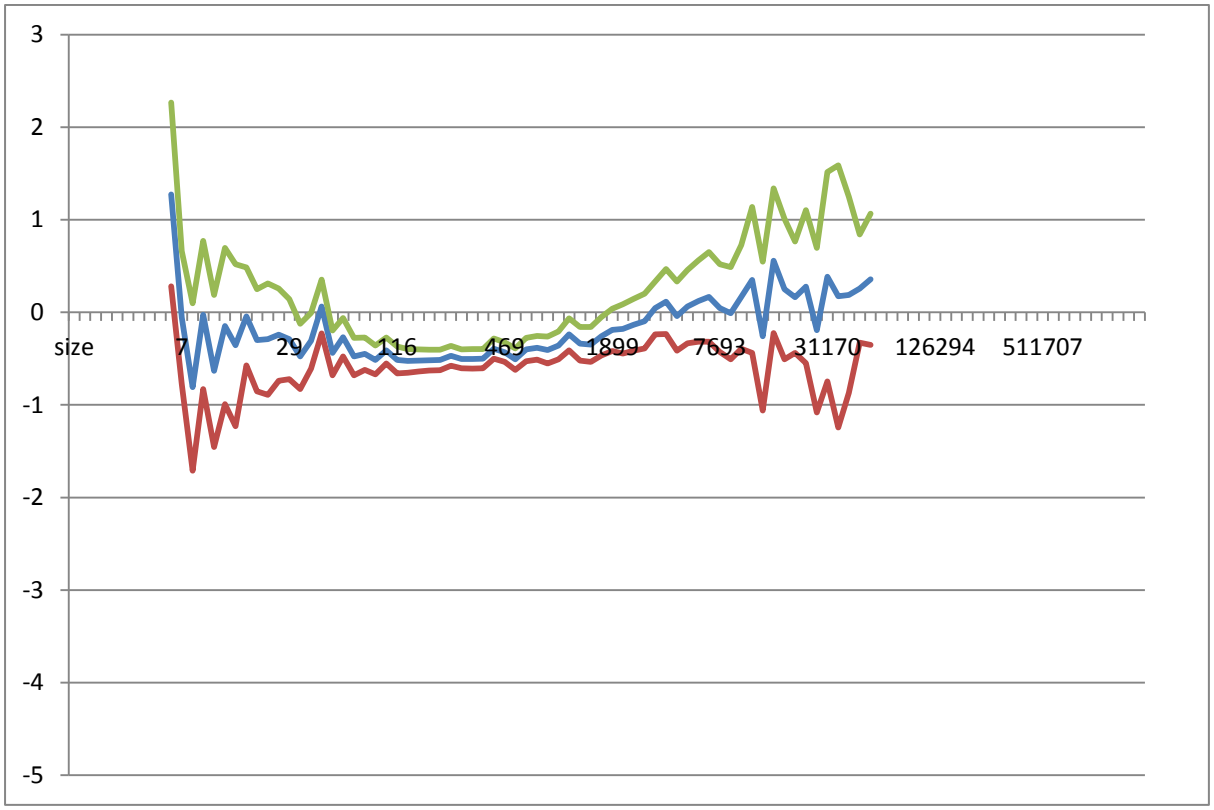
x) 1801-1841, England: industrial revolution counties only



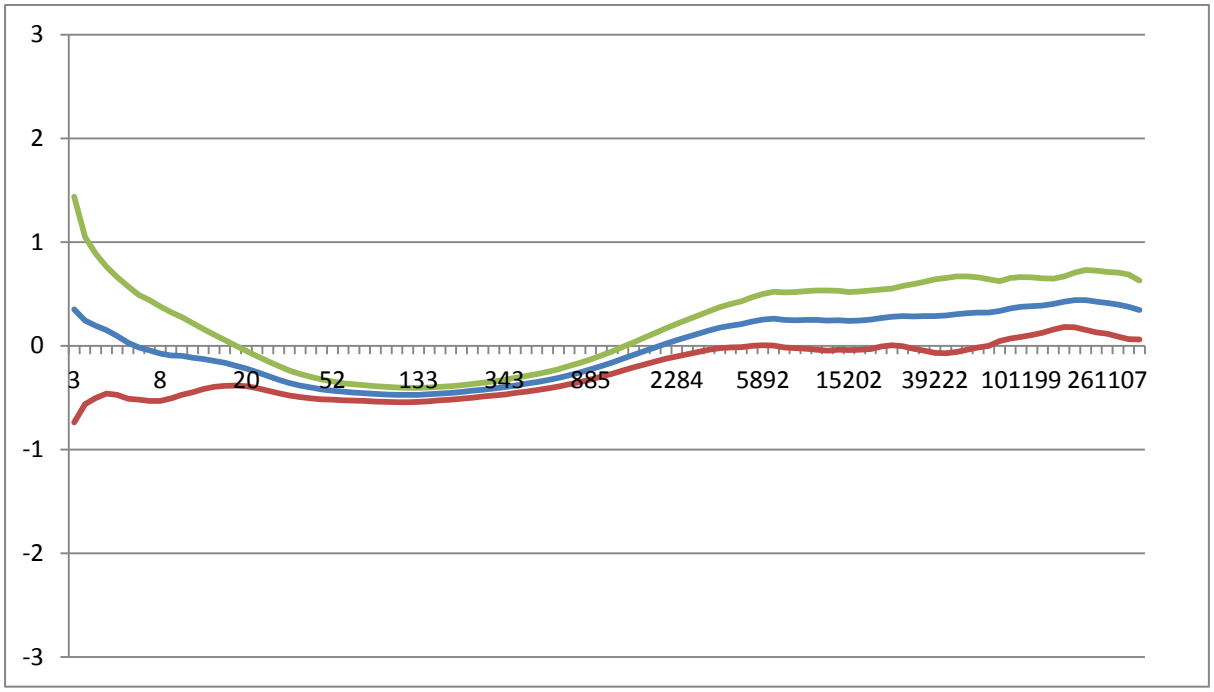
xi) 1801-1841, England: non- industrial revolution counties only



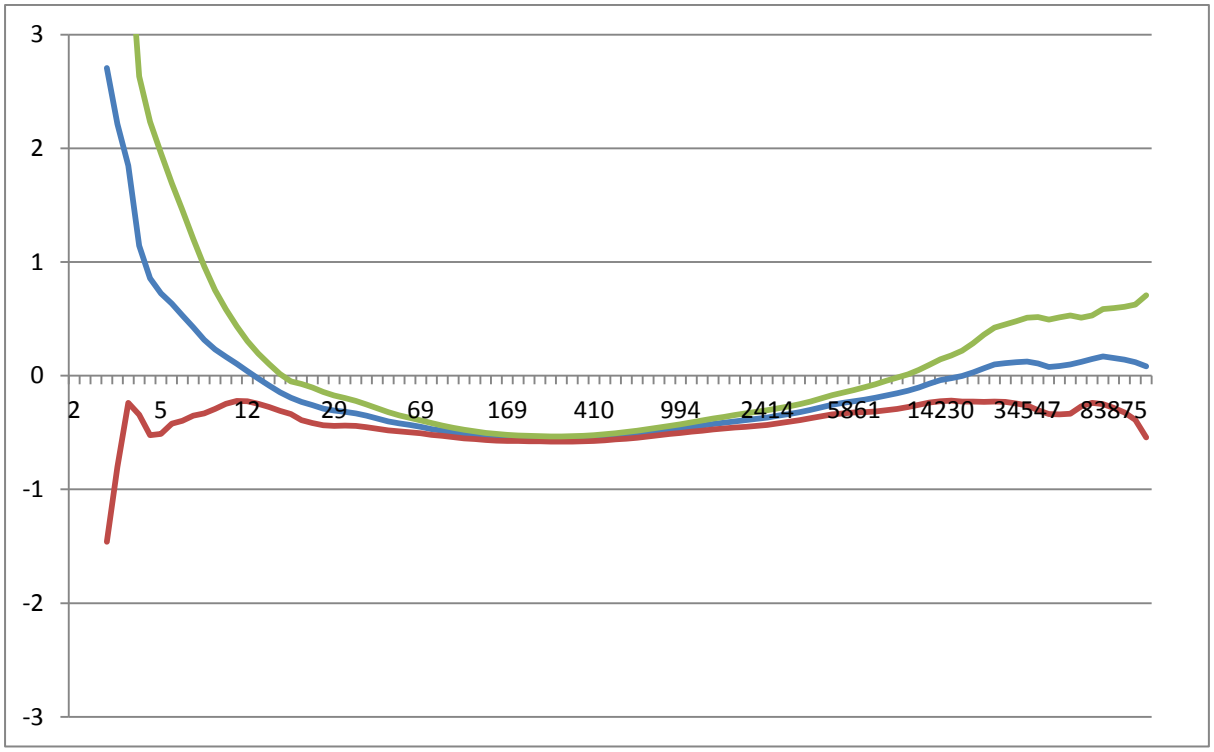
xii) 1841-1891, England



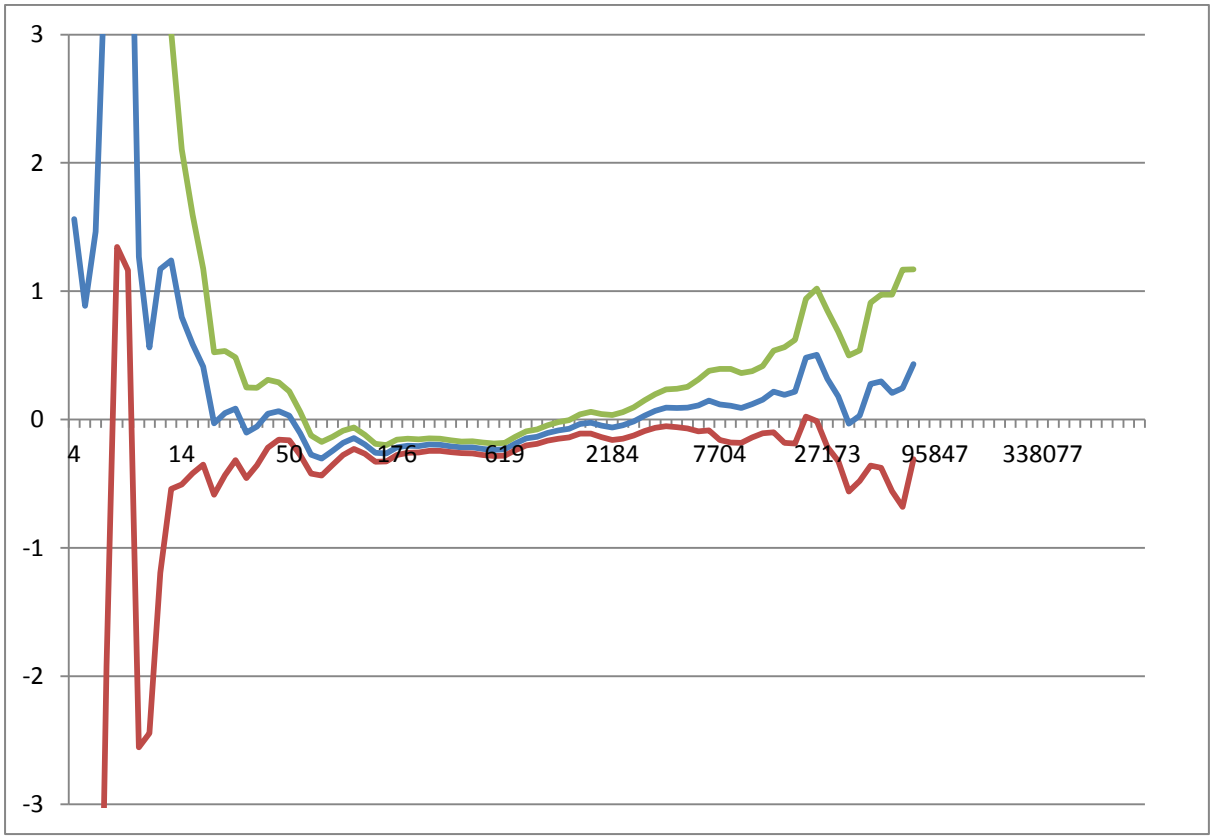
xiii) 1841-1891, England: industrial revolution counties only



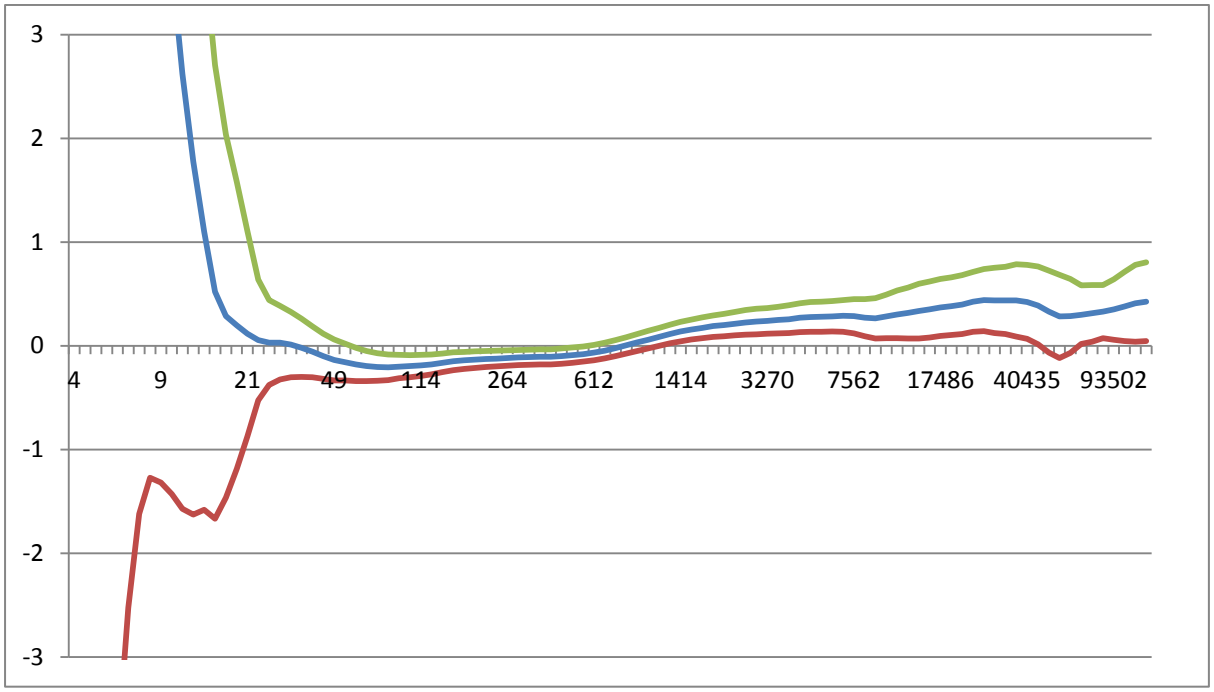
xiv) 1841-1891, England: non- industrial revolution counties only



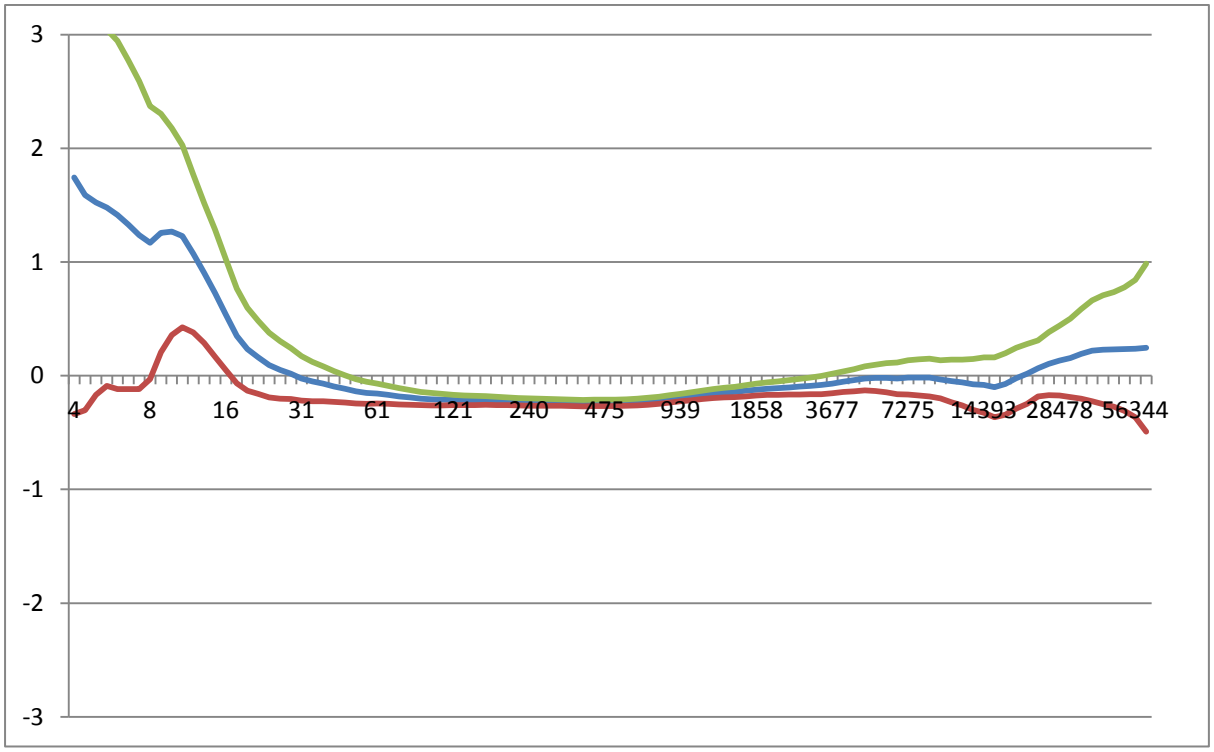
xv) 1801-1811, England



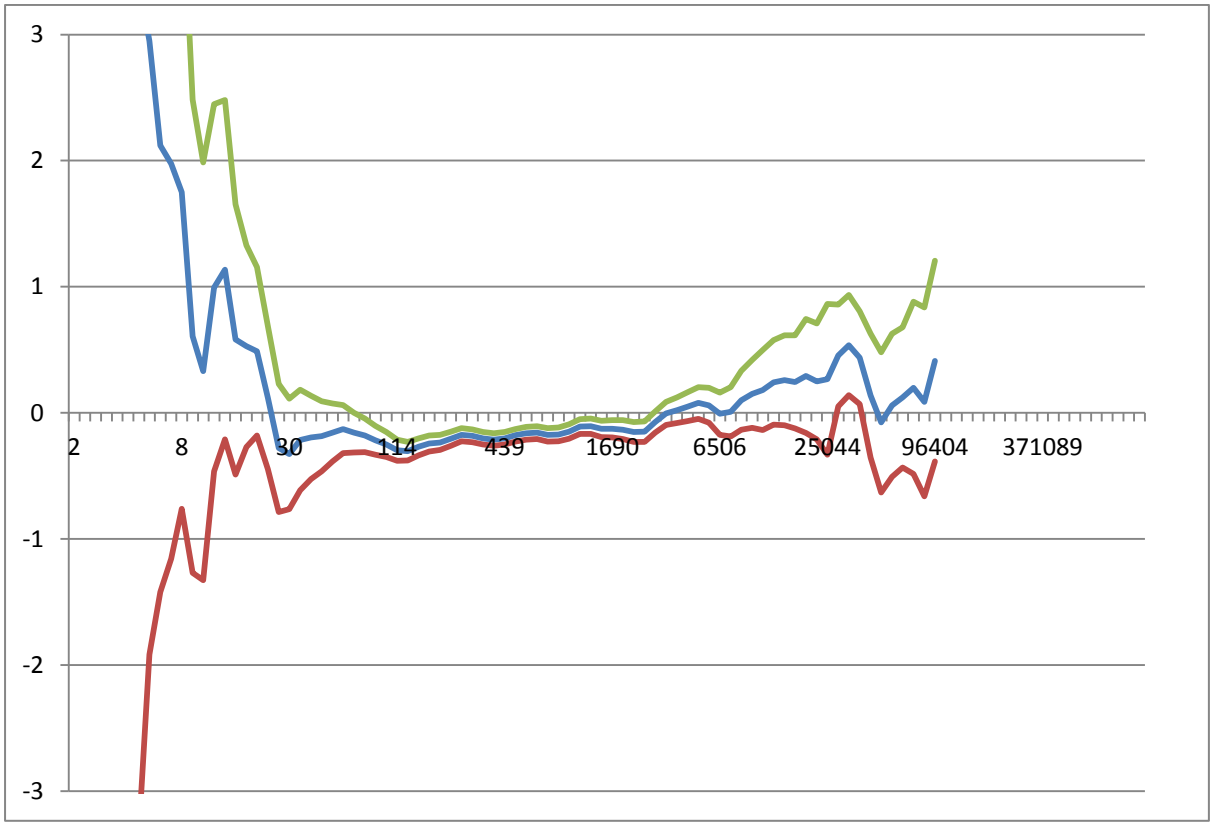
xvi) 1801-1811, England: industrial revolution counties only



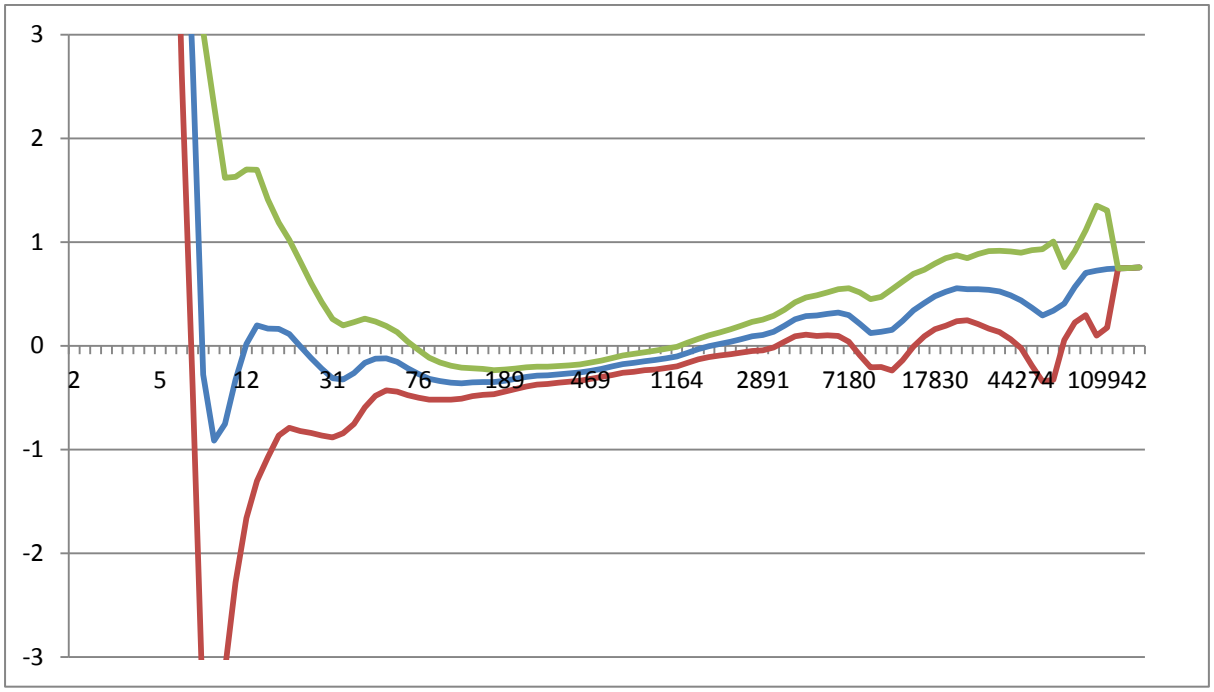
xvii) 1801-1811, England: non- industrial revolution counties only



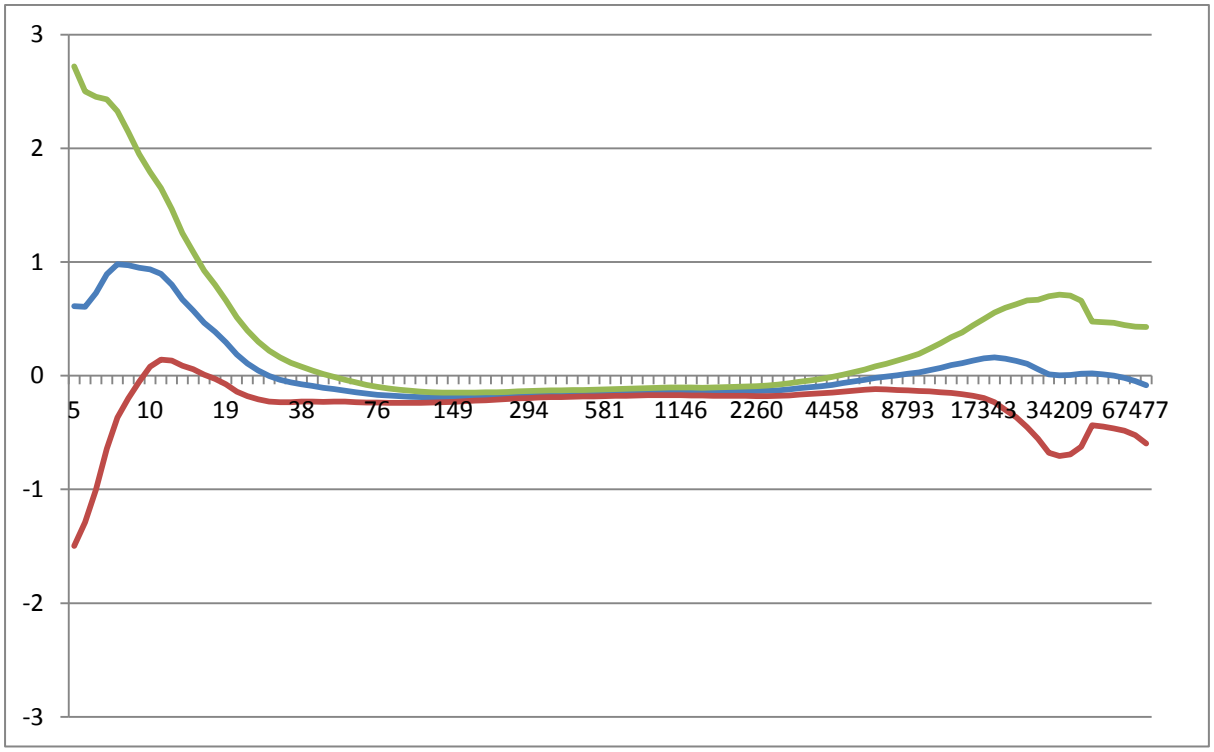
xviii) 1811-1821, England



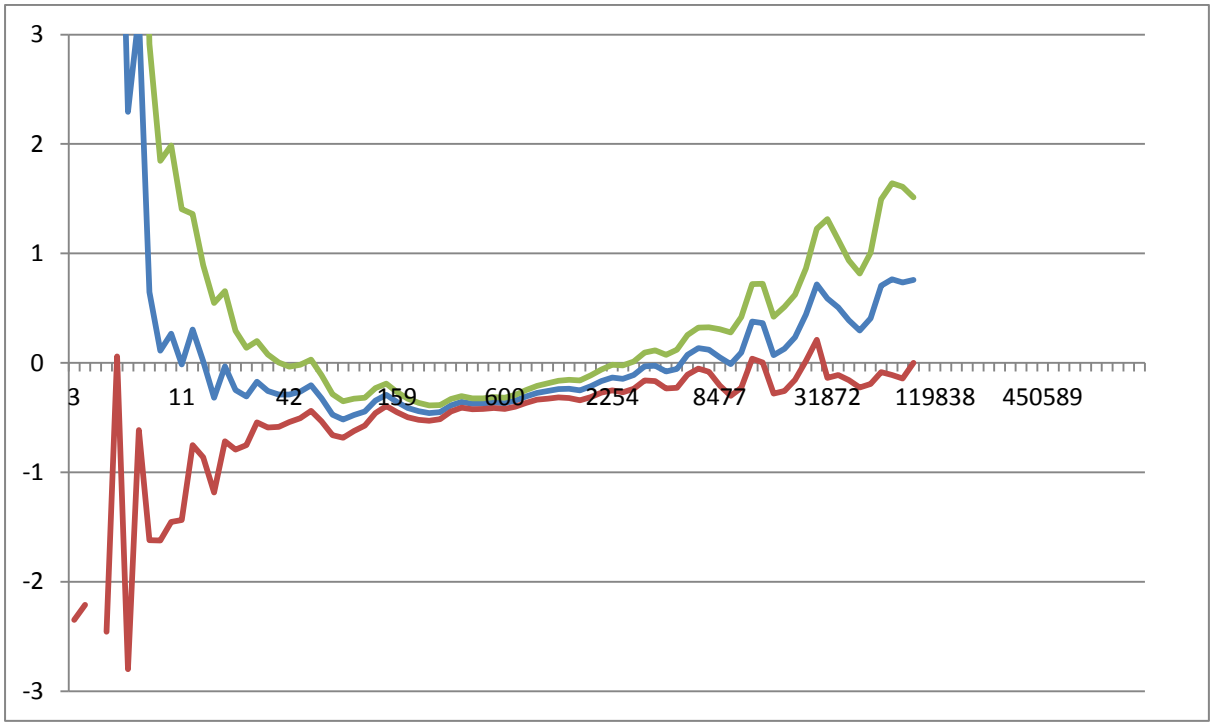
xix) 1811-1821, England: industrial revolution counties only



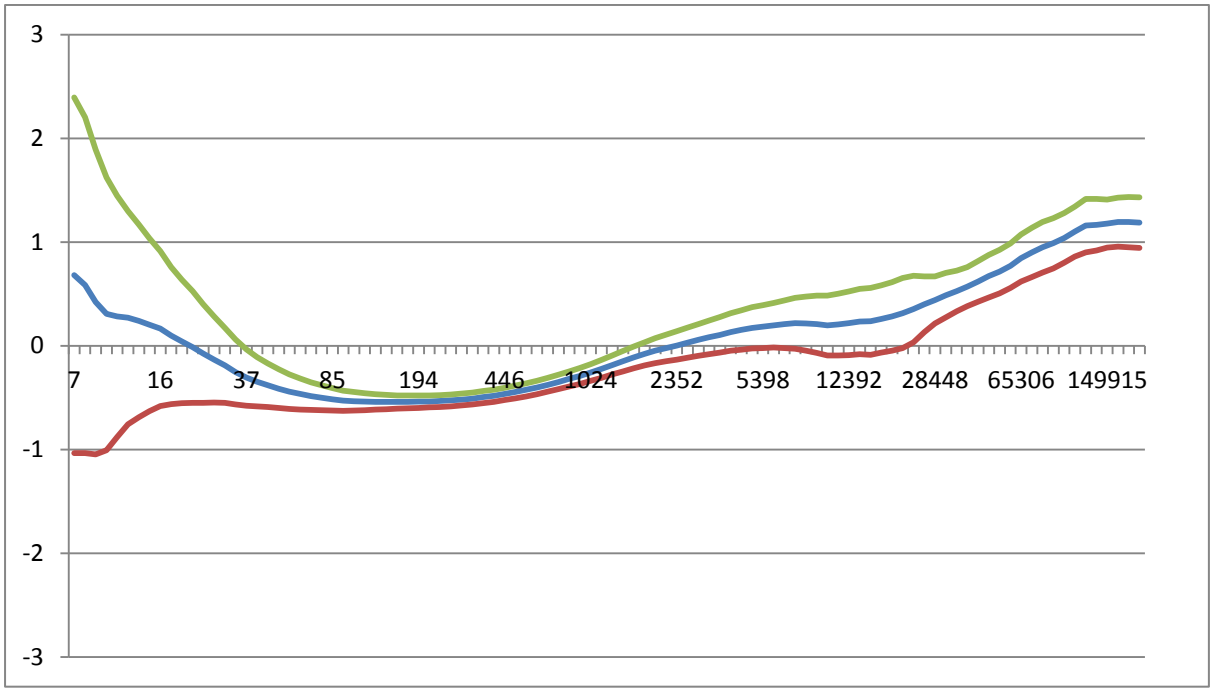
xx) 1811-1821, England: non- industrial revolution counties only



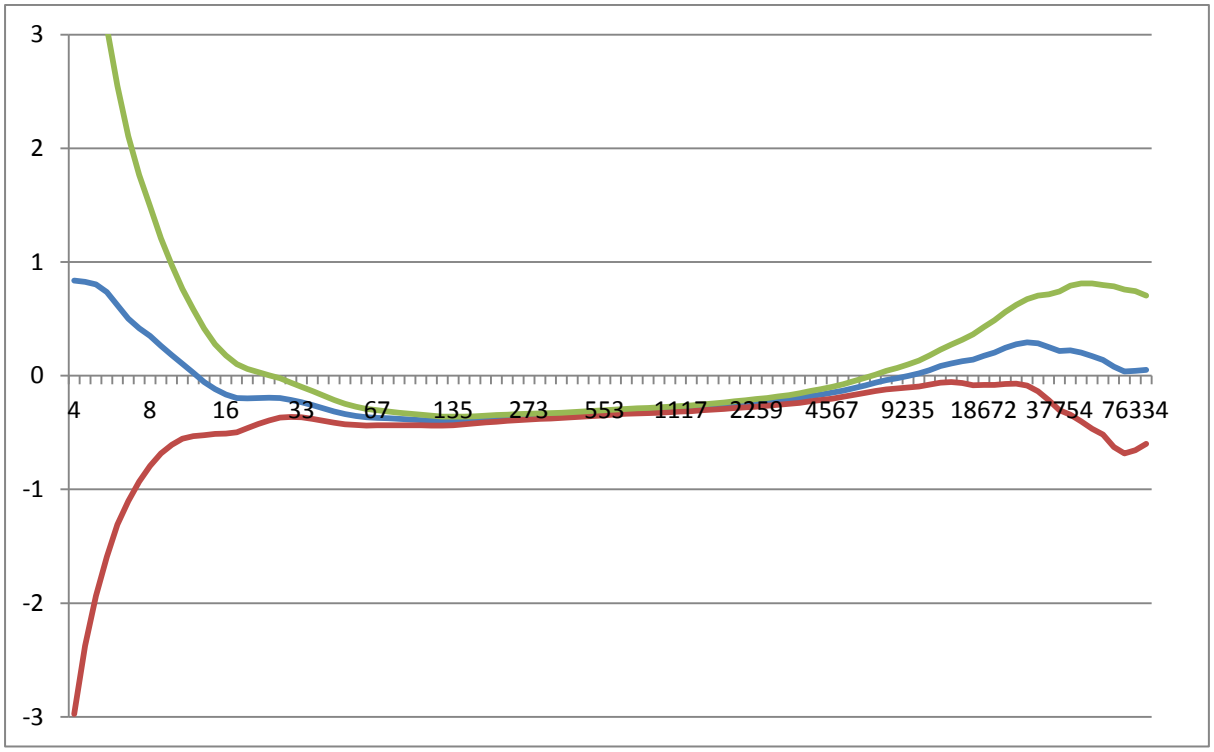
xxi) 1821-1831, England



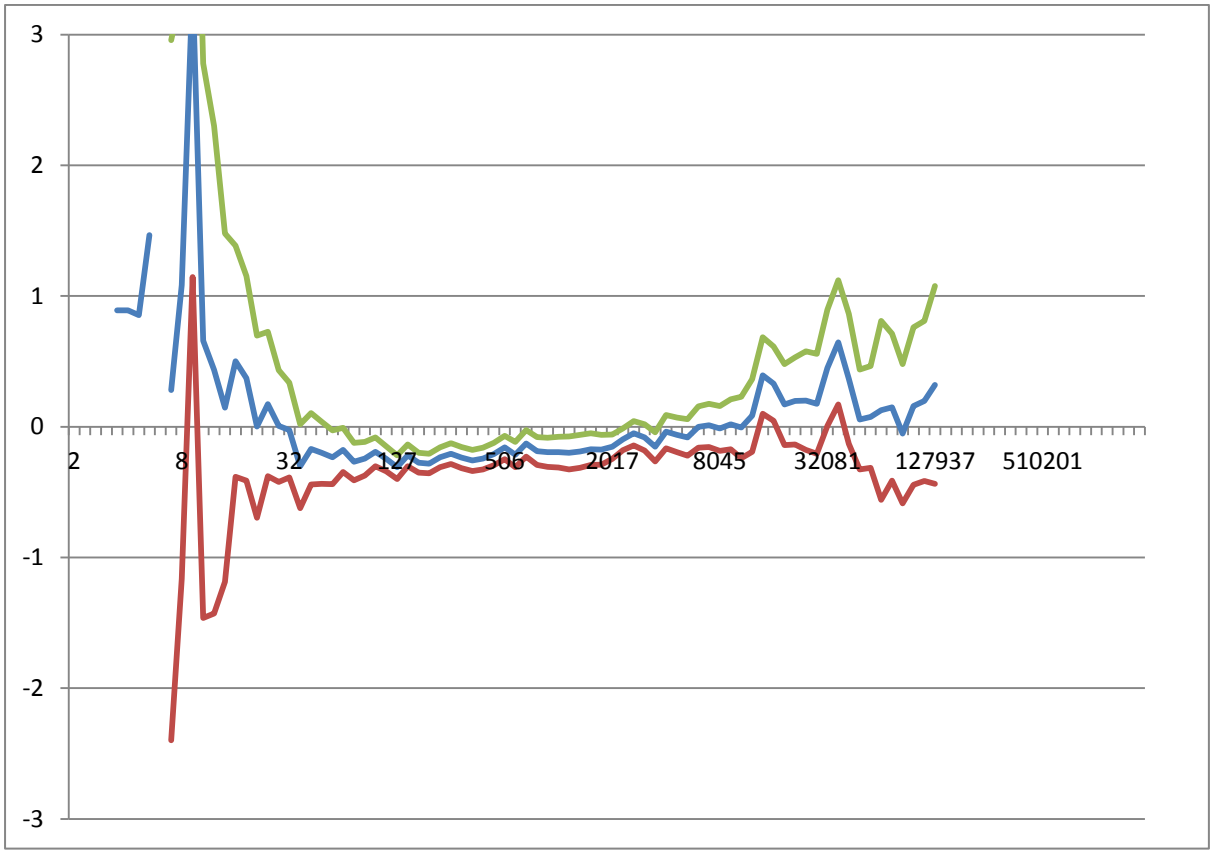
xxii) 1821-1831, England: industrial revolution counties only



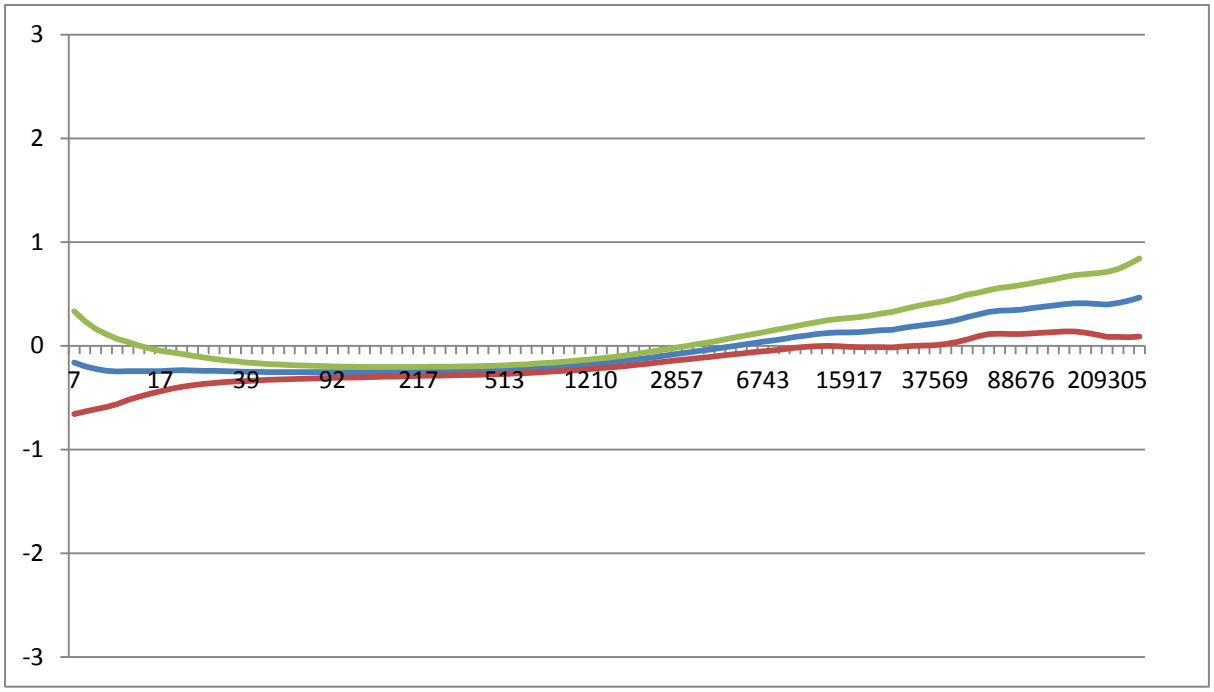
xxiii) 1821-1831, England: non- industrial revolution counties only



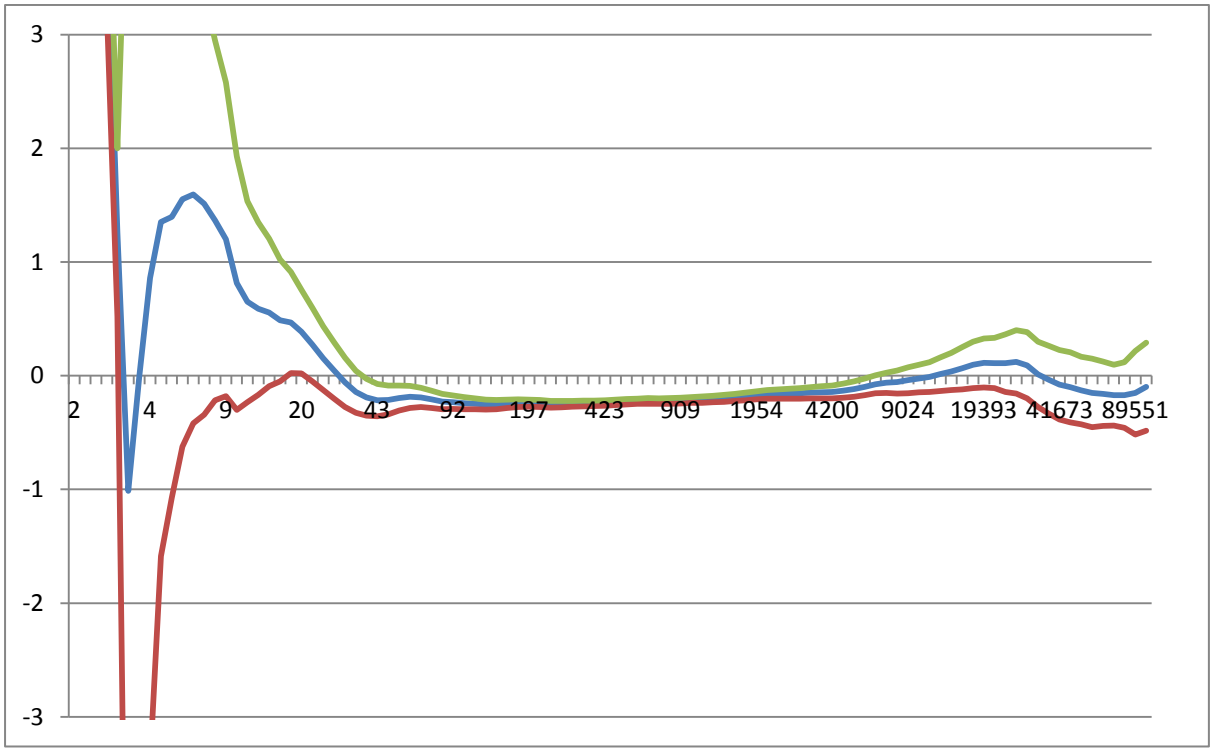
xxiv) 1831-1841, England



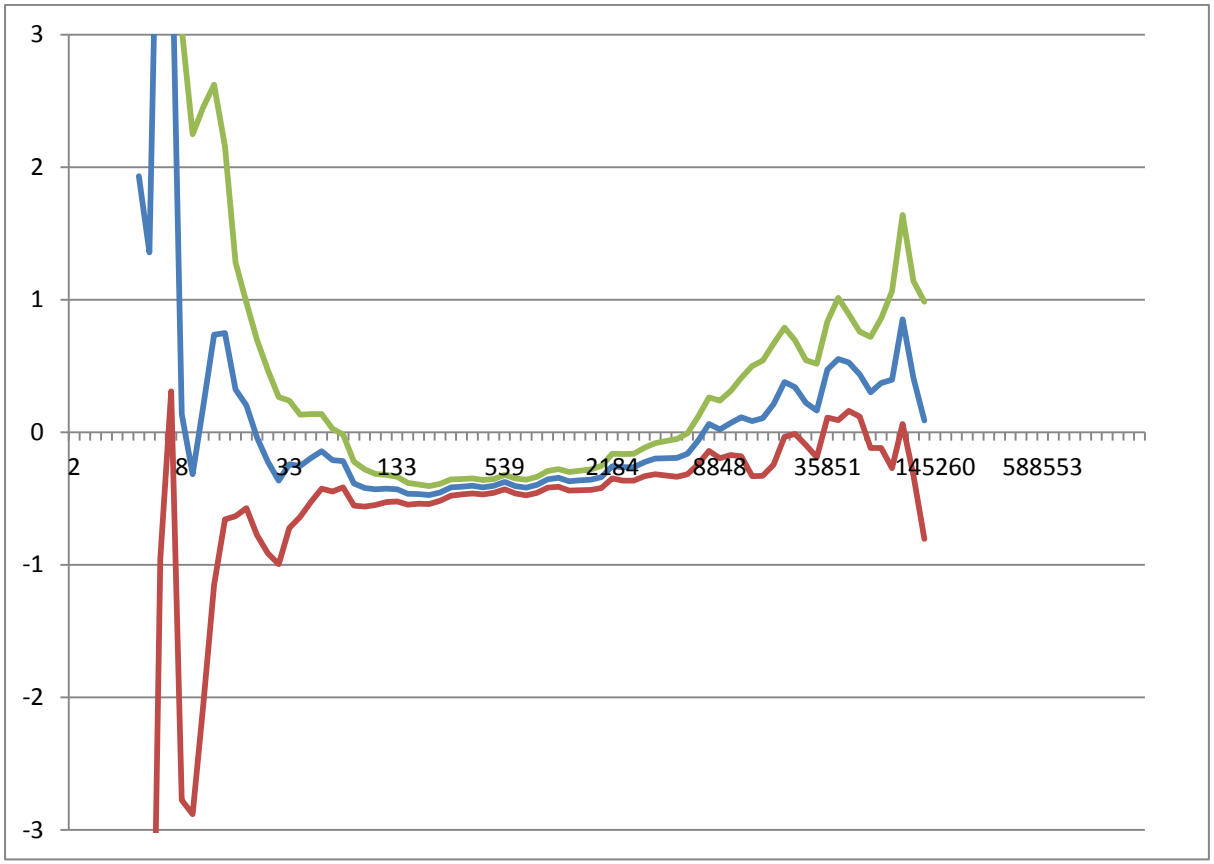
xxv) 1831-1841, England: industrial revolution counties only



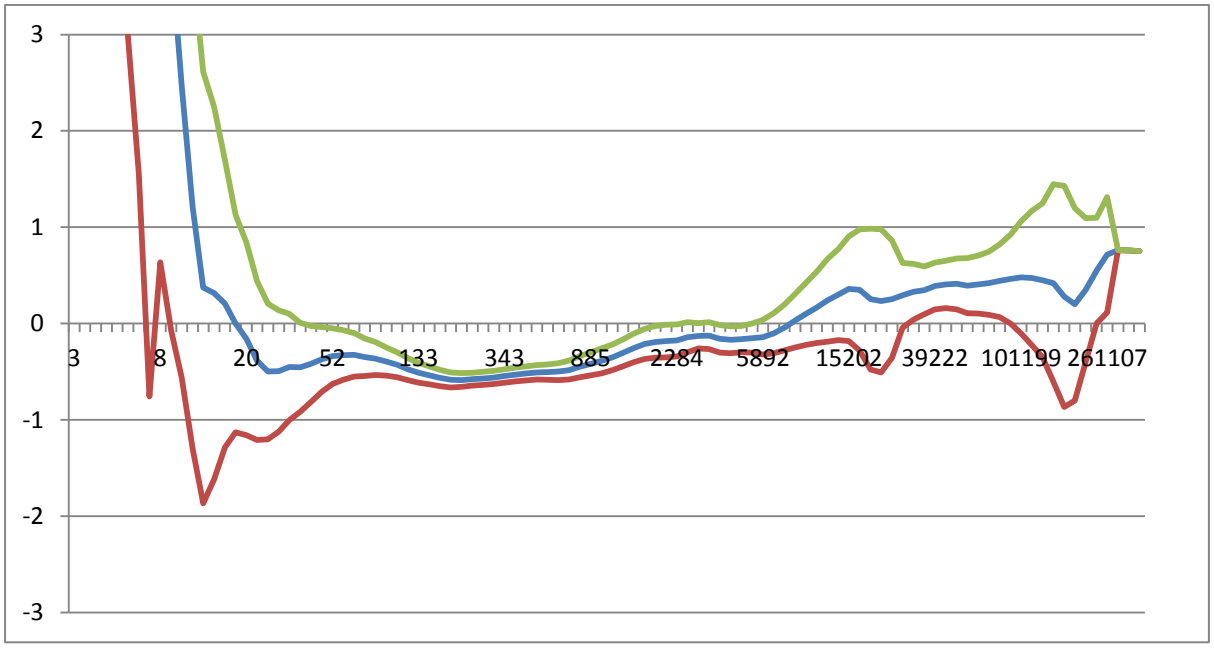
xxvi) 1831-1841, England: non- industrial revolution counties only



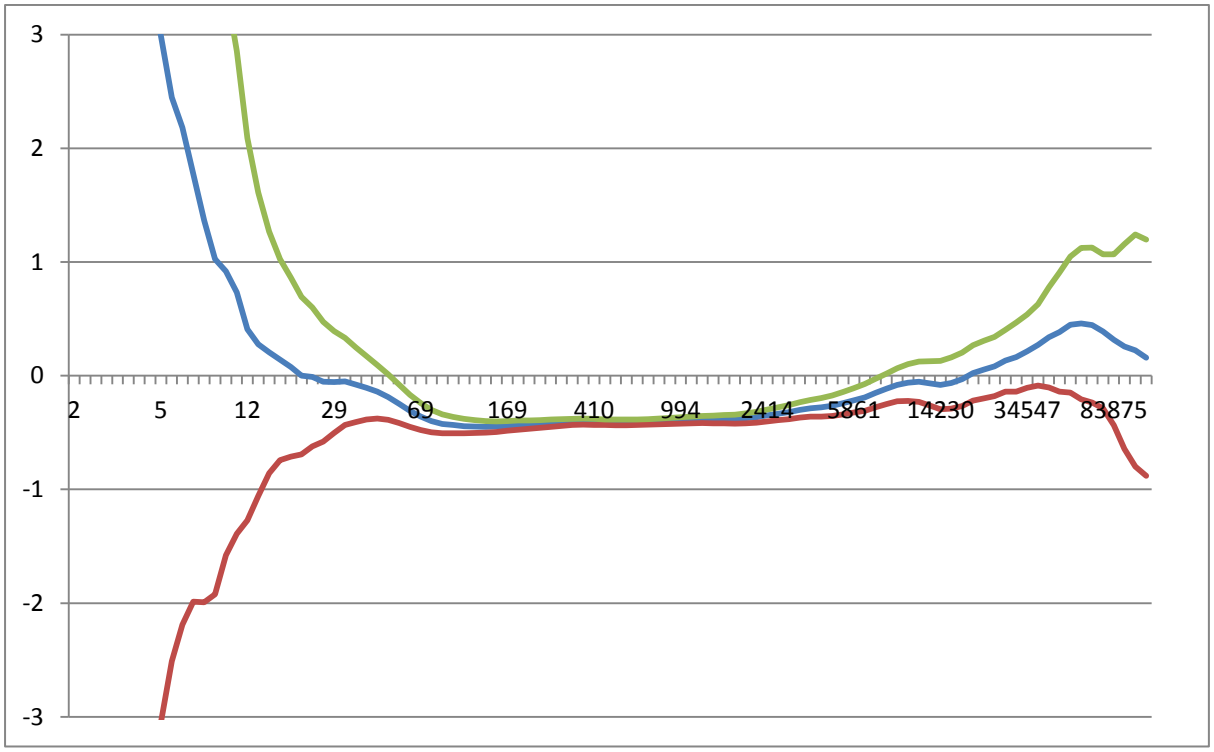
xxvii) 1841-1851, England



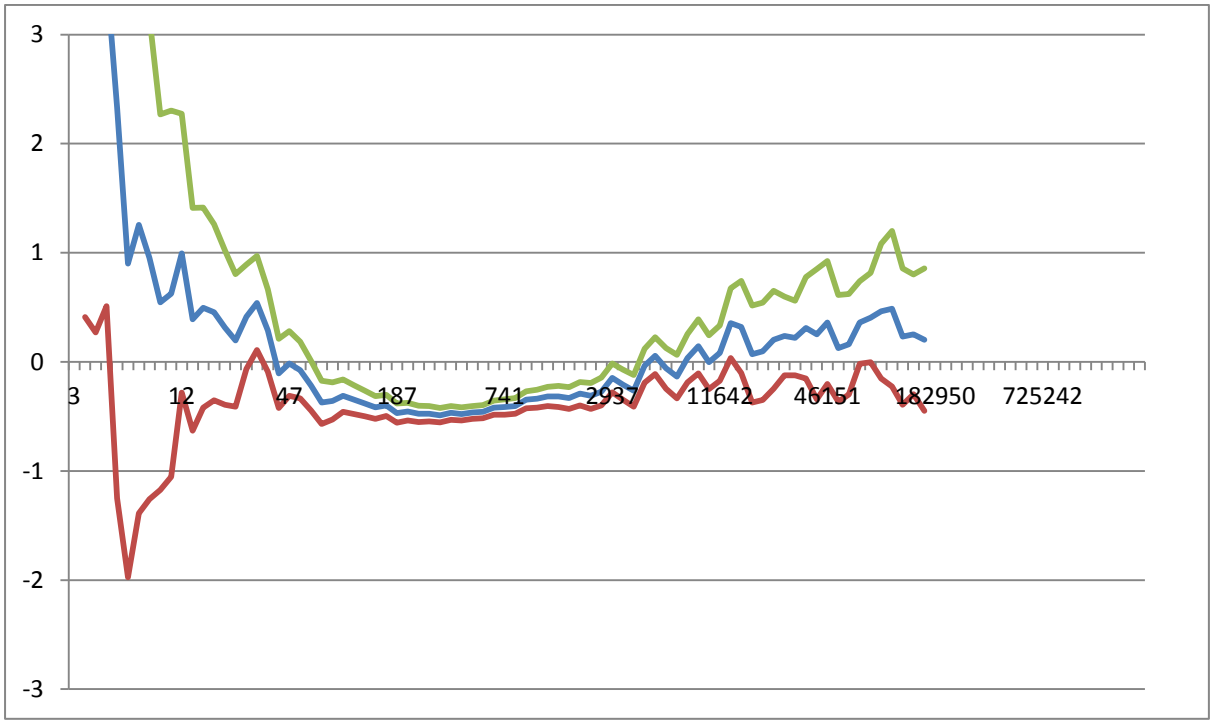
xxviii) 1841-1851, England: industrial revolution counties only



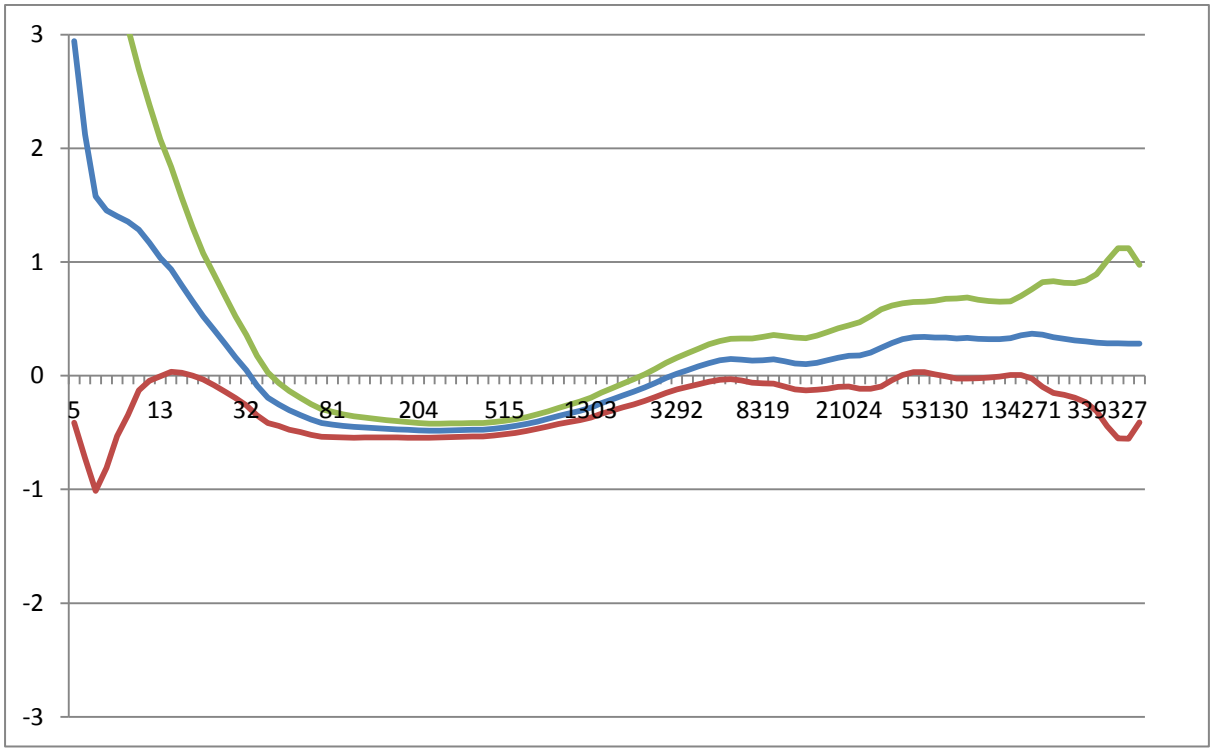
xxix) 1841-1851, England: non- industrial revolution counties only



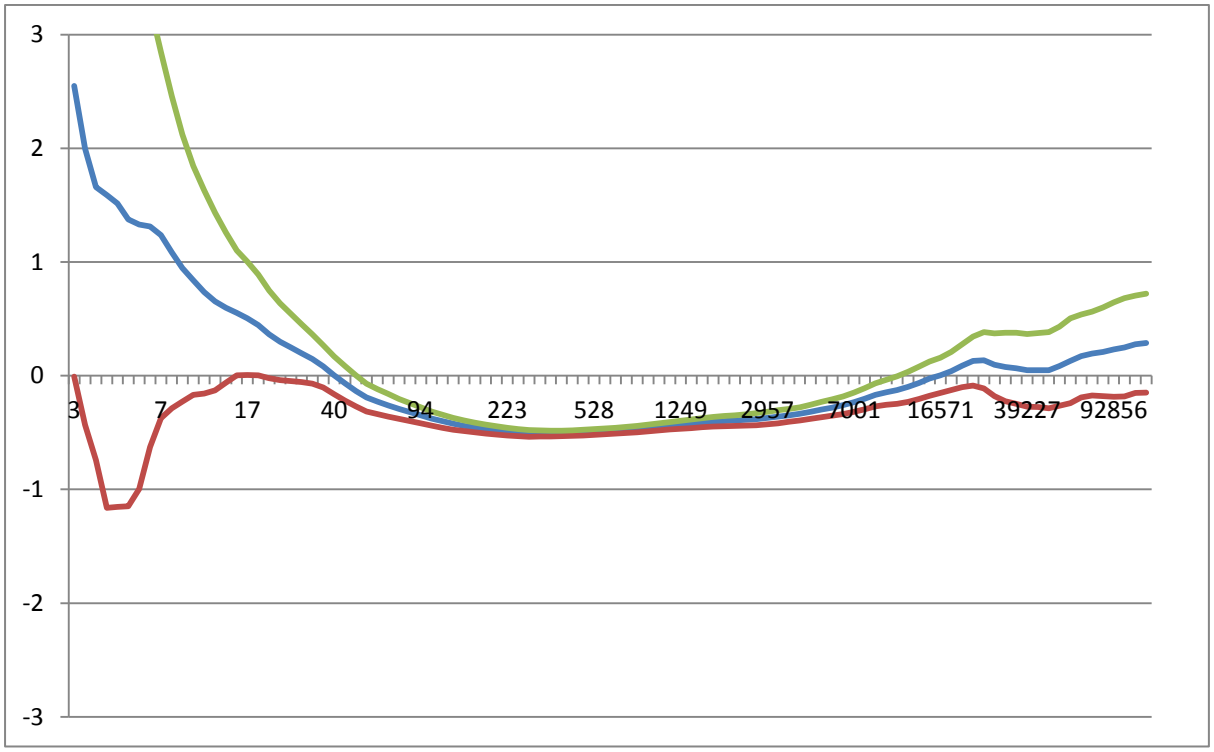
xxx) 1851-1861, England



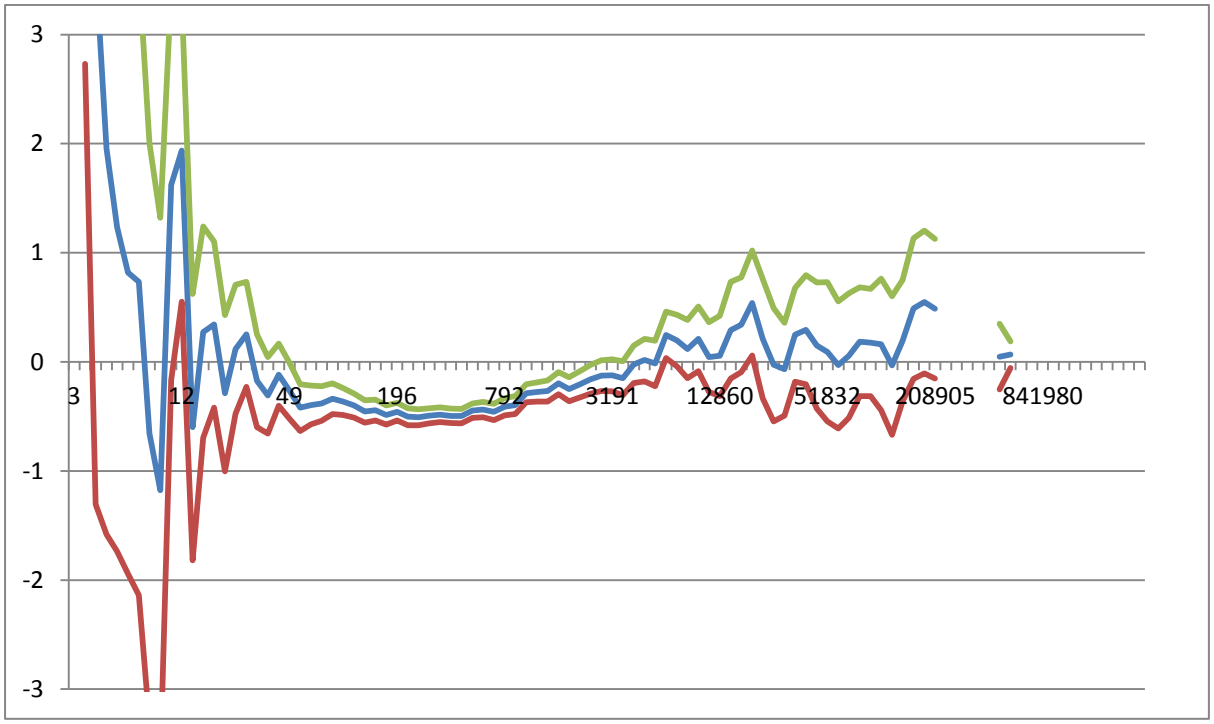
xxxi) 1851-1861, England: industrial revolution counties only



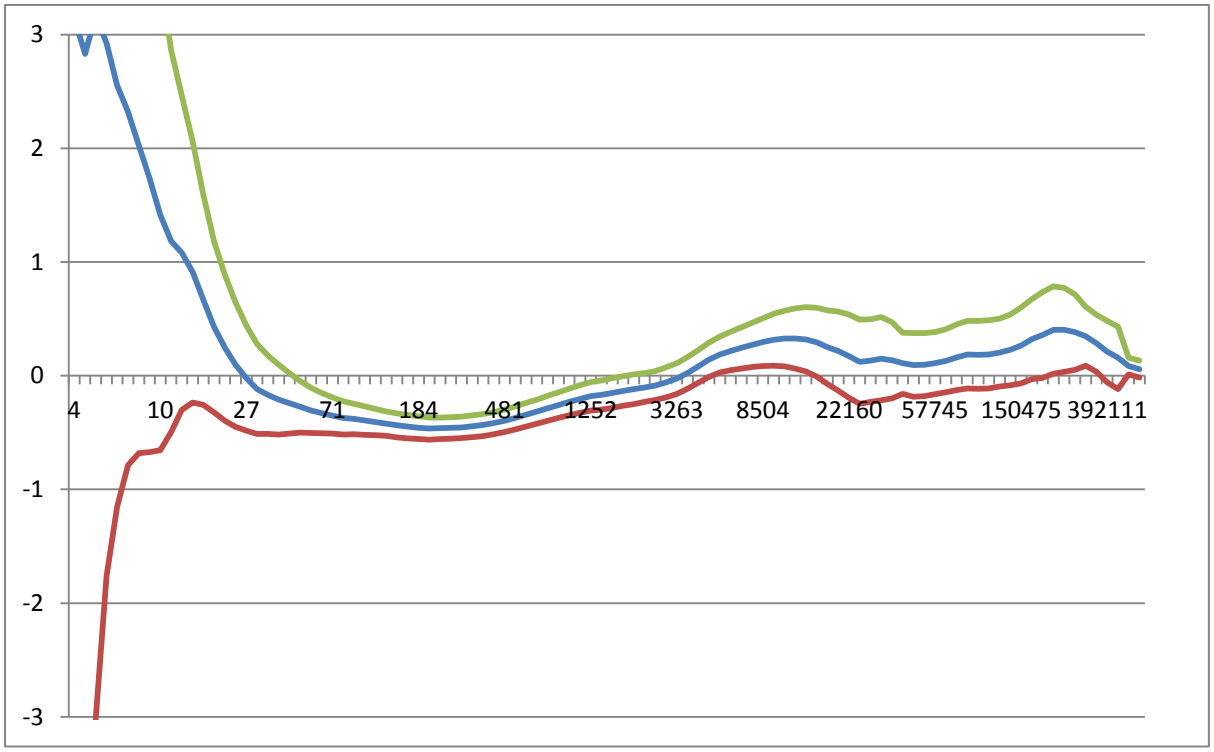
xxxii) 1851-1861, England: non- industrial revolution counties only



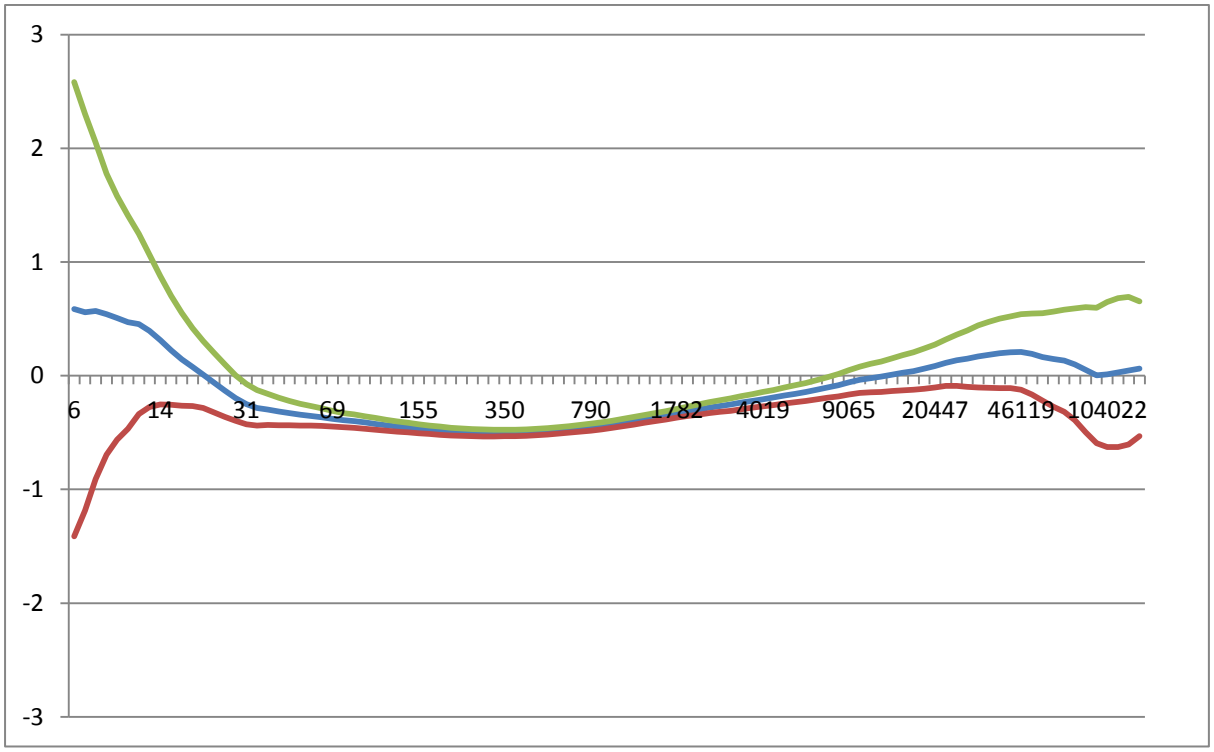
xxxiii) 1861-1871, England



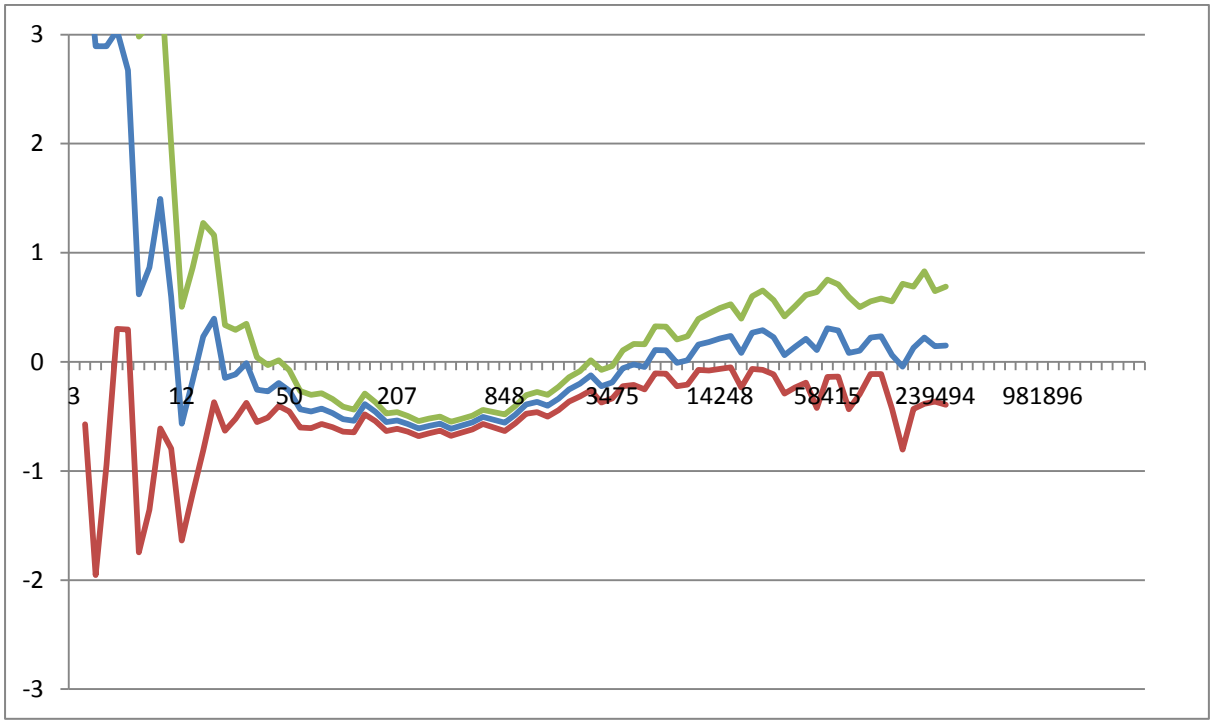
xxxiv) 1861-1871, England: industrial revolution counties only



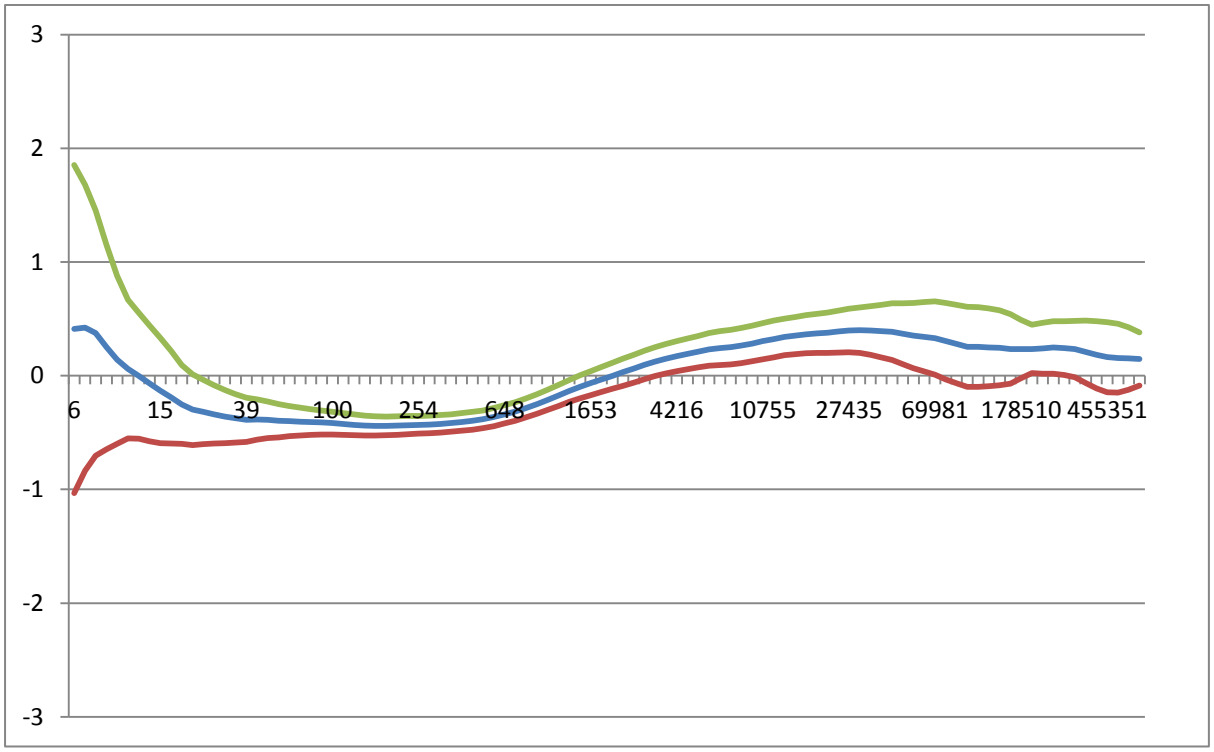
xxxv) 1861-1871, England: non- industrial revolution counties only



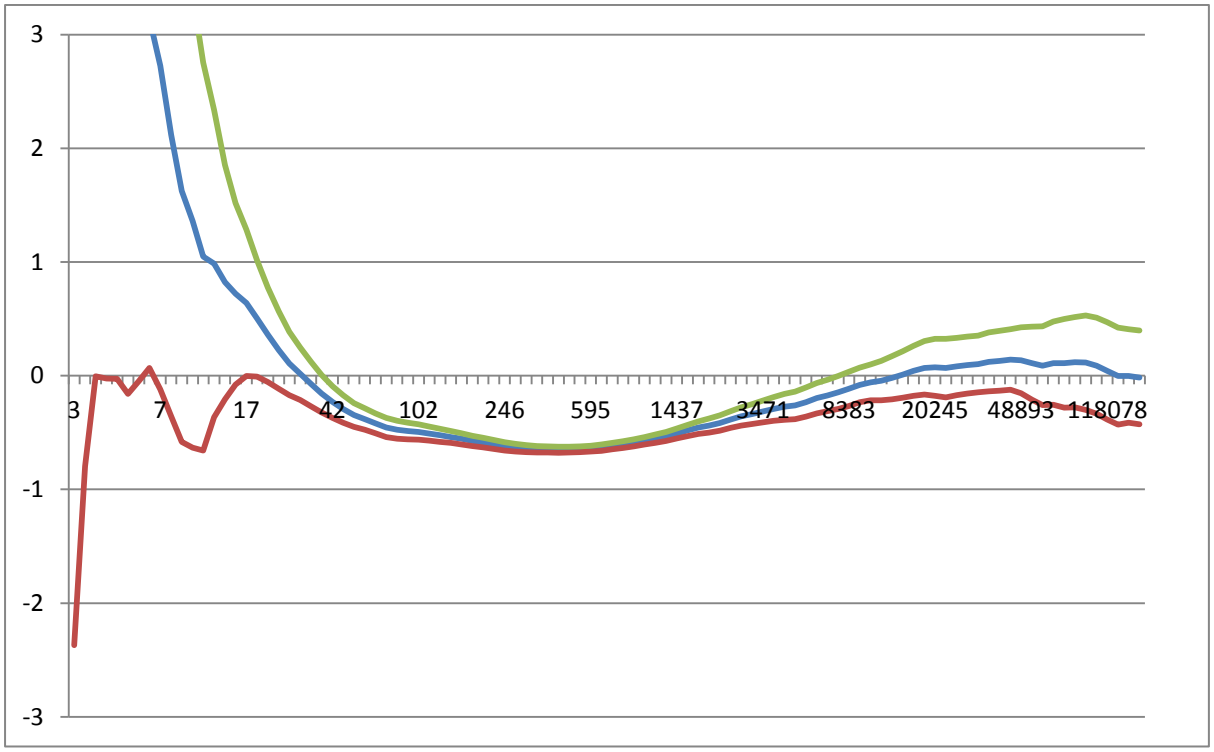
xxxvi) 1871-1881, England



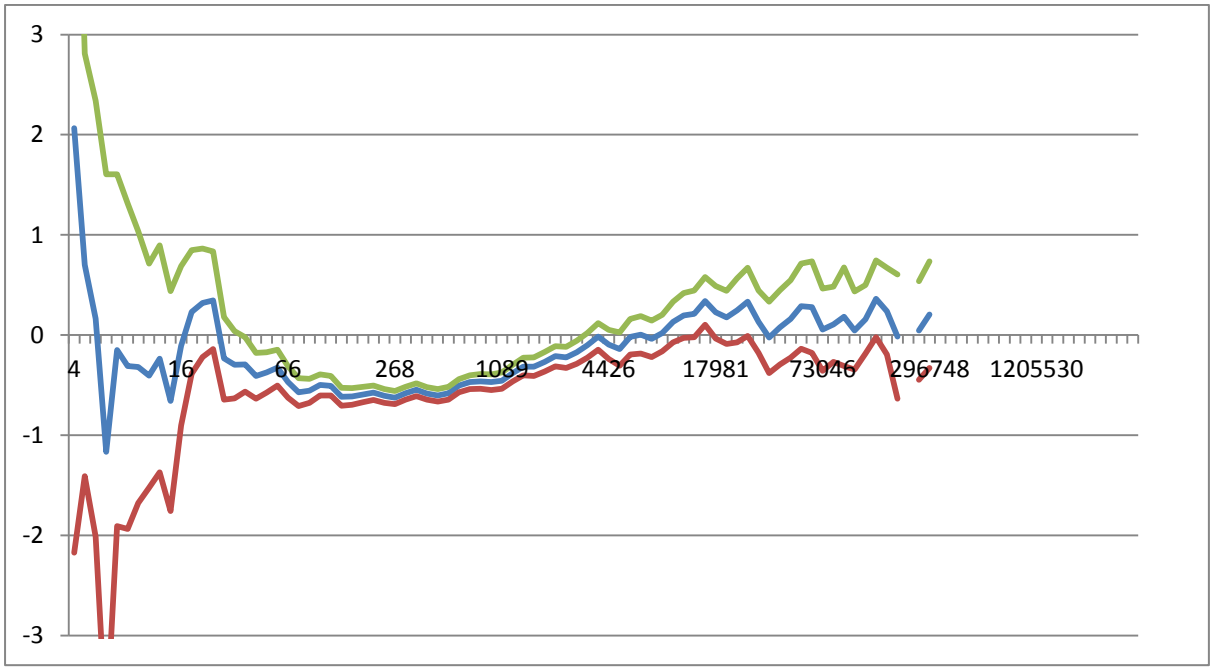
xxxvii) 1871-1881, England: industrial revolution counties only



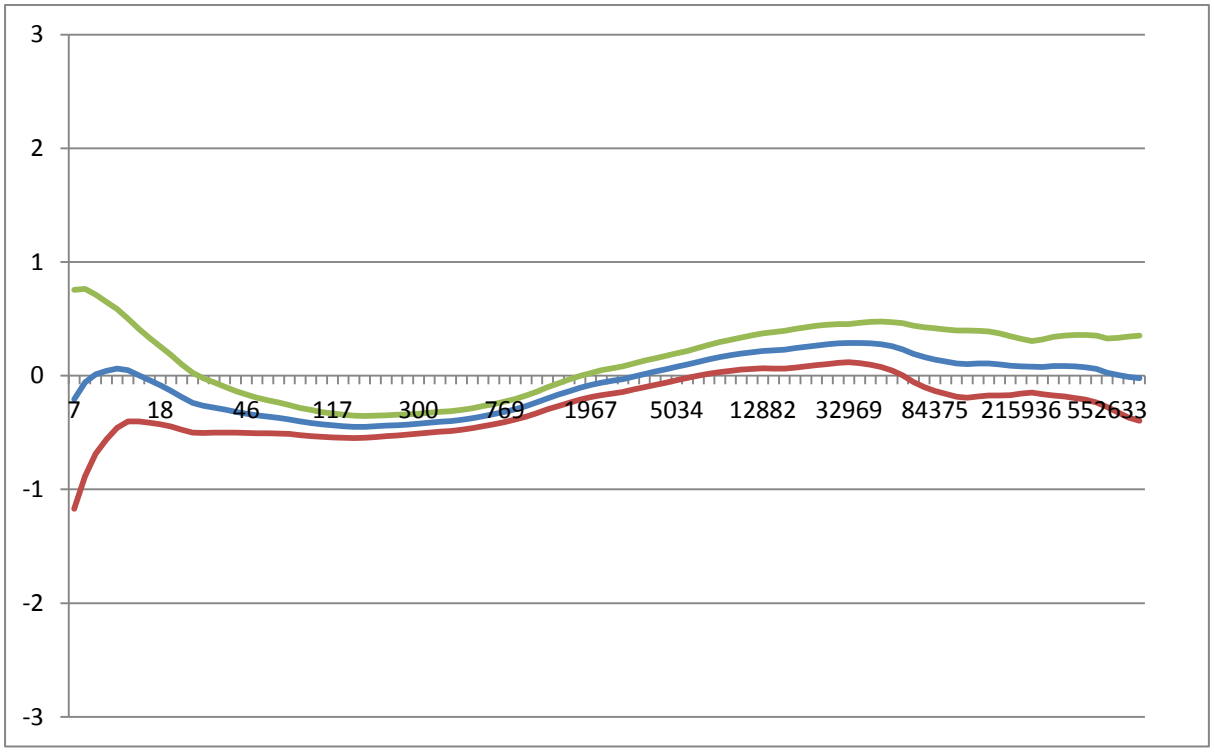
xxxviii) 1871-1881, England: non- industrial revolution counties only



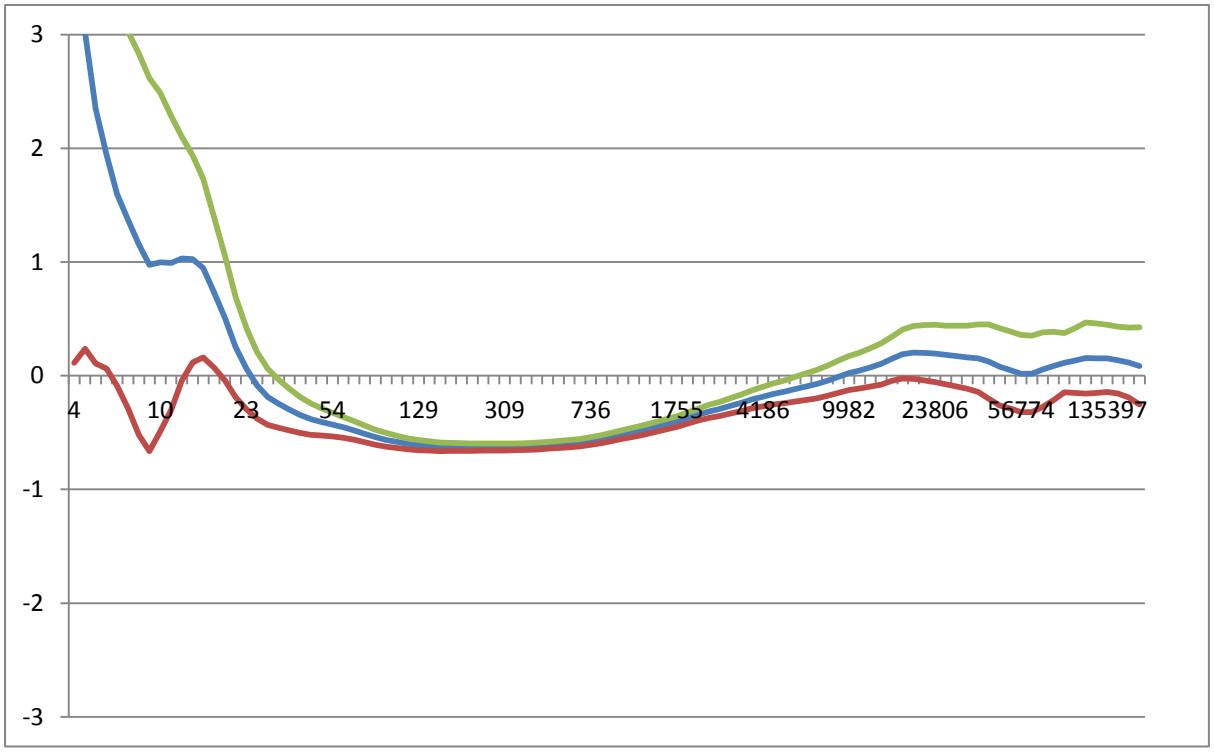
xxxix) 1881-1891, England



xl) 1881-1891, England: industrial revolution counties only



xli) 1881-1891, England: non- industrial revolution counties only



Stata code

Click here to download Supplementary Material: Stata_Code_Gibrats_Law.docx

```
*******************************All
places****************************************

quietly su wstandard_pers_ratio_1891_1801_L  , d

gen sadj1801 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1891_1801 = 1.06 * sadj1801 / (r(N)^0.2)

display $bw1891_1801

drop sadj1801

lpoly wstandard_pers_ratio_1891_1801_L ln_persons_1801_L, n(100) bwidth ($bw1891_1801)
nograph ci level(99) generate(grid_1891_1801 smoothvalues_1891_1801) se(se_1891_1801)



quietly su wstandard_pers_ratio_1841_1801_L  , d

gen sadj1801 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1841_1801 = 1.06 * sadj1801 / (r(N)^0.2)

display $bw1841_1801

drop sadj1801

lpoly wstandard_pers_ratio_1841_1801_L ln_persons_1801_L, n(100) bwidth ($bw1841_1801)
nograph ci level(99) generate(grid_1841_1801 smoothvalues_1841_1801) se(se_1841_1801)



quietly su wstandard_pers_ratio_1891_1841_L  , d

gen sadj1841 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1891_1841 = 1.06 * sadj1841 / (r(N)^0.2)

display $bw1891_1841

drop sadj1841

lpoly wstandard_pers_ratio_1891_1841_L ln_persons_1841_L, n(100) bwidth ($bw1891_1841)
nograph ci level(99) generate(grid_1891_1841 smoothvalues_1891_1841) se(se_1891_1841)
```

```
quietly su wstandard_pers_ratio_1811_1801_L  , d

gen sadj1801 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1801 = 1.06 * sadj1801 / (r(N)^0.2)

display $bw1801

drop sadj1801

lpoly wstandard_pers_ratio_1811_1801_L ln_persons_1801_L, n(100) bwidth ($bw1801) nograph ci level(99) generate(grid_1811_1801 smoothvalues_1811_1801) se(se_1811_1801)
```

```
quietly su wstandard_pers_ratio_1821_1811_L  , d

gen sadj1811 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1811 = 1.06 * sadj1811 / (r(N)^0.2)

display $bw1811

drop sadj1811

lpoly wstandard_pers_ratio_1821_1811_L ln_persons_1811_L, n(100) bwidth ($bw1811) nograph ci level(99) generate(grid_1821_1811 smoothvalues_1821_1811) se(se_1821_1811)
```

```
quietly su wstandard_pers_ratio_1831_1821_L  , d

gen sadj1821 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1821 = 1.06 * sadj1821 / (r(N)^0.2)

display $bw1821

drop sadj1821

lpoly wstandard_pers_ratio_1831_1821_L ln_persons_1821_L, n(100) bwidth ($bw1821) nograph ci level(99) generate(grid_1831_1821 smoothvalues_1831_1821) se(se_1831_1821)
```

```
quietly su wstandard_pers_ratio_1841_1831_L  , d

gen sadj1831 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1831 = 1.06 * sadj1831 / (r(N)^0.2)

display $bw1831

drop sadj1831

lpoly wstandard_pers_ratio_1841_1831_L ln_persons_1831_L, n(100) bwidth ($bw1831) nograph ci level(99) generate(grid_1841_1831 smoothvalues_1841_1831) se(se_1841_1831)



quietly su wstandard_pers_ratio_1851_1841_L  , d

gen sadj1841 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1841 = 1.06 * sadj1841 / (r(N)^0.2)

display $bw1841

drop sadj1841

lpoly wstandard_pers_ratio_1851_1841_L ln_persons_1841_L, n(100) bwidth ($bw1841) nograph ci level(99) generate(grid_1851_1841 smoothvalues_1851_1841) se(se_1851_1841)



quietly su wstandard_pers_ratio_1861_1851_L  , d

gen sadj1851 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1851 = 1.06 * sadj1851 / (r(N)^0.2)

display $bw1851

drop sadj1851

lpoly wstandard_pers_ratio_1861_1851_L ln_persons_1851_L, n(100) bwidth ($bw1851) nograph ci level(99) generate(grid_1861_1851 smoothvalues_1861_1851) se(se_1861_1851)



quietly su wstandard_pers_ratio_1871_1861_L  , d
```

```
gen sadj1861 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1861 = 1.06 * sadj1861 / (r(N)^0.2)

display $bw1861

drop sadj1861

lpoly wstandard_pers_ratio_1871_1861_L ln_persons_1861_L, n(100) bwidth ($bw1861) nograph ci level(99) generate(grid_1871_1861 smoothvalues_1871_1861) se(se_1871_1861)



quietly su wstandard_pers_ratio_1881_1871_L  , d

gen sadj1871 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1871 = 1.06 * sadj1871 / (r(N)^0.2)

display $bw1871

drop sadj1871

lpoly wstandard_pers_ratio_1881_1871_L ln_persons_1871_L, n(100) bwidth ($bw1871) nograph ci level(99) generate(grid_1881_1871 smoothvalues_1881_1871) se(se_1881_1871)



quietly su wstandard_pers_ratio_1891_1881_L  , d

gen sadj1881 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1881 = 1.06 * sadj1881 / (r(N)^0.2)

display $bw1881

drop sadj1881

lpoly wstandard_pers_ratio_1891_1881_L ln_persons_1881_L, n(100) bwidth ($bw1881) nograph ci level(99) generate(grid_1891_1881 smoothvalues_1891_1881) se(se_1891_1881)



**********IR places**********
```

```
quietly su wstandard_pers_ratio_1891_1801_L if RevolutIndustry_Percent_1801>=29.6 , d

gen sadj1801 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1891_1801IR = 1.06 * sadj1801 / (r(N)^0.2)

display $bw1891_1801IR

drop sadj1801

lpoly wstandard_pers_ratio_1891_1801_L ln_persons_1801_L if
RevolutIndustry_Percent_1801>=29.6, n(100) bwidth ($bw1891_1801IR) nograph ci level(99)
generate(grid_1891_1801IR smoothvalues_1891_1801IR) se(se_1891_1801IR)



quietly su wstandard_pers_ratio_1841_1801_L if RevolutIndustry_Percent_1801>=29.6 , d

gen sadj1801 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1841_1801 = 1.06 * sadj1801 / (r(N)^0.2)

display $bw1841_1801

drop sadj1801

lpoly wstandard_pers_ratio_1841_1801_L ln_persons_1801_L if
RevolutIndustry_Percent_1801>=29.6, n(100) bwidth ($bw1841_1801IR) nograph ci level(99)
generate(grid_1841_1801IR smoothvalues_1841_1801IR) se(se_1841_1801IR)



quietly su wstandard_pers_ratio_1891_1841_L if RevolutIndustry_Percent_1841>=29.6 , d

gen sadj1841 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1891_1841 = 1.06 * sadj1841 / (r(N)^0.2)

display $bw1891_1841

drop sadj1841

lpoly wstandard_pers_ratio_1891_1841_L ln_persons_1841_L if
RevolutIndustry_Percent_1841>=29.6, n(100) bwidth ($bw1891_1841IR) nograph ci level(99)
generate(grid_1891_1841IR smoothvalues_1891_1841IR) se(se_1891_1841IR)
```

```
quietly su wstandard_pers_ratio_1811_1801_L if RevolutIndustry_Percent_1801>=29.6 , d

gen sadj1801 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1801 = 1.06 * sadj1801 / (r(N)^0.2)

display $bw1801

drop sadj1801

lpoly wstandard_pers_ratio_1811_1801_L ln_persons_1801_L if
RevolutIndustry_Percent_1801>=29.6, n(100) bwidth ($bw1801IR) nograph ci level(99)
generate(grid_1811_1801IR smoothvalues_1811_1801IR) se(se_1811_1801IR)
```

```
quietly su wstandard_pers_ratio_1821_1811_L if RevolutIndustry_Percent_1811>=29.6 , d

gen sadj1811 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1811 = 1.06 * sadj1811 / (r(N)^0.2)

display $bw1811

drop sadj1811

lpoly wstandard_pers_ratio_1821_1811_L ln_persons_1811_L if
RevolutIndustry_Percent_1811>=29.6, n(100) bwidth ($bw1811IR) nograph ci level(99)
generate(grid_1821_1811IR smoothvalues_1821_1811IR) se(se_1821_1811IR)
```

```
quietly su wstandard_pers_ratio_1831_1821_L if RevolutIndustry_Percent_1821>=29.6 , d

gen sadj1821 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1821 = 1.06 * sadj1821 / (r(N)^0.2)

display $bw1821

drop sadj1821

lpoly wstandard_pers_ratio_1831_1821_L ln_persons_1821_L if
RevolutIndustry_Percent_1821>=29.6, n(100) bwidth ($bw1821IR) nograph ci level(99)
generate(grid_1831_1821IR smoothvalues_1831_1821IR) se(se_1831_1821IR)
```

```
quietly su wstandard_pers_ratio_1841_1831_L if RevolutIndustry_Percent_1831>=29.6 , d

gen sadj1831 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1831 = 1.06 * sadj1831 / (r(N)^0.2)

display $bw1831

drop sadj1831

lpoly wstandard_pers_ratio_1841_1831_L ln_persons_1831_L if
RevolutIndustry_Percent_1831>=29.6, n(100) bwidth ($bw1831IR) nograph ci level(99)
generate(grid_1841_1831IR smoothvalues_1841_1831IR) se(se_1841_1831IR)
```

```
quietly su wstandard_pers_ratio_1851_1841_L if RevolutIndustry_Percent_1841>=29.6 , d

gen sadj1841 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1841 = 1.06 * sadj1841 / (r(N)^0.2)

display $bw1841

drop sadj1841

lpoly wstandard_pers_ratio_1851_1841_L ln_persons_1841_L if
RevolutIndustry_Percent_1841>=29.6, n(100) bwidth ($bw1841IR) nograph ci level(99)
generate(grid_1851_1841IR smoothvalues_1851_1841IR) se(se_1851_1841IR)
```

```
quietly su wstandard_pers_ratio_1861_1851_L if RevolutIndustry_Percent_1851>=29.6 , d

gen sadj1851 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1851 = 1.06 * sadj1851 / (r(N)^0.2)

display $bw1851

drop sadj1851

lpoly wstandard_pers_ratio_1861_1851_L ln_persons_1851_L if
RevolutIndustry_Percent_1851>=29.6, n(100) bwidth ($bw1851IR) nograph ci level(99)
generate(grid_1861_1851IR smoothvalues_1861_1851IR) se(se_1861_1851IR)
```

```
quietly su wstandard_pers_ratio_1871_1861_L if RevolutIndustry_Percent_1861>=29.6 , d

gen sadj1861 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1861 = 1.06 * sadj1861 / (r(N)^0.2)

display $bw1861

drop sadj1861

lpoly wstandard_pers_ratio_1871_1861_L ln_persons_1861_L if
RevolutIndustry_Percent_1861>=29.6, n(100) bwidth ($bw1861IR) nograph ci level(99)
generate(grid_1871_1861IR smoothvalues_1871_1861IR) se(se_1871_1861IR)
```

```
quietly su wstandard_pers_ratio_1881_1871_L if RevolutIndustry_Percent_1871>=29.6 , d

gen sadj1871 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1871 = 1.06 * sadj1871 / (r(N)^0.2)

display $bw1871

drop sadj1871

lpoly wstandard_pers_ratio_1881_1871_L ln_persons_1871_L if
RevolutIndustry_Percent_1871>=29.6, n(100) bwidth ($bw1871IR) nograph ci level(99)
generate(grid_1881_1871IR smoothvalues_1881_1871IR) se(se_1881_1871IR)
```

```
quietly su wstandard_pers_ratio_1891_1881_L if RevolutIndustry_Percent_1881>=29.6 , d

gen sadj1881 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1881 = 1.06 * sadj1881 / (r(N)^0.2)

display $bw1881

drop sadj1881

lpoly wstandard_pers_ratio_1891_1881_L ln_persons_1881_L if
RevolutIndustry_Percent_1881>=29.6, n(100) bwidth ($bw1881IR) nograph ci level(99)
generate(grid_1891_1881IR smoothvalues_1891_1881IR) se(se_1891_1881IR)
```

**********NIR
places**********

quietly su wstandard_pers_ratio_1891_1801_L if RevolutIndustry_Percent_1801<14 , d

gen sadj1801 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1891_1801NIR = 1.06 * sadj1801 / (r(N)^0.2)

display $bw1891_1801NIR

drop sadj1801

lpoly wstandard_pers_ratio_1891_1801_L ln_persons_1801_L if RevolutIndustry_Percent_1801<14, n(100) bwidth ($bw1891_1801NIR) nograph ci level(99) generate(grid_1891_1801NIR smoothvalues_1891_1801NIR) se(se_1891_1801NIR)

quietly su wstandard_pers_ratio_1841_1801_L if RevolutIndustry_Percent_1801<14 , d

gen sadj1801 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1841_1801 = 1.06 * sadj1801 / (r(N)^0.2)

display $bw1841_1801

drop sadj1801

lpoly wstandard_pers_ratio_1841_1801_L ln_persons_1801_L if RevolutIndustry_Percent_1801<14, n(100) bwidth ($bw1841_1801NIR) nograph ci level(99) generate(grid_1841_1801NIR smoothvalues_1841_1801NIR) se(se_1841_1801NIR)

quietly su wstandard_pers_ratio_1891_1841_L if RevolutIndustry_Percent_1841<14 , d

```
gen sadj1841 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1891_1841 = 1.06 * sadj1841 / (r(N)^0.2)

display $bw1891_1841

drop sadj1841

lpoly wstandard_pers_ratio_1891_1841_L ln_persons_1841_L if RevolutIndustry_Percent_1841<14, n(100) bwidth ($bw1891_1841NIR) nograph ci level(99) generate(grid_1891_1841NIR smoothvalues_1891_1841NIR) se(se_1891_1841NIR)
```

```
quietly su wstandard_pers_ratio_1811_1801_L if RevolutIndustry_Percent_1801<14 , d

gen sadj1801 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1801 = 1.06 * sadj1801 / (r(N)^0.2)

display $bw1801

drop sadj1801

lpoly wstandard_pers_ratio_1811_1801_L ln_persons_1801_L if RevolutIndustry_Percent_1801<14, n(100) bwidth ($bw1801NIR) nograph ci level(99) generate(grid_1811_1801NIR smoothvalues_1811_1801NIR) se(se_1811_1801NIR)
```

```
quietly su wstandard_pers_ratio_1821_1811_L if RevolutIndustry_Percent_1811<14 , d

gen sadj1811 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1811 = 1.06 * sadj1811 / (r(N)^0.2)

display $bw1811

drop sadj1811

lpoly wstandard_pers_ratio_1821_1811_L ln_persons_1811_L if RevolutIndustry_Percent_1811<14, n(100) bwidth ($bw1811NIR) nograph ci level(99) generate(grid_1821_1811NIR smoothvalues_1821_1811NIR) se(se_1821_1811NIR)
```

```
quietly su wstandard_pers_ratio_1831_1821_L if RevolutIndustry_Percent_1821<14 , d

gen sadj1821 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1821 = 1.06 * sadj1821 / (r(N)^0.2)

display $bw1821

drop sadj1821

lpoly wstandard_pers_ratio_1831_1821_L ln_persons_1821_L if RevolutIndustry_Percent_1821<14,
n(100) bwidth ($bw1821NIR) nograph ci level(99) generate(grid_1831_1821NIR
smoothvalues_1831_1821NIR) se(se_1831_1821NIR)



quietly su wstandard_pers_ratio_1841_1831_L if RevolutIndustry_Percent_1831<14 , d

gen sadj1831 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1831 = 1.06 * sadj1831 / (r(N)^0.2)

display $bw1831

drop sadj1831

lpoly wstandard_pers_ratio_1841_1831_L ln_persons_1831_L if RevolutIndustry_Percent_1831<14,
n(100) bwidth ($bw1831NIR) nograph ci level(99) generate(grid_1841_1831NIR
smoothvalues_1841_1831NIR) se(se_1841_1831NIR)



quietly su wstandard_pers_ratio_1851_1841_L if RevolutIndustry_Percent_1841<14 , d

gen sadj1841 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1841 = 1.06 * sadj1841 / (r(N)^0.2)

display $bw1841

drop sadj1841

lpoly wstandard_pers_ratio_1851_1841_L ln_persons_1841_L if RevolutIndustry_Percent_1841<14,
n(100) bwidth ($bw1841NIR) nograph ci level(99) generate(grid_1851_1841NIR
smoothvalues_1851_1841NIR) se(se_1851_1841NIR)
```

```
quietly su wstandard_pers_ratio_1861_1851_L if RevolutIndustry_Percent_1851<14 , d

gen sadj1851 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1851 = 1.06 * sadj1851 / (r(N)^0.2)

display $bw1851

drop sadj1851

lpoly wstandard_pers_ratio_1861_1851_L ln_persons_1851_L if RevolutIndustry_Percent_1851<14,
n(100) bwidth ($bw1851NIR) nograph ci level(99) generate(grid_1861_1851NIR
smoothvalues_1861_1851NIR) se(se_1861_1851NIR)



quietly su wstandard_pers_ratio_1871_1861_L if RevolutIndustry_Percent_1861<14 , d

gen sadj1861 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1861 = 1.06 * sadj1861 / (r(N)^0.2)

display $bw1861

drop sadj1861

lpoly wstandard_pers_ratio_1871_1861_L ln_persons_1861_L if RevolutIndustry_Percent_1861<14,
n(100) bwidth ($bw1861NIR) nograph ci level(99) generate(grid_1871_1861NIR
smoothvalues_1871_1861NIR) se(se_1871_1861NIR)



quietly su wstandard_pers_ratio_1881_1871_L if RevolutIndustry_Percent_1871<14 , d

gen sadj1871 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1871 = 1.06 * sadj1871 / (r(N)^0.2)

display $bw1871

drop sadj1871

lpoly wstandard_pers_ratio_1881_1871_L ln_persons_1871_L if RevolutIndustry_Percent_1871<14,
n(100) bwidth ($bw1871NIR) nograph ci level(99) generate(grid_1881_1871NIR
smoothvalues_1881_1871NIR) se(se_1881_1871NIR)
```

```
quietly su wstandard_pers_ratio_1891_1881_L if RevolutIndustry_Percent_1881<14 , d

gen sadj1881 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1881 = 1.06 * sadj1881 / (r(N)^0.2)

display $bw1881

drop sadj1881

lpoly wstandard_pers_ratio_1891_1881_L ln_persons_1881_L if RevolutIndustry_Percent_1881<14, n(100) bwidth ($bw1881NIR) nograph ci level(99) generate(grid_1891_1881NIR smoothvalues_1891_1881NIR) se(se_1891_1881NIR)
```

```
quietly su wstandard_pers_ratio_1771_1761_L  , d

gen sadj1761 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1771_1761 = 1.06 * sadj1761 / (r(N)^0.2)

display $bw1771_1761

drop sadj1761

lpoly wstandard_pers_ratio_1771_1761_L ln_persons_1761_L, n(100) bwidth ($bw1771_1761)
nograph ci level(99) generate(grid_1771_1761 smoothvalues_1771_1761) se(se_1771_1761)



quietly su wstandard_pers_ratio_1781_1771_L  , d

gen sadj1771 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1781_1771 = 1.06 * sadj1771 / (r(N)^0.2)

display $bw1781_1771

drop sadj1771

lpoly wstandard_pers_ratio_1781_1771_L ln_persons_1771_L, n(100) bwidth ($bw1781_1771)
nograph ci level(99) generate(grid_1781_1771 smoothvalues_1781_1771) se(se_1781_1771)



quietly su wstandard_pers_ratio_1791_1781_L  , d

gen sadj1781 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1791_1781 = 1.06 * sadj1781 / (r(N)^0.2)

display $bw1791_1781

drop sadj1781

lpoly wstandard_pers_ratio_1791_1781_L ln_persons_1781_L, n(100) bwidth ($bw1791_1781)
nograph ci level(99) generate(grid_1791_1781 smoothvalues_1791_1781) se(se_1791_1781)
```

```
quietly su wstandard_pers_ratio_1801_1791_L  , d

gen sadj1791 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1801_1791 = 1.06 * sadj1791 / (r(N)^0.2)

display $bw1801_1791

drop sadj1791

lpoly wstandard_pers_ratio_1801_1791_L ln_persons_1791_L, n(100) bwidth ($bw1801_1791)
nograph ci level(99) generate(grid_1801_1791 smoothvalues_1801_1791) se(se_1801_1791)
```

```
quietly su wstandard_pers_ratio_1801_1761_L  , d

gen sadj1761 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1801_1761 = 1.06 * sadj1761 / (r(N)^0.2)

display $bw1801_1761

drop sadj1761

lpoly wstandard_pers_ratio_1801_1761_L ln_persons_1761_L, n(100) bwidth ($bw1801_1761)
nograph ci level(99) generate(grid_1801_1761 smoothvalues_1801_1761) se(se_1801_1761)
```

```
quietly su wstandard_pers_ratio_1771_1761_L  , d

gen sadj1761 = min(r(sd), ((r(p75)-r(p25))/1.349))

global bw1771_1761 = 1.06 * sadj1761 / (r(N)^0.2)

display $bw1771_1761

drop sadj1761

lpoly wstandard_pers_ratio_1771_1761_L ln_persons_1761_L, n(100) bwidth ($bw1771_1761)
nograph ci level(95) generate(grid_1771_1761vs2 smoothvalues_1771_1761vs2)
se(se_1771_1761vs2)
```

***Population data by place. (Not zipped, small file)**

Click here to download Replication Data (.ZIP): raw data.xlsx