Revolutionary change and structural breaks: A time series analysis of wages and commodity prices in Britain 1264-1913

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4. January 2011

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Abstract

In this paper we empirically test the hypothesis that economic revolutions are associated with structural breaks in historical economic data. A simple test for structural breaks in economic time series is applied to British wage and price data from the medieval to the modern period. Evidence for structural change is found in nearly half of the series studied – suggesting that structural breaks are an intrinsic feature of such historic data. Structural changes are most closely linked to the Commercial Revolution followed by the Agricultural Revolution and the Industrial Revolution, with changes linked to an underlying process of price stabilisation as measured by a decrease in the long-term level of volatility.

Keywords: historical economics, economic revolutions, structural breaks, price stabilisation.

1 Introduction

This paper seeks to establish whether changes in the UK economy over the period 1264-1913 reflected a revolutionary or evolutionary process. Historians have taken different

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views on this subject, depending on the period they study. Medieval historians tend to emphasise the evolutionary or incremental nature of change, and some even suggest that this process of evolution carried on right up to the industrial developments of the Victorians (Munro, 2003; Jones, 1988). Early modern and modern historians tend to adopt a revolutionary approach. However they often vary in the revolutionary events to which they attach importance, for example the Glorious Revolution or the Industrial Revolution, and largely view each revolution as an isolated event unconnected to previous or subsequent revolutions (Hartwell, 1967, 1971). Furthermore, they do not always agree on the exact dates of revolutions (Crafts and Harley, 2000).

Here, we take the view that a revolution should have a measurable impact as otherwise a revolution may simply represent a redundant concept. A revolution may be well-documented in primary and secondary sources but if its changes were restricted to a small group of people or a limited geographical area then it may actually have contributed little to the level of change overall. Furthermore, a revolution may only result in social and/or political changes, rather than economic changes, in which case it cannot be classified as an economic revolution. A genuine economic revolution should lead to structural breaks in relevant economic variables.

This paper presents an exploratory study that seeks to resolve some of the differences of opinion mentioned above through an analysis of long-run wage and price data. We seek to contribute to the evolution/revolution debate by examining wage and price series for change points in the drift and volatility. Under the evolutionary view there is continuous incremental change and emphasis is placed on the flexibility of institutions, traders and customers in adapting to changing circumstances, by responding to adversity and taking advantage of new opportunities. Under the evolutionary interpretation the parameters of the economic system remain stable. The underlying environment is volatile, but the economic system adapts and economic indicators, such as prices and wages, randomly fluctuate within the limits of normality. Under the revolutionary view of economic change there is intermittent radical change. The economic system is rigid and pressure for change builds up until there is a sudden radical upheaval. Under the revolutionary interpretation the parameters of the economy may change periodically – behaviour which may then be verified by observing structural breaks in economic indicators.

The paper also seeks to clarify which revolutions were the most significant and exactly when they occurred. Testing data for structural breaks is a relatively new concept, as it is only recently that the relevant statistical techniques and computing power have been available (Zeileis et al., 2003). This paper therefore conducts an exploratory study, combining new relatively recent applied statistical techniques with informed historical analysis and novel historical economic data on prices and wages. In so doing we provide a systematic explanation, not only of what economic changes occurred, but also why and how.

This paper focuses on the UK economy. Due to the availability of data we focus upon the period 1264-1913. The UK economy is chosen due to the availability of rich sources of historic data and because the UK has been widely studied with an extensive list of potential economic revolutions purported to have impacted upon the UK economy. These include

- Credit revolution (14th and 15th century)
- Commercial Revolution (later 16th and 17th centuries)
- Glorious Revolution (1689 onwards)
- Agricultural Revolution (18th century)
- Industrial Revolution (18th and 19th centuries)
- Railway Revolution (19th century).

The extent to which these events altered the course of economic development in the UK remains unresolved. Some writers on the Industrial Revolution, for example, regard it as the most significant revolution of the last millennium (Berg and Hudson, 1992). They argue that it led to a self-sustaining increase in the pace of technological progress, driven by the profitability of commercialising science in a systematic way. Others, however, do not attach such fundamental importance to the Industrial Revolution and instead argue that the preceding commercial and agricultural revolutions were essential pre-requisites for the Industrial Revolution (O'Brien, 2010). This paper tests which of these views best explains economic development in the UK by exploiting the fact that they have different implications for structural breaks in economic time series.

One of the problems of testing for revolutions is that the dates involved are often unclear. Thus the Industrial Revolution is often dated to 1760-1850, but some writers detect its origins even earlier. Others argue that in its early years the Revolution was largely confined to the textile industry and the North of England and so its impact on the rest of the country was relatively small until 1790. Enthusiastic advocates of the Industrial Revolution argue that it did not end in 1850 but has in fact continued to the present day. Others suggest that the Industrial Revolution ended with the Railway Revolution, which allowed for faster transport and communication and an enhanced distribution of domestic and international products, especially perishable foodstuffs.

A similar dating problem applies to the Glorious Revolution which is usually dated to a single year - 1689 - when King James II was overthrown and William of Orange ascended to the throne. However some of the alleged effects of the Glorious Revolution may have been due to earlier events, such as the Restoration. Furthermore, many of the events associated with the Glorious Revolution occurred after 1689, such as the creation of the Bank of England in order to fund The Treaty of Ryswick of 1697 (Morrill, 2004).

There are other revolutions where the dating is less precise. The Credit Revolution of the fourteenth and fifteenth centuries and the Commercial Revolution of the later sixteenth and seventeenth centuries are such examples. The Credit Revolution has been dated to the reigns of Edward II and Edward III but also to c. 1450 when new business techniques and trading companies developed amongst merchants (Bell, Brooks and Moore, 2009; Wiesner-Hanks, 2006). The Commercial Revolution, meanwhile, may be identified in an English context with the victory over the Spanish Armarda, the formation of the East India Company or a change in monarchy. The Commercial Revolution may be merged with the Price Revolution caused by Spanish silver and gold discoveries. It is possible too that the Commercial Revolution may also encapsulate other revolutions, such as a Mining Revolution. In testing for revolutions *both* the number of revolutions and their precise timings may be uncertain.

Imprecision in dating revolutions suggests that in testing for structural breaks it may be better to "let the data speak" by allowing the data to decide where structural breaks occur. Instead of specifying where breaks could have occurred, it is more scientific to test for breaks without making these prior assumptions. This is the approach taken in this paper, which searches for breaks using a specially developed algorithm (Zeileis et al., 2003) rather than testing for breaks using dummy variables, the conventional econometric approach of such a historical event study, which would presuppose that the dates of the revolutions are known exactly. Dating revolutions is often difficult to do using conventional historical methods and so the statistical techniques employed in this paper are appropriate to the broader aims of our study.

The layout of this paper is as follows. Section 2 describes the data and the sources used. Section 3 summarises our methodological approach and the model used. Section 4 gives the empirical results of our tests for structural breaks. Section 5 concludes.

2 Data and sources

The paper will test for structural breaks in Allen's data on the real wages of craftsmen and building labourers for the period 1264-1931 and Clark's data on English prices and wages for 1209-1914 (Allen, (accessed 2010); Clark, (accessed 2010)). This data was selected because it provides a relatively continuous run of data across a number of centuries and locations. We are thus able to undertake a comparative study into the impact of a wide range of economic and political events and the relative importance of national and local developments.

Other long-run wage and price series that are available for England are those in *The Agrarian History of England and Wales* and those derived by Thorold Rogers and Beveridge, Phelps Brown and Hopkins (Farmer, 1988; Farmer, 1991; Thirsk, 1967; Thirsk, 1992; Mingay, 1989; Collins, 2000; Whetham, 1978; Rogers, 1866-1892; Phelps Brown and Hopkins, 1955; Phelps Brown and Hopkins, 1956; Phelps Brown and Hopkins, 1981). These were not used because they are already incorporated into the Allen and Clark data. Allen's data offers improvements and expansions on the Phelps Brown and Hopkins indices (Allen, 2001). Clark's data synthesises data from *The Agrarian History of England and Wales*, from published work by Thorold Rogers and Beveridge and unpublished Beveridge and Farmer papers (Clark, 2004). Furthermore, whilst *The Agrarian History of England and Wales* provides a continuous run of national data on agricultural and building wages for each year in the period 1165-1500, there are simply too many gaps in the early modern and modern periods for us to use this data here.

The prices relate to basic commodities and are based on the records of individual buyers and sellers (e.g. university colleges and large estates) or of specific markets and towns (notably London). Wages for craftsmen and labourers are provided by Allen while Clark's data provides wages for craftsmen, farm labourers and building labourers. All prices and wages are measured annually. Allen provides data relating to nominal and real wages and a consumer price index. Clark provides only nominal price data and nominal data on wages and no real price or wage data. We therefore calculated real values for the Clark data by dividing it by Allen's composite price index. Hence, we follow standard econometric practice by correcting nominal prices for fluctuations in the time value of money, such as those associated with changes in the money supply, inflation etc. There are some limitations to using Allen's and Clark's data. Firstly, in Allen's data not all the towns have full spans of data from the medieval through to the modern period. Furthermore, while the London and Oxford data are both available for the full period and start at the same time, data on other towns starts later. In Clark's data commodity prices start at different times and not all cover the full span of 1209-1914. Furthermore, Allen's data covers several individual cities from across Europe while Clark's data relates only to England.

To obtain data that covered as wide a period as possible, but also allowed for accurate geographical comparisons, we focused on Allen's English data from Oxford and London. These towns had the longest runs of data and could be compared with Clark's English data. From Clark's data we used only the sets that covered a wide range from the medieval to the modern period, corresponding as closely as possible to the date span of Allen's data. The sets we used, and the corresponding dates, are listed in Tables 1-2.

Bias in the collection of the data also needs to be taken into account. This can occur because of the sources used and due to weighting and missing observations. Both Clark and Allen's data faces a potential bias because both use the accounts of institutions as sources, and such accounts may not reflect the prices paid by ordinary consumers (Allen, 2001). This bias, however, also applies to the data collected by Thorold Rogers, Beveridge and the authors of the Agrarian History of England and Wales. The second bias arises from how the authors calculated the weighting of the shares of different commodities. In long-run series covering wide geographical areas the composition of the shares of different commodities, and of the workforce, may differ over time and between region. Clark deals with this in his calculation of the price of the net output of products by weighting the shares of different commodities and calculates a national wage using weighted averages of the estimated wage in each region, weighing by the numbers of male agricultural workers in each region (Clark, 2001; Clark, 2004). Allen, meanwhile, varied the composition of his consumer price index for different countries, for example in Italy by substituting wine and olive oil for bread and butter (Allen, 2001). Clark provided the number of observations that he used in his calculations whereas Allen interpolated gaps in the series and, in instances where series were missing, used prices from neighbouring cities or interpolated them from the series available. The data from Allen and Clark contains several missing values. The advantage of our methodological approach in Section 4 is that under the assumption of independence in equation (1) we can account for missing data. However, our model is unable to account for random measurement error.

Allen and Clark did not test their datasets for structural breaks. However both of them have used their individual data sets to examine issues related to the timing and impact of the Industrial Revolution. Clark used his data to examine how much of Britain's rise to world dominance by 1850 can be explained by the Industrial Revolution (Clark, 2007). He places more emphasis on the population boom that accompanied the Industrial Revolution than on its technological developments. Allen examined the same question and attributed Britain's dominance to a sharp rise in living standards between 1870 and 1913. Allen also investigated the discrepancies in the evidence relating to the 'consumer revolution' of the seventeenth and eighteenth centuries and considered the extent to which body size was related to real income (Allen, 2001).

Previous work on long-run price and wage dynamics in England has often focused on studying the impact of events considered to be revolutions (Clark, accessed 2010). Alternatively, evidence from long-run wage and price series has been used to suggest 'remedies' for contemporary situations (Thorold Rogers, 1917). Thorold Rogers, for example, includes a chapter outlining proposed remedies for contemporary problems at the end of his work on Six Centuries of Work and Wages in which he refers to 'the evidence of the present and the example of the past (Thorold Rogers, 1917).

Work that has been conducted on long-run wage in other countries has often examined the effects of aggregation of wage data and the effects of storage on commodity prices. Rossana and Seater (1992) studied the effects of aggregation on seasonally unadjusted monthly nominal wage data from the U.S. Bureau of Labor Statistics, employment and earnings tape which they converted into real wages by dividing by the consumer price series. They found that using aggregated data artificially simplified the patterns that occurred in the data. Deaton and Laroque (1992) developed a theory based on competitive storage that explained the actual behaviour of commodity prices. They based their theory upon prices from the World Bank Commodity division for the period 1900-1987. Beck (2001) examined this theory by looking at the difference in price volatility between twenty storable and non-storable commodities. She used American data from the nineteenth and early twentieth century obtained from the 'Commodity Yearbook', the 'Fruit and Tree Nut Situation and Outlook' and the Vegetables and Specialities Situation and Outlook Report'. A slightly different approach to analysing commodity price series is that of Wang and Tomek (2007) who sought to examine whether commodity price series are stable in order to help with agricultural risk management and forecasting. They analysed monthly observations from Illinois on corn, soybeans, barrows and gilts[1] and milk for the period September 1975 to August 2005, and weekly observations for corn and soybeans from the same period.

3 Methodology

3.1 Hypotheses and interpretation

Before introducing tests for structural breaks we consider the observable features of an economic revolution that we would expect to see. We note that under a Markowitzian interpretation, drift represents the rate of return and volatility represents risk (Markowitz, 1959).

[1]A barrow is a young castrated male hog and a gilt is a female hog.

Under a Revolutionary interpretation, structural changes that occur are anticipated to be the fundamental result of human progress. As such, change points are hypothesised to represent landmarks pointing to technological or administrative advances which lead to increased profitability and efficiency. Such change points may be linked to, but not limited to, new business techniques and trading opportunities (Credit Revolution), enhanced overseas trade (Commercial Revolution), increased productivity (Agricultural Revolution) and scientific discoveries and their commercialisation (Industrial Revolution).

Increased Profitability would be represented by an increase in drift which is unaccompanied by an increase in volatility. The return increases but the level of risk remains the same.

Increased Efficiency/Productivity. Suppose that technological/administrative advancements lead to an increase in efficiency/productivity. These changes have the effect of smoothing fluctuations in the business cycle, leading to more stable prices and a decrease in volatility which is in turn unaccompanied by a decrease in drift. The level of risk decreases but the rate of return does not diminish.

In addition to our revolutionary interpretation, there a number of different ways in which structural breaks may occur. External shocks, such as wars, international trade disputes etc, may be anticipated to have a negative impact on economic development. The level of price risk increases but the rate of return does not rise to compensate. As such, we would expect these events to impact upon prices by causing an increase in volatility without increasing the drift. Alternatively, suppose systematic over-supply leads to a decline in prices. In this case one may see an associated decline in the drift or rate of return without an increase in price volatility.

3.2 The Model

In this section we lay out our statistical model for prices. This provides the very essence of our approach and allows us to generate appropriate hypotheses as outlined above. We use as our starting point the normal random walk model for prices. Under this model, and in the absence of change points, the first differences of log prices should constitute an independent and identically distributed sequence of normal random variables. This enables us to test for change points using tests originally conceived for standard regression models (Bai and Peron, 2003; Zeilis et al., 2003). We note that equation (1) below represents a standard regression model in which ΔX_t is regressed against a constant term. Further, under this approach the statistical analysis reduces to a tractable series of univariate tests. Both univariate and multivariate models have previously been used in the examination of structural breaks (Zeileis et al., 2003; Rossana and Seater, 1992). Here, the large number of parameters, missing data and further issues related to computation and model selection mean that a multivariate analysis is infeasible.

Let P_t denote the price of an asset at time t. Let $X_t = \log(P_t)$ and let $\Delta X_t = X_{t+1} - X_t$ be the series of log-returns. We write

$$\Delta X_t \sim N(\mu,\ \sigma^2). \tag{1}$$

In equation (1) μ is known as the drift and σ is known as the volatility. Under a Markowitzian interpretation means represent returns and variances/volatility represents risk (Markowitz, 1959). As μ increases the return increases. As σ increases the level of risk increases.

We test for structural change by testing for changes in the value of μ and σ. We test for change points in the drift by applying the method of (Bai and Perron, 2003) to test for multiple change points in the sequence of log returns. The appropriate number of change points is chosen automatically using the Bayesian Information Criterion (BIC) (Schwarz, 1978). Statistical uncertainty around point estimates of structural breaks is conducted by calculating 95% confidence intervals. Confidence intervals associated with the estimated change points are calculated using the method of (Bai, 1997). In those circumstances where confidence intervals for break points extend beyond the range of the sample, the estimated number of break-points is reduced by one and the model is then re-estimated from the beginning. Thus we avoid over-fitting and over-estimating the number of break points. Having tested for breaks in drift using the series in equation (1), we use the squared log-returns, ΔX_t^2 , as an empirical proxy for the unobserved volatility series and test for change points in volatility by applying the same method to the sequence of squared log-returns. Further details of the method used, and practical application of these and related tests for structural change can be found in (Zeileis et al., 2003).

Our general approach can be defined as follows. Consider for the sake of simplicity a model in which there is one change point and two different regimes. Under Regime 1

$$\Delta X_t \sim N\left(\mu_1, \sigma_1^2\right), \tag{2}$$

and under Regime 2

$$\Delta X_t \sim N\left(\mu_2, \sigma_2^2\right). \tag{3}$$

Increased profitability. Suppose a regime switch occurs and is associated with increased profitability as illustrated by an increase in the level of growth without an associated increase in the level of risk. It follows that if structural changes are associated with increased profitability that $\mu_2 > \mu_1$ and $\sigma_2^2 = \sigma_1^2$.

Price stabilisation. Suppose that a regime switch occurs and is associated with technological or administrative innovation which leads to price stabilisation. Under price stabilisation we have that

$$\mu_1 = \mu_2 \quad \text{and} \quad \sigma_2^2 < \sigma_1^2. \tag{4}$$

Response to a temporary shock. Suppose that prices undergo a temporary shock. Prices are destabilised before becoming more stable after the effects of the temporary shock subsides. This implies that we have three regimes, 1, 2 and 3 say, with $\mu_1 = \mu_2 = \mu_3$ and

$$\sigma_1^2 < \sigma_2^2 \quad \text{and} \quad \sigma_3^2 < \sigma_2^2. \tag{5}$$

Moreover, if the effect of the shock in prices is temporary we would anticipate that the price risk would eventually settle down to levels originally seen in Regime 1. This implies that

$$\sigma_1^2 = \sigma_3^2. \tag{6}$$

If we reject the hypothesis (6) in favour of the hypothesis

$$\sigma_1^2 > \sigma_3^2, \tag{7}$$

then, in a similar manner to the above, we conclude that the observed structural breaks are associated with long-term price stabilisation as measured by a long-term decrease in volatility. If we reject the hypothesis (6) it is also possible that

$$\sigma_1^2 < \sigma_3^2. \tag{8}$$

However, the economic interpretation of (8) is less clear and would be at odds with our revolutionary interpretation of structural change. We can test the hypotheses (6-8) using a variance ratio F-test (Snedecor and Cochrance, 1989, Chapter 6). If there are n_1 observations (log-returns) in Regime 1 and n_3 observations in Regime 3 we compute unbiased estimates of the population variance $\hat{\sigma}_1^2$ and $\hat{\sigma}_3^2$ and perform a two-sided F-test using

$$\frac{\hat{\sigma}_1^2}{\hat{\sigma}_3^2} \sim F_{n_1-1,n_3-1}. \tag{9}$$

4 Results

As shown in Table 1 structural breaks were found in ten of the twenty two series examined, suggesting that structural breaks are an intrinsic feature of these historical series. In twelve series shown in Table 2 no evidence of a structural break was found.

Table 1: English prices and wages – structural breaks found

Description	Series	Change points (Confidence Interval)
Decrease in volatility	London Labourer Wages (1301-1900)	1710 (1694-1824)
	Firewood 1270-1865	1569 (1568-1770)
	Hay 1373-1913	1595 (1594-1754)
	Iron (Manufactured) 1268-1869	1536 (1532-1622)
	Linencloth 1268-1866	1574 (1571-1866)
	Peas 1268-1902	1603 (1601-1676)
	Pepper 1369-1858	1664 (1662-1838)
	Straw 1403-1865	1565 (1555-1737)
	Suet 1265-1869	1598 (1560-1765)
Increase in volatility	London Craft Wages 1264-1913	1540 (1378-1565)
Decrease in volatility		1662 (1659-1742)

Table 2: English prices and wages – no structural breaks found

Barley 1268-1913
Bricks 1401-1865
Candles Tallow 1320-1869
Farm Wages 1268-1869
Housing 1290-1869
Nails 1271-1831
Oats 1268-1913
Oxford Craft Wages 1264-1913
Pewter 1395-1844
Salt 1264-1869
Wage Building Labourer 1274-1913
Wool 1264-1913

When structural breaks were found, in all cases they were found to be associated with change points in volatility rather than changes in drift. This reflects well-documented stylized empirical facts, see e.g. (Cont and Tankov, 2004, Chapter 5), in which dynamical behaviour in financial time series is typically dominated by fluctuations in volatility. In the first nine cases the break resulted in a decrease in volatility in line with our evolutionary interpretation in equation (4). In the case of London Craft Wages, volatility was seen to increase before later decreasing. For the London Craft Wages the F-test in equation (9) was performed giving an F-statistic of 1.687 and a p-value of 0.000 suggesting that $\sigma_1^2 > \sigma_3^2$, pointing to a reduction in long-term volatility and consistent with our hypothesis of revolutionary structural change. Structural changes consistent with this picture of long-term stabilisation of prices were found in the 16th-17th Centuries (Iron (Manufactured)), 16th-18th Centuries (Firewood, Hay, Suet, Straw), 16th-19th Centuries (Linencloth), 17th Century (Peas), 17th-18th Centuries (London Craft Wages) and 17th Centuries (London Labourer Wages, Pepper). These structural changes appear closest linked to Commercial Revolution (16th-17th Centuries), the Agricultural Revolution (18th Century) and the Industrial Revolution (18th-19th Centuries), see Table 3.

Table 3: Structural breaks and associated economic revolutions

Commercial Revolution 16-17th Century	Agricultural Revolution 18th Century	Industrial Revolution 19th Century
Iron (Manufactured)	Firewood	Firewood
Firewood	Hay	Hay
Hay	Suet	Suet
Suet	Straw	Straw
Straw	Linencloth	Linencloth
Linencloth	London Craft Wages	London Craft Wages
Peas		
London Craft Wages		
London Labourer Wages		
Pepper		

5 Conclusions

This paper has introduced a statistical methodology to test for structural breaks and related hypotheses in historical price series. Evidence for structural breaks was found in 10 out of the 22 series examined, suggesting that break points are a common feature of such historical price series. Breaks found are linked to change points in volatility rather than in drift and are seen to point to a long-term decrease in price volatility. This suggests that structural breaks are associated with technological and administrative innovation. This in turn leads to a process of price stabilisation, a reduction in the overall level of price risk, and a smoothing of business cycle fluctuations. The chronology of the estimated breaks indicates that changes are most closely linked to the Commercial Revolution followed by the Agricultural Revolution and the Industrial Revolution. This ties in closely with the interpretation of (O'Brien, 2006, 2010), for example, where the preceding commercial and agricultural revolutions are seen as essential pre-requisites for the Industrial Revolution.

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