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**Exuberance in British Share Prices
during the Railway Mania of the 1840s:
Evidence from the Phillips, Shi and Yu Test**

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Abstract

In this study, we empirically investigate evidence of explosive behaviour in the British share prices of canals, railways and waterworks in the nineteenth century using the right-tailed unit root test of Phillips, Shi and Yu (2015, PSY). Of particular interest to the Railway Mania in the 1840s, our results provide evidence of exuberance in share prices of railways during the most remarkable events in history. In addition, we find signs of exuberance in canals and waterworks share prices. Our findings will be of great interest to both economic historians and scholars who are interested in the rage of speculation in historical share prices during the Railway Mania.

Keywords

explosive behaviour
exuberance
generalized sup ADF test
railway mania

JEL Classifications

C12; N2

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1. Introduction

Bubble is one of the most beautiful concepts in economics and finance (Garber, 2001). Empirical studies mainly focus on some recent bubble episodes including Japan's Lost Decade in the 1980s, the 1990s NASDAQ bubble and the US house price bubble in the 2000s. For example, Japan had experienced the most severe episode of speculation in stock and real estate markets in history. The first myth in the Japanese market was that land prices could never go down, and the second myth was that stock prices could only go up (Malkiel, 2003). Moreover, the total value of all Japanese property was valued about \$20 trillion, which equated to over 20% of the world's wealth (Stone & Ziemba, 1993; Malkiel, 2003). Malkiel (2003) also indicates that the Japanese can buy all the property in America by selling of Tokyo area only. The 1990s NASDAQ bubble or Dotcom bubble is a very recent example of speculation in stock prices, see Ofek & Richardson (2003), Pástor & Veronesi (2006), Perez (2009) and Phillips, Wu & Yu (2011). Perhaps the most famous phrase -'irrational exuberance' introduced by Alan Greenspan in 1996 is used for describing the significant surge in the stock market of the 1990s. According to Shiller (2005), the famous Greenspan's speech in 1996 was given at the beginning of the most speculative growth in the US stock market history. The Dow Jones Industrial Average was 3600 at the beginning of 1994. It reached 10000 in March 1999 and peaked at 11722 in early 2000. The unusual rise and fall in the stock prices of technology stocks has led many academics and practitioners to describe such a phenomenon as a 'bubble'. Several prominent economists acknowledged that the US experienced a speculative bubble in the housing market during the 2000s. Baker (2002) claimed no obvious explanation for the rapid rise house prices and concluded the presence of a housing bubble in August 2002. In June 2005, Robert Shiller warned that "The market is in the throes of a bubble of unprecedented proportions that probably will end ugly"¹. He also argues that the house price could drop up to 50% in next decade. In August 2005, Paul Krugman pointed out the existence of a housing bubble in the coasts-areas due to a combination of high population density and land-use restrictions². During the Economic Club of New York in 2005, Alan Greenspan concluded that: "we don't perceive that there is a national bubble, but it's hard not to see that there are a lot of local bubbles". However, Ben Bernanke argued that "house price increases largely reflect strong economic fundamentals including robust growth in jobs and incomes, low mortgage rates, steady rates of household formation, and factors that limit the expansion of housing supply in some areas"³. A number of studies therefore investigate the US housing bubbles during the 2000s, for example, see Case & Shiller (2003), McCarthy & Peach (2004), Himmelberg et al. (2005) and Martin (2011).

¹Laing, Jonathan R, "The Bubbles New Home," Barron's, 20 June, 2005.

²Krugman, Paul, "That Hissing Sound," The New York Times, 8 August, 2005

³Bernanke, Ben S., "The Economic Outlook," Testimony before the Joint Economic Committee, 20 October, 2005.

However, few studies investigate the presence of historical bubbles. Examples of the well-documented historical bubbles include but not limited to the Tulipmania, the Mississippi Bubble and the South Sea Bubble. Among many historical episodes, the Tulipmania during 1634-7 in Holland is widely
35 believed to be the first bubble in the literature, see Garber (1990) and Shiller (2005). The flower's bulbs were traded for their wealth and even real estate. At the beginning of 1637, some tulip contracts reached a level about 20 times the level of three months earlier. A particularly rare tulip, *Semper Augustus*, was priced at around 1,000 guilders in the 1620s. It was valued at 5,500 guilders per bulb before the crash-roughly the cost of luxurious house in Amsterdam.⁴ However, in February 1637, these
40 tulips could not be sold at 10 percent of their peak values (Garber, 1990). The Mississippi Bubble during 1719-20 and the closely related South Sea Bubble in 1720 are the most influential episodes in stock markets. Both the Mississippi Company and South Sea Company involved the government debt-for-equity swap, which was regarded as a major financial innovation, see Frehen et al. (2013). The motivation of the Mississippi and the South Sea schemes was to refinance the national debts
45 accumulated during the War of the Spanish Succession, see Hamilton (1947) and Dickson (1967). In particular, Mississippi bubble is an economic bubble that resulted from John Law's 'system'. Law developed and adopted a 'system' to take over the French national debt using equity. Similar to the Mississippi episode, the South Sea Bubble involved a company (the South Sea Company) that acquired some outstanding British government debt in 1720. In 1720, the South Sea Company had monopoly
50 rights on British trade with the Spanish colonies of South America. The most important event during early 1720 was that Parliament passed the South Sea Bill on 21 of March. The South Sea Company won the competitive bidding against the Bank of England to obtain the privilege of converting the government debt. Both Mississippi and South Sea shares rose quickly to unsustainable heights with a sudden collapse in 1720. These three famous historical episodes have been discussed extensively in
55 the literature, see Neal (1990), Murphy (1997), Garber (2001) and Temin & Voth (2004).⁵

Apart from these prominent episodes, the British Railway Mania in the mid-1840s is one of the earliest and well-known examples of financial bubbles in history. The Economist simply describes such an episode as 'arguably the greatest bubble in history' based on the scale of investment as a proportion of national income (18 December 2008). The Railway Mania resulted in a boom of railway construction
60 and a financial panic. The boom of railway construction was reflected in the number of new Acts, the amount of capital and miles authorised by Parliament, see Porter (1851), Cleveland-Stevens (1915) and Simmons (1978). According to the Economist, Parliament approved 9,500 miles of new railway

⁴The Economist, "Economic history: Was tulipmania irrational?", 4 Oct, 2013

⁵A recent paper by Hu & Oxley (2017) provides evidence of explosive behaviour in share prices of the Mississippi Company and the South Sea Company during 1719-20 using the right-tailed unit root test of Phillips, Shi & Yu (2015).

lines between 1844 and 1847 (Britain's current railway mileage is about 11,000 miles). Jackman (1916, p.585) also indicated that during the 1844-6, Parliament sanctioned Bills for the construction of 8470
65 miles of railways, which was three times mileage than constructed. The mania is also accompanied by a speculative run-up and sudden collapse of railway shares. The railway speculation also comes along with a bull market in share prices. The railway shares soared to astounding heights during the early period. As described in Gayer et al. (1953), the railway share index was 112.7 at the beginning of 1844, and it continued its speculative climb to a peak of 167.9 in July 1845. The index fell to 128.5
70 and 105.3 at the end of 1846 and 1847. The share index was 73.5 in January 1850, which was less than half of peak value in July 1845. Chancellor (1999) also concluded that railway shares had fallen from their peak over 85% by 1850. However, the sudden bursting of share prices ruined many investors and led to difficulties for many railway companies.

The Economist concludes that 'technological revolutions and financial bubbles seem to go hand in
75 hand' (21 September 2000). Existing studies have attempted to examine potential linkages between bubble-like behaviour in stock prices and technological innovation. For example, Hall (2001) and Shiller (2005) argued that the arrival of new technology promoted the 1920s and 1990s stock market run-ups in the US. Several authors hold similar views, for example, see DeMarzo et al. (2007), Nicholas (2008) and Pástor & Veronesi (2009). DeMarzo et al. (2007) suggest that the bubble of the 1920s is mainly driven
80 by some new technology stocks (e.g., the automobile, aircraft, motion picture, and radio industries). Nicholas (2008) also argues that the development of technological innovation during the 1920s is a key driver of the US stock market run-up. Pástor & Veronesi (2009) point out that technological innovations are often associated with bubble-like behaviour in stock prices of those innovative firms. Stock prices for those innovative firms tend to rise initially due to high prospects, but prices fall due
85 to the risks associated with new technology changes. They explain that both high uncertainty and quick adoption during the revolution promote bubbles. Railways had the greatest impact of any single innovation in Britain in the nineteenth century (Hawke & Reed, 1969). It is believed that the Railway Mania is caused by the advance of new technology innovation, see Perez (2009). DeMarzo et al. (2007) conclude that overinvestment increases with the risk of the technology and their model can explain
90 why technological innovations may promote investment bubbles. Examples considered in DeMarzo et al. (2007) include the Mississippi Bubble, the South Sea Bubble, the Railway Mania and the stock market bubble of the 1920s, which are commonly regarded as the most dramatic events. It seems that the bubble-like behaviour in stock prices is associated with innovative firms adopting a new technology (DeMarzo et al., 2007; Pástor & Veronesi, 2009).

95 The main aim of this paper is to investigate explosive behaviour in three historical British stock price sub-indices for canals, railways and waterworks covering the period 1811-1850 by applying the

right-tailed unit root test of Phillips, Shi & Yu (2015, PSY). The PSY is used for assessing explosive behaviour in a price-fundamental ratio, and a finding of explosive behaviour in such a ratio can be interpreted as evidence of a ‘bubble’.⁶ In this paper, however, we interpret evidence of explosive
100 behaviour in the real stock price as exuberance and such an episode is interpreted as an ‘exuberant episode’ rather than a ‘bubble’ as we only consider the real stock index without taking into account its fundamental value. One of the major focus of this paper is to investigate the explosive behaviour in the share price of railways during the Railway Mania episode. Moreover, attention has also been paid to canals share prices as well due to its early competition with railways as a public transport
105 in the British history. This paper also investigates signs of exuberance in waterworks share prices. Overall, this paper considers several important share prices related to the most speculative episodes in stock markets during the nineteenth century and the corresponding results will be of great interest and importance.

Even if the British Railway Mania is commonly regarded as the greatest example of financial bub-
110 bles, little attention has been drawn on this prominent episode compared with other well-documented financial episodes in the literature. Empirical work on testing for the Railway Mania is even scarce. Campbell (2010) concludes that the British Railway Mania is not a bubble using a cross-sectional method. After controlling for fundamentals (e.g., dividends, growth and risks), railway stock prices were priced consistently with non-railway stock prices during 1843-50. Campbell & Turner (2010)
115 create a daily stock price index for the period 1843-1850 based on daily stock price data for the 442 railway companies, which is a key novelty in this paper despite previous work mainly rely on monthly index of Gayer et al. (1953). They acknowledge the bubble-like behaviour in their data. They also compare the stock prices, the risk, and the volatility of railway shares with other equity securities. However, their results do not seem to suggest that the bubble-like patterns in stock prices are caused
120 by the technological revolution hypothesis, which contributes to the on-going debate in the literature. Campbell & Turner (2012) also argue that inexperienced and naive investors resulted in the Railway Mania.

We also consider the sub-index of canals in our study as it could be a very representative and excellent example. Especially, the competition of railways and canals are of interest during the early
125 1800s. The canal boom in the early 1790s was a prelude to the great Railway Mania in the 1840s (Pratt, 1912). During the canal boom of 1791-4, Pratt (1912, p.183) concluded that no more than 81 Acts for canals were passed. Hadfield (1973, p.106), however, suggested that the number of canals authorized in the Acts during the canal mania of 1791-4 was 44. Hadfield (1973) also indicated that

⁶A common definition of an asset price bubble is that a deviation from its fundamental value, see Stiglitz (1990).

the number of canals Acts authorized during 1789-90 and 1795-7 were 3 and 8, respectively. Despite
130 the differences in the number of authorized Acts, Pratt (1912) and Hadfield (1973) acknowledge the
speculation of canals, which is reflected in the legislation. Baines (1852, p.488) also stated that the
canal fever of 1792 was not less intense than the railway fever of 1845. Every mania was associated with
the expansion of credit with no exception of canal mania in Great Britain, where the canal mania was
fed by loans from newly-established country banks to entrepreneurs who were developing the canals
135 (Kindleberger & O'Keefe, 2005).

This paper is organized as follows. Section 2 describes the data and Section 3 gives a brief descrip-
tion of the PSY of Phillips, Shi & Yu (2015). Section 4 presents the empirical results and Section 5
concludes.

2. Data

140 Gayer et al. (1953) create a monthly index of British share prices from as early as 1811 to 1850.
A total index of share prices is constructed in two forms: one including mine share prices, the other
excluding mine share prices. Before 1824, both the index inclusive of mines and the index exclusive of
mines are identical as the mine shares are not entered the index until 1824.⁷ There are eight sub-groups
considered in the total index including canals, docks, waterworks, insurance companies, gas-light and
145 coke companies, mines, railways and Banks. In this study, we obtain the sub-index of railways, canals
and waterworks share prices from Gayer et al. (1953). The index of canals and waterworks consist of
seven and five companies between February 1811 and December 1850, respectively. Railway index is
not introduced until 1827. The index of railways comprises fourteen companies between May 1827 and
December 1850.

150 We also obtain the annual British retail price index between 1811 and 1850. To deflate these share
prices into real values, we use the method of Dagum & Cholette (2006) to interpolate the annual retail
price index to a monthly series. A time series plot of the real share price index for railways, canals and
waterworks is provided in Figure 1. As can be seen in Figure 1, there is a rising trend of railway share
prices between 1827 and 1845, which can be attributed to the prospects of the new transportation by
investors (Gayer et al., 1953). Figure 1 also indicates a pronounced upward trend for the waterworks
155 share index after 1818 in contrast to the trend of the canals and railways share indexes. The canal
share index climbs to a peak in 1824 while the rail share index reaches its peak in 1835 and 1846. All
real share prices are transformed into log scale before analysis.

⁷Mine share prices reached its highest point in 1825. The heavy investment in mining companies shares during 1824-5
was speculative, see Gayer et al. (1953).

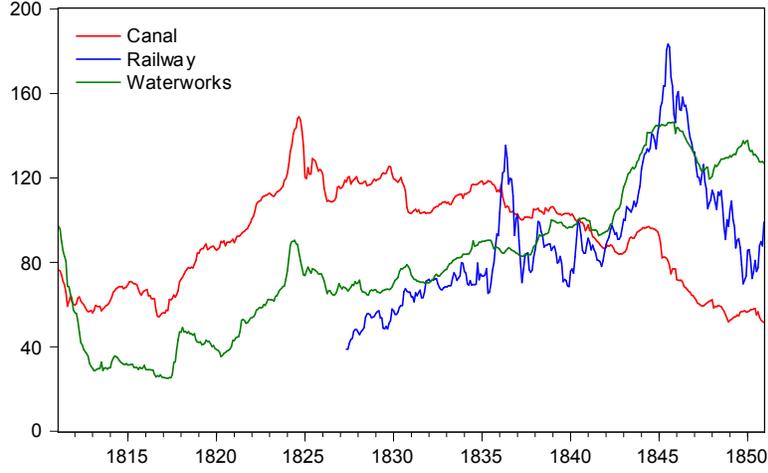


Figure 1: Real share prices for railways, canals and waterworks between 1811M02 and 1850M12 (June 1840=100).

3. Method

In Phillips, Shi & Yu (2015), the martingale null with an asymptotically drift is specified as:

$$H_0 : y_t = dT^{-\eta} + y_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim \text{NID}(0, \sigma^2), \quad (1)$$

where d is a constant, T is the sample size and η is a localizing coefficient. The alternative hypothesis is a mildly explosive process:

$$H_1 : y_t = \delta_T y_{t-1} + \varepsilon_t, \quad (2)$$

160 where $\delta_t = 1 + cT^{-\theta}$ with $c > 0$ and $\theta \in (0, 1)$.

The following regression model for y_t is estimated:

$$\Delta y_t = \alpha + \beta y_{t-1} + \sum_{i=1}^K \gamma_i \Delta y_{t-i} + \varepsilon_t, \quad (3)$$

where α is an intercept. The GSADF test relies on repeated estimation of the ADF test resissions of Equation (3) on subsamples of the data in a recursive fashion. The window size r_w expands from r_0 to 1, where r_0 is the minimum window size. The ending point r_2 varies from r_0 to 1 and the starting point r_1 varies from 0 to $r_2 - r_0$. The GSADF statistic is the largest ADF statistic over range of r_1 and r_2 . The GSADF statistic is defined as:

$$GSADF(r_0) = \sup_{\substack{r_2 \in [r_0, 1] \\ r_1 \in [0, r_2 - r_0]}} ADF_{r_1}^{r_2}$$

However, the GSADF test does not provide the origination and termination dates of bubble episodes.

The backward SADF statistic is defined as the sup value of the ADF statistic sequence:

$$BSADF_{r_2}(r_0) = \sup_{r_1 \in [0, r_2 - r_0]} ADF_{r_1}^{r_2}$$

The BSADF statistic and its corresponding critical value are used for dating the origination and termination dates of multiple bubbles. The minimum window size r_0 is equal to $0.01 + 1.8/\sqrt{T}$. A fixed lag order of 0 is also selected. The finite sample critical values are obtained from Monte Carlo
165 simulations with 2,000 replications.

Phillips et al. (2014) consider different regression model formulations for right-tailed unit root tests and suggest to include an intercept term in the regression in assessing explosive behaviour. In this study, we use two different model specifications for the regression model (a model without an intercept and a model with an intercept to explore the evidence of explosive behavior and compare
170 the results obtained from both formulations. We will demonstrate and compare the results using the aforementioned model specifications⁸.

4. Results

We present empirical bubble detection results for railways, canals and waterworks based on two model specifications using the PSY test in Sections 4.1, 4.2 and 4.3, respectively.

175 4.1. Railways share price index

Our date-stamping outcomes for real railway share prices are presented in Figure 2. Under the assumption with an intercept, the null hypothesis of no explosive behaviour in the railway share index is rejected at the 5% level ($2.1462 > 2.1445$). As shown in Figure 2a, we can identify two exuberant episodes, where the first episode is between 1836M02 and 1836M07 and the second episode is from
180 1843M12 to 1845M10. These two exuberant episodes coincide very well with the development of innovation in the British railway industry during the nineteenth century. The first exuberant episode in 1836 corresponds to the railway boom in 1836 and the second exuberant episode can be referred to the great Railway Mania in the mid-1840s. Hence we may interpret such findings as evidence of exuberance in railways share index.

185 We present our date-stamping outcomes under the assumption without the intercept in the regression model as well. The null hypothesis of no explosive behaviour in the real railway share index is

⁸Chong & Hurn (2016) show that the regression model specification without an intercept is preferable.

rejected at the 1% level, where the test statistic is greater than the critical value ($4.4648 > 4.1968$), indicating strong evidence of exuberance in the index of railways. As presented in Figure 2b, we spot two exuberant episodes: 1835M09-1836M11 and 1843M12-1846M10. Although there are some differences in the origination and collapse dates of exuberant episodes under two model specifications, the date-stamping outcomes identified in Figure 2b are similar with those of Figure 2a. However, we notice a spurious episode between 1830M01 and 1834M03 in Figure 2b. It seems that under the assumption without the intercept in the regression model, the PSY approach could identify a spurious episode if the share price exhibits an increasing trend, which could be a pitfall of the PSY. Therefore it is necessary and important to plot the actual data series to allow us to avoid identifying a ‘spurious’ episode.

Under both models, we find evidence of exuberance in 1836 for railway shares, which indicates a period of speculative boom in railways. Considerable interest in railway investment is stimulated by the successful launching of the Liverpool & Manchester and other steam railways (Lewin, 1914). The Liverpool & Manchester was the first railway to be built, and it opened on 15 September 1830, making the year 1830 as one of the outstanding years in history. The earned income enabled the Liverpool & Manchester to pay dividends of 10% (Porter, 1851). The financial success of the Liverpool & Manchester not only reacted to the prices of railway shares but also attracted promoters with new projects (Gayer et al., 1953).

As a result of the boom in 1836, there were 2000 miles of railway in operation by 1842 compared with only 200 miles in operation in 1833. However, Matthews (1954) argued that the railway mania of 1836 was a promotion boom, not a construction boom as the railway investment reached the peak in 1839/1840 rather than 1836 (see, Mitchell (1964), Kenwood (1965) and Hawke & Reed (1969)). The development during the first phase of the railway enthusiasm in the early 1830s was not a bubble but the railway boom during the second phase from later 1835 was a mania/bubble (Matthews, 1954; Kindleberger & O’Keefe, 2005). Confidence engendered by the prosperous state of trade and the relatively easy conditions in the market seemed to contribute to the share speculation in the mid-1830s (Matthews, 1954; Kenwood, 1965).

Gayer et al. (1953) argued that the formation of various railways led to the boom in the share market in 1835-6, where the index of railway shares was more than doubled between May 1835 and May 1836, rising from 60.2 to 129.4. In his book, the amount authorised by Parliament in 1836 for railway construction (nearly £23 million) exceeded the total sum authorised during 1826-1835 (£19 million). In 1837, £13.5 million were authorised by Parliament, however, it contrasts with only £2 million in 1838. Kenwood (1965) also concluded that a growing speculative interest in railway building

220 was simulated by a large-scale railway construction and the rising railway shares in the early 1830s.

It is quite clear that the boom in 1835-6 indicates the more intense railway speculation ten years later. Another key finding of our results is that we find evidence of exuberance in share prices between 1843 and 1845/1846 under both model specifications. Our finding is of great importance and interest as it provides evidence of explosive behaviour in the index of real share prices during the most important
225 British Railway Mania in the mid-1840s. This is the first study to investigate the speculative stock prices of railways during the British Railway Mania using the PSY approach.

The Railway Mania of the mid-1840s was reflected in the number of new Acts for railways. The construction of a railway required the Parliament to pass an Act for granting the right and privileges to the company at a considerable cost (Matthews, 1954). Based on statistics from Porter (1851, p.327),
230 the number of Acts passed in England were 120, 270 and 190 in each year during 1845-7 while only 48 Acts were adopted in 1844. According to Simmons (1978, p.42), 330 Railway Acts were passed to establish new companies or extend existing lines in England and Wales during the 1845-7 (e.g., 79 Acts in 1845, 154 Acts in 1846 and 97 Acts in 1847). Even if these numbers of Acts authorised for railways from Simmons (1978) are different from those discussed in Porter (1851), the general conclusion of
235 a boom in railway construction during 1845-7 still holds. However, only 54 Acts were passed during the early railway boom of 1835-6 based on the statistics from Porter (1851). It is evident that the Railway Mania in the mid-1840s is much larger in scale than the rail boom in 1835/6 as the number of Acts authorised for railways during the great Railway Mania is far more than the number of Acts authorised during the 1835-6 boom.

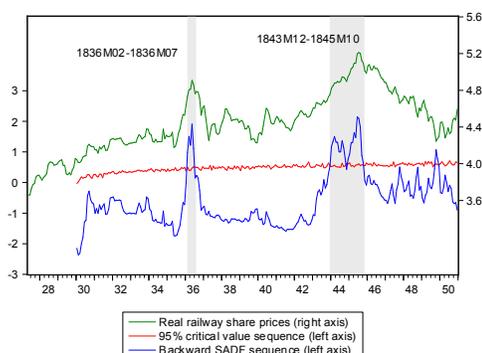
240 The Railway Mania was also reflected in the amount of capital authorised and miles of railway authorised by Parliament. Only were £20 million authorised for construction 805 miles in 1844. The amount authorized by Parliament are £60 million for construction 2700 miles in 1845, £132 million for construction 4538 miles in 1846 and £40 million for construction 1354 miles in 1847, respectively ⁹. It is clear that the year 1846 was one of the most remarkable years in the history of British railways.
245 The Railway Mania of the mid-1840s was a construction boom due to the promotional and speculative activity (Kenwood, 1965).

There are fundamental differences between the boom in 1835-6 and the Railway Mania in 1845. The boom in 1835-6 differs in that it lasts only a year and it does not reach the same level intensity/speculation of the mania in the 1840s. The railways share index reached a peak of 167.5 in July

⁹The details of miles of railway authorized and capital authorized during the 1840s for the Britain can be obtained from Porter (1851) and Cleveland-Stevens (1915).

(a) Real railway share prices

under the model with an intercept



(b) Real railway share prices

under the model without an intercept

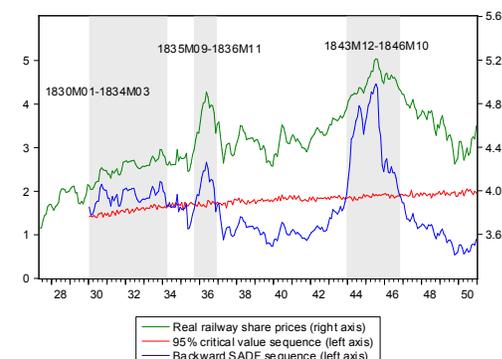


Figure 2: Date-stamping strategy of real railway share prices index between May 1827 and December 1850 based on different model formulations.

1845 during the great Railway Mania compared with the peak of the 1836 boom of 129.4 in May 1836. Campbell & Turner (2010) also argue that the Railway Mania in the mid-1840s differed from the boom in 1835-6 in two ways. First, more railway companies were promoted and formed during the Railway Mania. Second, more middle classes started to invest in the equity market during the Railway Mania.

4.2. Canals share price index

Our date-stamping results for real canal shares are presented in Figure 3. Under the assumption with an intercept, the null hypothesis of no explosive behaviour in canals share prices is rejected at the 1% level ($3.4483 > 2.8008$). Several points of interest can be highlighted in Figure 3a. First, we identify an exuberant episode between 1821M11 and 1825M01. Share prices reached a peak in 1824, indicating that canals grew remarkably and played a crucial role in transportation during the early stage of British Industrial Revolution.

Some successful canal companies were able to pay dividends of far more than 10% in the year of 1825, see Table 1. These dividend figures in Table 1 shows that these canal companies were in a financially sound position in 1825, a decade before the locomotive began to compete with canals.¹⁰ As demonstrated in Table 1, of the seven canal companies considered in Gayer et al. (1953), five of

¹⁰Among the ten most successful canals in 1825, they paid an average dividend of 27.6 per cent (Arnold & McCartney, 2011).

265 them were able to pay a decent dividend for more than 10 %, indicating the financial success of some canals.

However, canals are under threatening by railway competition. Hickson et al. (2011) noted that there was a significant fall in the proportion of canal securities listed from 20%-30% before the mid-1830s to less than 10% in 1845 while there was a substantial increase in the number of railway securities
270 from less than 2% in 1825 to approximately 65% in 1845. The canal's share of market capitalization is 50% in 1825, and it significantly reduced to only 8% in 1845. In contrast to canals, the railways dominated the share of market capitalization in 1845, making up more than 50% of total market capitalization. Hickson et al. (2011) also listed top 20 companies by market capitalization in 1825, 10 of them were canals. Our identified exuberant episode in the 1820s seems to coincide with the boom
275 of canals. Moreover, this finding indicates that the exuberant episode of the canals foreshadowed the most speculative episode in railways two decades.

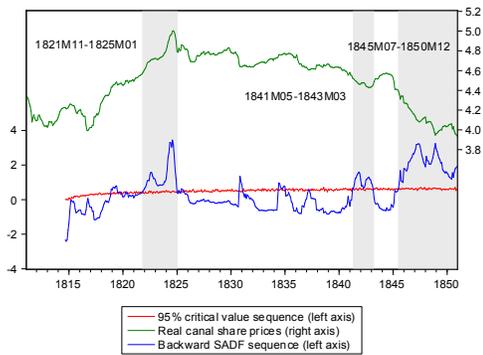
Second, a collapse and recovery episode during the period 1841M05-1843M03 and a collapse episode from 1845M07 to 1850M12 are noted. As shown in Figure 3, the share price index for canals fell significantly after 1845, indicating the end of the canal era. By 1845, railways seemed to gain too
280 much control over canals. Parliament planned to take actions to strengthen the competitive position of canals. The Canal Acts of 1845 was passed to encourage canal companies to engage in the carrying trade. Canal companies were also given powers to vary their tolls and to lease their tolls to each other. These privileges were made possible for canal companies to compete with railway companies as the Railway Clauses Consolidation Act of 1845 granted railway companies similar privileges, see Jackman
285 (1916, p.638). The Canal Acts of 1845 were initially designed to enhance the competitive position of canals. However, these Acts made railway companies dominated over canals. It did not take too long for railway companies to realize that these Acts would stop them getting monopoly power. Moreover, railway companies also realized that they could gain control over canals and claim the corresponding privileges if they became new owners of these canal companies. Hence, railway companies made use
290 of the Acts of 1845 to take over canals. As discussed in Clapham (1939, p.398), a canal mileage of 948 were bought or leased by railway companies during 1845-7, leaving 2750 miles of independent canals in Britain.

Without the intercept in the regression model, the null hypothesis of no explosive behaviour in canals share prices is rejected at the 1% level ($6.6529 > 4.4509$). We find a spurious episode between
295 1811M11 and 1839M05 in Figure 3b due to its duration. As mentioned before, this spurious episode is likely caused by the model specification without the intercept in the regression when the share index exhibits an upward trend. Such an episode should be interpreted with caution.

Table 1: Dividend figures for canal companies are reproduced from Clapham (1939). Companies with * are included in Gayer's index.

	Dividend	Dividend
Selected successful canal companies	1825	1838-9
Mersey and Irwell Navigation	35%	
Grand Junction*	13%	12%
Leeds and Liverpool*	16%	20%
Coventry*	44%	46%
Monmouthshire*	10%	4.5%
Trent and Mersey*	75%	32.5%
	Dividend	Dividend
Selected unsuccessful canal companies	1825	1838-9
Ellesmere*	2.8%	2.8%
Worcester and Birmingham*	2%	1.75%

(a) Real canal share prices under the model with an intercept



(b) Real canal share prices under the model without an intercept

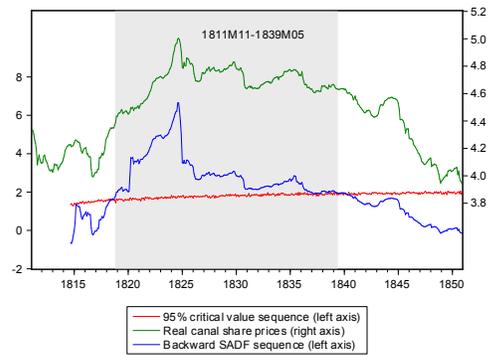
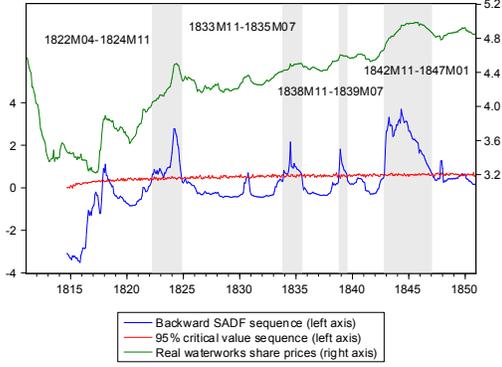


Figure 3: Date-stamping strategy of real canal share prices between February 1811 and December 1850 based on different model formulations.

(a) Real waterworks share prices
under the model with an intercept



(b) Real waterworks share prices
under the model without an intercept

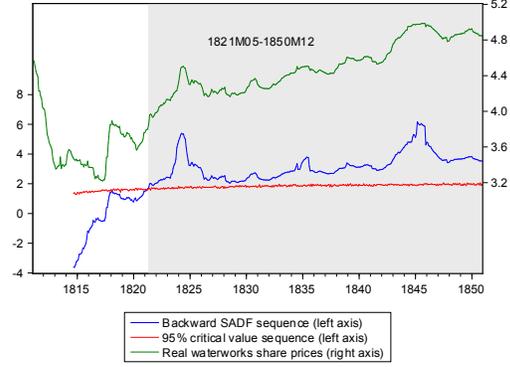


Figure 4: Date-stamping strategy of real waterworks share prices between February 1811 and December 1850 based on different model formulations.

4.3. Waterworks share price index

Our date-stamping strategies for British waterworks share price index are presented in Figure 4. The null hypothesis of no explosive behaviour in waterworks share prices is rejected at the 1% level (3.6951 > 2.8008) if the intercept is included in the regression model.

A key feature of the waterworks share index is that it exhibits an upward movement after 1818. As explained by Gayer et al. (1953, p.388), the waterworks companies engaged in a monopolistic agreement to eliminate competition in 1818 and these companies were able to raise their rates due to the expanding demand in London. As clearly shown in Figure 1, the waterworks share index shows a continuous rise between 1828 and 1845. During the speculative increase in this period, we find several exuberant episodes, where the share index also reached several peaks in 1824, 1835, 1838 and 1845.

On the other hand, without considering the intercept in the regression model specification, the null hypothesis of no explosive behaviour is rejected at the 1% level (6.1717 > 4.4509). As shown in Figure 4b, we identify a spurious episode during 1821M05-1850M12. The take home message from this example is that the episode identified from the PSY must be interpreted with care.

5. Conclusion

In this paper, we apply the right-tailed unit root test of Phillips, Shi & Yu (2015, PSY) to access explosive behaviour in real stock prices in Britain during the nineteenth century. Three sub-indices of

315 canals, railways and waterworks are obtained from Gayer et al. (1953) and considered in this study. We interpret evidence of explosive behaviour as exuberance rather than bubbles as we only investigate explosive behaviour in the real stock index without considering its fundamental value. Of particular interest is that we look for explosive behaviour in the sub-index of railways during the great Railway Mania in the mid-1840s as the Railway Mania is widely regarded as a great example of financial bubble.

320 Several interesting findings are presented in our study. First, we find signs of exuberance in share prices of railways in 1835/6 and 1846, which are related to the railway boom in 1836 and the more prominent Railway Mania in the mid-1840s, respectively. These two exuberant episodes are of great interest as they correspond to the significant events in the British history. The railway speculation of 1836 has been a prelude to the great Railway Mania of the 1840s, where the Railway Mania is one of the most well-known historical episodes in the literature. This is the first empirical study to
325 investigate railway share prices during the well-documented Railway Mania using the PSY, contributing the novelty of this study to the literature. Second, we also find evidence of exuberance in sub-index of canals in the 1820s under the assumption with an intercept in the regression model. The highlight of the speculative rise in canal shares is that it reached the peak in 1824 at a level that it never climbed to. This finding indicates that the exuberant episode of the sub-index of the real share index foreshadowed
330 the most speculative episode in the railways share index during the mid-1840s two decades. Third, exuberance is confirmed in the sub-index of waterworks as well. Last, the PSY approach seems to identify a spurious episode under the regression model specification without the intercept if the share price exhibits an increasing trend in several cases, see Figure 3b and Figure 4b.

335 The above findings will be of great interest not only to scholars who work on identifying financial bubbles but also economic historians who are interested in the rage of speculation in historical share prices during the Railway Mania. In particular, the regression model specification with/without an intercept is considered as the model specification plays an important role in assessing the explosiveness. As suggested in Hu & Oxley (2016), there is a need to be careful when interpreting empirical results
340 from these new time series-based methods of PSY, minimally checking that failed test date-stamping have both an empirical and where possible, some historiographically sourced supporting information. This work and Hu & Oxley (2017) provide new insights into the most documented bubble episodes in history. Future work may consider investigating some classic examples of historical episodes, for example, the Mississippi and South Sea episodes and Railway Mania using alternative approaches,
345 rather than some very recent episodes.

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