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UK World War I and Interwar Data for Business Cycle and Growth Analysis

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Abstract: This article contributes new time series for studying the U.K. economy during World War I and the interwar period. The time series are per capita hours worked and average tax rates of capital income, labor income, and consumption. Uninterrupted time series of these variables are provided for an annual sample that runs from 1913 to 1938. We highlight the usefulness of these time series with several empirical applications. We use per capita hours worked in a growth accounting exercise to measure the contributions of capital, labor, and productivity to output growth. The average tax rates are employed in a Bayesian model averaging experiment to reevaluate the Benjamin and Kochin (1979) regression.

JEL classification: E32, E62, N14, N34, N44

Key words: hours worked, average tax rates, growth accounting, Bayesian model averaging

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1. Introduction

Macroeconomics arguably exists as a field of economics because the UK suffered two depressions between the world wars. Keynes (1964, pp. 2–3) acknowledges that *The General Theory* is his response to interwar UK economic outcomes and policies. Although Keynesian analysis of the Great Depression is sometimes criticised, it can be difficult to study alternative theories using quantitative methods. An obstacle confronting quantitative Keynesian and non-Keynesian analysis of the interwar UK economy is that several key time series are missing.

This paper contributes time series previously unavailable for the UK during the World War I and interwar periods. We compile per capita hours worked and average capital income, labour income, and consumption tax rates. Table 1 lists uninterrupted annual observations of per capita hours worked and average tax rates from 1913 to 1938. This data fills in several gaps that have inhibited quantitative research on UK labour markets and fiscal policy during the interwar period. For example with this data, quantitative methods can study the narratives of Dowie (1975) and Daunton (2002) that emphasise the impact on the UK economy of changes in labour markets and fiscal policy during and after World War I.

The first part of the paper discusses the data sources, construction, and additional assumptions needed to construct per capita hours worked and the average tax rates. Along with summary statistics of these variables, we report unit root tests of the average capital income, labour income, and consumption tax rates on a 1916–1938 sample. These tests indicate that the average capital income and consumption tax rates are observationally equivalent to unit root processes, while the average labour income tax rate is not. Thus, the average labour income tax rate is less persistent than the average capital income and consumption tax rates.

We also present two applications that exploit the World War I and interwar period per capita hours worked and average tax rates time series. The applications show that these series contain information useful for studying the interwar UK economy.

The first application employs per capita hours worked to construct annual observations of total factor productivity (TFP) series for the UK from 1916 to 1938. Our productivity accounting exercise identifies labour input with total hours worked that equals per capita hours worked multiplied by the employment rate. On the 1916–1938 and interwar samples, average capital and total factor productivity growth are nearly unchanged. There are changes in average total hours worked and output growth across these samples. In contrast once the World War I observations are dropped, the average growth rate of total hours worked shifts from negative to positive which helps drive average UK output growth higher during the interwar period. These results match Cole and Ohanian (2002a). They argue that a large drop in employment explains weak UK output growth during the interwar period.

The second application revisits the Benjamin and Kochin (1979) regression. Benjamin and Kochin (BK) estimate a regression to test their hypothesis that larger unemployment benefits produced a higher UK unemployment rate during the interwar period. The average tax rates are placed into the BK regression to explore the impact of uncertainty surrounding the BK regression on the fragility of the BK hypothesis. Using Bayesian methods and the 1916–1938 sample, this assessment reveals that the precision of estimates of the response of the UK unemployment rate to the ratio of unemployment benefits to wages is overstated by ignoring the distortionary effects of taxes on factor inputs, labour supply, and consumption-saving decisions.

The paper follows this order. Section 2 describes our contributions to the World War I and interwar UK time series. We present two applications in section 3 that use the per capita hours worked and average tax rate data. The final section concludes.

2. UK Average Tax Rates and Per Capita Hours Worked, 1913–38

This section reviews the construction of the UK average capital income, labour income, and consumption tax rates and per capita hours worked. The data is sampled at an annual frequency and begins in 1913 and ends with 1938.[1] We conduct some preliminary analysis of these times series to close this section, which draws attention to the importance of understanding the data prior and subsequent to 1920.

2.1 Average Tax Rates during World War I and the Interwar Period

Table 1 lists average capital income, labour income, and consumption tax rates from 1913 to 1938. These tax rates are plotted in figure 1. The focus is on average tax rates because UK marginal tax rates are unavailable for this sample. Our approach mimics Cooley and Ohanian (1997). They compile annual average tax rates for World War II and its post-war period.

Feinstein (1972) and Mitchell (1988) are the primary sources for the data used to compute the average tax rates. We discuss the numerator and denominator of an average tax rate separately to be explicit about its construction.[2] Average tax rates are reported on a calendar year (CY) basis. We convert from the fiscal year (FY) to the CY with $CY_t = 0.25FY_t + 0.75FY_{t+1}$.

The average capital income tax rate equals the ratio of capital tax revenue to capital income. We obtain pre-1920 capital tax revenue and income from Mitchell (1988). Capital tax revenue is imputed using death duties revenue found in Mitchell (1988, pp. 583–584) from 1913 to 1919. Death duties were the only source of capital tax revenue in the UK before 1920. Prior to 1920, capital income is imputed using gross trading profits from Mitchell (1988, pp. 829–830), which average about 60 percent of total corporate

[1]The sample period covers Irish independence from the UK. We follow conventions established by Feinstein (1972) and Mitchell (1988) that exclude Eire's contribution to post-1919 data.

[2]The numerators and denominators are in nominal terms (*i.e.*, current year pounds).

income post-1919. The ratio of pre-1920 capital tax revenue to pre-1920 capital income equals the average capital income tax rate, $\tau_{K,t}$, from 1913 to 1919.

Feinstein (1972) lacks capital tax revenue and income for the pre-1920 period, but has it for the interwar period.[3] For 1920 to 1938, capital tax revenue equals the sum of taxes levied on corporate income found in Feinstein (T77) plus other taxes paid by capital from Feinstein (T79).[4] Capital income is identified with corporate income post-1919, which is provided by Feinstein (T77). We splice pre-1920 $\tau_{K,t}$ to the 1920–1938 ratio of capital tax revenue to capital income to generate $\tau_{K,t}$ from 1913 to 1938.

Calculation of $\tau_{K,t}$ excludes revenue generated by the Excess Profit Duty (EPD). The budget of September 1915 includes an announcement that the EPD would be implemented in 1916. The EPD is an unique part of the UK's World War I fiscal policy regime, which is known as the McKenna rule for the then Chancellor of the Exchequer, Reginald McKenna. Citing Daunton (2002) among others, Nason and Vahey (2007) contend that the McKenna rule regime existed from 1916 to 1938.[5]

The McKenna rule consists of several pieces. Among the most important are year-by-year budget balance on non-defense expenditures, commitment to a path of debt retirement subsequent to the end of World War I, and use of the EPD to prevent excess 'war profits'.[6] EPD revenue is generated by confiscating initially 50 percent of a covered firm's profits net of labour costs, investment, and in excess of £100 above average 1912–1913 profits. This scheme sets EPD revenue to net profits multiplied by the EPD statutory rate, which is the numerator of the average EPD rate, $\tau_{EPD,t}$. The denominators of $\tau_{EPD,t}$ and $\tau_{K,t}$ are equivalent, which permits aggregation of these tax

[3]The 'List of Table' in Feinstein (1972) are prefixed by T.

[4]Death duties are on average about 50 percent of capital tax revenue from 1920 to 1938.

[5]Nason and Vahey (2007) show that McKenna rule regime had a negative impact on the UK economy within the context of the permanent income hypothesis.

[6]Under the McKenna rule, the EPD is intended to last only for the duration of World War I; see Daunton (2002, pp. 55–57). He argues that policymakers viewed the EPD as a device to mitigate war profits and monopolistic rents thought to be caused by temporary excess demand during World War I.

rates. In the September 1915 budget, the EPD is 50 percent as previously noted, but it was raised to 60 percent in late 1916 and to 80 percent in 1918 before the 1920 budget began its phase out.

The UK war budgets of 1916–1918 lean heavily on the EPD. It contributes 24, 30, and 32 percent of government revenue in 1916, 1917, and 1918, respectively. By 1922, however, the EPD is only three percent of government revenue. Although summing $\tau_{EPD,t}$ and $\tau_{K,t}$ gives an indication of the total capital tax effort, these taxes created different economic incentives for firms during World War I and the immediate post-war years that suggest it is reasonable to treat the two tax rates as distinct. This helps for comparing $\tau_{EPD,t}$ and $\tau_{K,t}$ to the average labour income and consumption tax rates. We include $\tau_{EPD,t}$ in table 1 and figure 2 to enable these comparisons, which show the importance of the EPD for UK World War I fiscal policy.

Average labour income and consumption tax rates are straightforward to compute from available revenue and base data. The labour income tax base is employment income taken from Feinstein (1972, T5–6). We set labour income tax revenue equal to income tax revenue available in Feinstein (1972, T31–32), subsequent to netting for EPD and corporate tax revenue that is also found in Feinstein (1972, T31–32). The ratio of labour tax revenue to labour income equals the average labour income tax rate, $\tau_{N,t}$.

A similar ratio defines the average consumption tax rate, $\tau_{C,t}$. Its numerator is expenditure tax revenue that is comprised of customs and other duties and post office, telephone, telegraph, and motor vehicle excise taxes from Mitchell (1988, pp. 583–584). The consumption tax base is household goods and services expenditures as listed in Mitchell (1988, pp. 833–834).

We plot $\tau_{K,t}$, $\tau_{N,t}$, $\tau_{C,t}$, and $\tau_{EPD,t}$ from 1913 to 1938 in figure 1. In this figure, the average tax rates are denoted $\tau_{K,t}$, $\tau_{N,t}$, $\tau_{C,t}$, and $\tau_{EPD,t}$ with a solid (red) line, dashed (green) line, dot-dash (brown) line, and solid (grey) line with circles, respectively.

UK fiscal policy holds $\tau_{K,t}$, $\tau_{N,t}$, and $\tau_{C,t}$ almost equal between 1913 and 1915 according to table 1 and figure 1. However, $\tau_{N,t}$, and $\tau_{C,t}$ rise slightly in 1915. This is consistent with the initial World War I budgets for the UK that attempted to maintain 'business as usual' and not disadvantage any interest or class; Daunton (2002, pp. 38–40 and p. 55).

Higher levies are placed on profits and to a lesser extent labour income beginning in 1916. Table 1 reports that in 1916 $\tau_{EPD,t}$ = 13.1 percent, which is almost double the next largest average tax rate $\tau_{N,t}$. The $\tau_{EPD,t}$ maintains this dominance until 1920 when the EPD begins to be phased out. Subsequently,$\tau_{EPD,t}$ falls to about 15 percent in 1921 before becoming negligible by the mid-1920s which is also seen in figure 1.

The inclination to tax capital more than labour income or consumption remains a cornerstone of UK fiscal policy during the interwar years. The EPD is supplanted by direct capital income taxation in 1921. Table 1 shows that $\tau_{K,t}$ reached 26.4 percent in 1921 from just three percent in 1918. Figure 1 also depicts the shift to $\tau_{K,t}$ from $\tau_{EPD,t}$ in the early 1920s. Although $\tau_{K,t}$ falls to 14 percent in 1937, its stays above $\tau_{N,t}$ and $\tau_{C,t}$ by 4.5 percentage points or more from 1921 to 1938.

Figure 1 pictures slow steady growth in $\tau_{C,t}$ from 1924 to 1938. Compare this to the greater volatility of $\tau_{N,t}$ during the same years. Steady growth in $\tau_{C,t}$ is sufficient for it to equal or exceed $\tau_{N,t}$ by the mid-1930s. Nonetheless, we find in figure 1 that $\tau_{K,t}$ exhibits larger (positive) spikes around the economic downturns of the early 1920s and early 1930s than observed for $\tau_{N,t}$ and $\tau_{C,t}$ in figure 1. This suggests that capital income taxation was an important tool of UK fiscal policy during the interwar period.

2.2 Working in War and Peace: Per Capita Hours Worked

Despite the attention paid to UK labour markets during the interwar years, little is known about hours worked in this period, as well as during World War I. The default sources of UK historical data, Feinstein (1972) and Mitchell (1988), lack an uninterrupted aggregate hours worked time series for 1913 to 1938. Mitchell (1988) references appendix D of Matthews, Feinstein, and Odling-Smee (1982) for hours worked in the UK for only the years 1913, 1924, and 1937. This paper fills in the missing hours worked observations for 1914–1923, 1925–1936, and 1938.

We draw on Clapham (1932) and Dowie (1975), as well as Matthews, Feinstein, and Odling-Smee (1982) and Mitchell (1988), to construct an uninterrupted 1913–1938 per capita hours worked time series. Matthews, Feinstein, and Odling-Smee (1982) report average hours worked per worker of 2753, 2219, and 2293 for 1913, 1924, and 1937, respectively; also see Mitchell (1988, p. 147). Nonetheless, Matthews, Feinstein, and Odling-Smee (pp. 71–72) argue that their 1913 figure of 2753 average hours worked per worker is too high. They refer to an estimate by Clapham (pp. 477–479) that the average annual reduction in hours worked is in the range of 2.5 to five percent from 1880 to 1914. We calibrate 1913 per capita hours worked to the midpoint of Clapham's range, which lowers this observation to 2641 from 2753 average hours worked per worker.

Two additional adjustments are needed to produce hours worked observations between 1913 and 1924. Evidence is presented by Matthews, Feinstein, and Odling-Smee (1982) that hours worked fell by ten to 20 percent in the occupational and industrial sectors between 1913 and 1924. We adopt the midpoint of this range. Given this assumption, it is straightforward to apportion the accumulated 15 percent loss in hours worked in equal amounts to each of the 11 years.

Matthews, Feinstein, and Odling-Smee (1982) and Dowie (1975) report that hours worked fell sharply in 1919. According to Dowie, firms begin to shorten the morning shift by one hour beginning in January 1919. He finds that these changes are fully implemented by July 1919. Given this evidence, we attribute to 1919 about 85 percent of the 15 percent fall in hours worked that occurred between 1913 and 1924. This implies that in 1919 the average employee lost 359 [$\approx 0.85 \times (2641 - 2219)$] hours of work plus the fixed amount equally allotted to all years from 1913 to 1924. We calculate the fixed annual drop in hours worked per worker by adding the 1919 loss of 359 hours to the 1924 observation of 2219 hours, subtracting this amount from the adjusted 1913 observation of 2641 hours, and dividing by 11. This sets the fixed annual decline at 5.73 hours worked per worker between 1913 and 1924.

Hours worked is constructed for the rest of the sample by following Cole and Ohanian (2002a). They assume a constant hours worked growth rate between 1924 and 1937.[7] Since there appears to be no evidence to suggest otherwise, we apply a fixed annual increase of 5.69 hours worked per worker [$\approx (2293 - 2219) \div 13$] from 1924 to 1937 to generate hours worked per worked observations from 1925 to 1938.

Two final calculations are needed to construct an uninterrupted per capita hours worked series from 1913 to 1938. Annual total hours worked per worker is multiplied by the number of UK employed civilians plus military personnel, as reported in Feinstein (1972, T126). In the last step, this series is divided by UK total population to produce the uninterrupted per capita hours worked series, h_t, that is found in table 1. The population series is taken from Feinstein (1972, T121). Appendix A1 gives more details about UK civilian employment, military employment, and population from 1913 to 1938, which also are listed in table A1.

Table 1 shows that h_t increased throughout World War 1 before a steep drop in 1919. The labour market outcome is repeated in 1921 and to a lesser extent in 1922. Otherwise, h_t slowly expands for the rest of the 1920s until it fell in 1930 and 1931. Subsequently, h_t starts to recover in 1933 which continues into 1937.

Our uninterrupted h_t series suggests a puzzle for an extant explanation of the interwar UK labour market. Table 1 shows h_t dropped by about 15 percent between

[7] The website `http://www.greatdepressionsbook.com/datasets/UKData.xls` is the link to the Cole and Ohanian (2002a) data set.

1918 and 1919, increased by less than two percent in 1920, only to fall by 12.7 percent in 1921. The puzzle is that Benjamin and Kochin (1979) and Cole and Ohanian (2002a) argue that more generous unemployment benefits beginning in 1920 explains much of the increase in UK unemployment during the 1920s.

2.3 Unit Root Tests and Sample Statistics: 1916-1938

Table 3 contains sample statistics of $\tau_{K,t}$, $\tau_{N,t}$, and $\tau_{C,t}$ on the 1916–1938 sample. This sample coincides with the McKenna rule regime. However, figure 1 shows that during this period $\tau_{K,t}$, $\tau_{N,t}$, and $\tau_{C,t}$ appear to display substantial persistence. Before reviewing the sample statistics, we test whether the average tax rates are stationary in levels or persistent enough to justify applying the first difference operator.

We report unit root tests to assess the role persistence has in average tax rate dynamics. The unit root tests are based on first-order autoregressions, AR(1)s. Table 2 contains ordinary least squares (OLS) estimates of the AR(1), $\tau_{i,t} = \alpha_{\tau_i} + \delta_{\tau_i}\tau_{i,t-1} + \xi_{\tau_i,t}$, for $i = K, N, C$, where $\xi_{\tau_i,t}$ is a mean zero, homoscedastic forecast innovation. The AR1 coefficient δ_{τ_i} measures persistence. Volatility is identified with the standard deviation of $\xi_{\tau_i,t}$, σ_{ξ,τ_i}, which is conditional on the AR(1) model.

The estimated AR(1)s yield a conditional volatility ranking of the average tax rates that reinforces a message of figure 1. The volatility of $\tau_{K,t}$ dominates that of $\tau_{N,t}$, and $\tau_{C,t}$. Table 2 includes an estimate of the standard deviation of $\xi_{\tau_K,t}$, $\widehat{\sigma}_{\xi,\tau_K}$ that is more than four times larger than $\widehat{\sigma}_{\xi,\tau_N}$ and seven times larger than $\widehat{\sigma}_{\xi,\tau_C}$.

Estimates of δ_{τ_i} are more more difficult to interpret. One issue is the problem that AR coefficients are biased downward in the presence of an unit root. An implication is that δ_{τ_i} has the non-standard Dickey-Fuller (DF) distribution; see MacKinnon (1996). We garner evidence about the unit root hypothesis for $\tau_{K,t}$, $\tau_{N,t}$, and $\tau_{C,t}$ with the DF t-ratio and the Andrews and Chen (1994) approximate median-unbiased estimate of the AR1 coefficient, δ_{MU,τ_i}. These statistics appear at the bottom of table 2.

The DF t-ratio operates under the null of a unit root, $\delta_{\tau_i} = 1$. The alternative is the average tax rate is stationary, $\left|\delta_{\tau_i}\right| < 1$. We obtain finite-sample one, five and ten percent critical values of -3.75, -3.00, and -2.64 from software of MacKinnon (1996).[8] Against these critical values, a unit root cannot be rejected for $\tau_{K,t}$ or $\tau_{C,t}$ at standard significance levels. The DF t-ratio of δ_{τ_N} is -3.81 which rejects the unit root null at the one percent level. We infer from these tests that $\Delta\tau_{K,t}$, $\tau_{N,t}$ and $\Delta\tau_{C,t}$ are stationary.

We report Andrews and Chen (1994) approximate median-unbiased estimates of the AR1 coefficient, $\hat{\hat{\delta}}_{MU,\tau_i}$, to measure the persistence of $\tau_{K,t}$ and $\tau_{C,t}$. With $\hat{\hat{\delta}}_{MU,\tau_C}$ = 1.02, persistence in $\tau_{C,t}$ almost matches the unit root null. The response of $\tau_{C,t}$ is permanent (*i.e.*, never decays) to an own shock $\xi_{\tau_C,t}$ at this point estimate. The estimate $\hat{\hat{\delta}}_{MU,\tau_K} = 0.85$ indicates that $\tau_{K,t}$ is persistent, but that its response to an own shock $\xi_{\tau_K,t}$ has finite duration with a half life of about four years. However, $T = 23$ years is a short annual sample which points to uncertainty surrounding $\hat{\hat{\delta}}_{MU,\tau_K}$ and $\hat{\hat{\delta}}_{MU,\tau_C}$. The last row of table 3 presents 90 percent confidence intervals that contain the unit root null for $\tau_{K,t}$, $\left[0.55,\ 1.09\right]$, and for $\tau_{C,t}$, $\left[0.74,\ 1.12\right]$. These 90 percent confidence intervals are more evidence that $\tau_{K,t}$ and $\tau_{C,t}$ are observationally equivalent to unit root processes on the McKenna rule regime of 1916 to 1938. Nonetheless, the lower end of these confidence intervals include values that signal less persistence in $\tau_{K,t}$ and $\tau_{C,t}$.

Tax rate persistence is also studied to examine competing models of optimal taxation. For example, Hess (1993) and Scott (2007) judge predictions of dynamic optimal tax theory with unit root tests of $\tau_{N,t}$. Although theory predicts that financial markets are complete if an unit root is rejected for $\tau_{N,t}$, Scott and Aiyagari, Marcet, Sargent, and Seppälä (2002) argue that unit root tests alone are unable to discriminate between competing predictions of optimal tax theory on actual data. Thus, there are limits to the inference that can be extracted from unit root tests of $\tau_{K,t}$, $\tau_{N,t}$, and $\tau_{C,t}$.

[8] The software is found at `http://www.econ.queensu.ca/faculty/mackinnon/numdist/`.

This section closes by reviewing sample statistics of $\Delta\tau_{K,t}$, $\tau_{N,t}$, $\Delta\tau_{C,t}$, and the growth rate of per capita hours worked, $\Delta \ln h_t$. We report sample statistics of $\Delta \ln h_t$ rather than h_t (or $\ln h_t$) because it contains trends by construction. Table 3 lists the sample mean $\overline{X}$, standard deviation $\widehat{\sigma}_X$, maximum X_{Max}, minimum X_{Min}, and first-order autocorrelation coefficient $\widehat{\rho}_X(1)$, for $X = \Delta\tau_K$, τ_N, $\Delta\tau_C$, and $\Delta \ln h$ on the 1916–1918 sample. Figure 2 plots $\Delta\tau_K$, $\Delta\tau_C$, and $\Delta \ln h_t$ from 1914 to 1938.

There are important differences across the sample statistics of $\tau_{N,t}$ compared to those of $\Delta\tau_{K,t}$ and $\Delta\tau_{C,t}$ in table 3. On average $\tau_{N,t}$ is about 10 percent, which is large relative to $\widehat{\sigma}_{\tau_N} = 1.3$. This is not true for $\overline{\Delta\tau_K}/\widehat{\sigma}_{\Delta\tau_K}$ and $\overline{\Delta\tau_C}/\widehat{\sigma}_{\Delta\tau_C}$. There is positive serial correlation in $\tau_{N,t}$, but $\widehat{\rho}_{\tau_N}(1) = 0.65$ indicates rapid decay in less than two years. Only weak positive first-order serially correlation arises in $\Delta\tau_{K,t}$ and $\Delta\tau_{C,t}$. Finally, the row labeled $\widehat{\sigma}_X$ reveals that $\Delta\tau_K$ is more volatile than τ_N or $\Delta\tau_C$.[9]

The sample statistics of $\Delta \ln h_t$ reveal it to be volatile and approximately serially uncorrelated. The fifth column of table 3 shows that relative to (the absolute value of) $\overline{\Delta \ln h}$, $\widehat{\sigma}_{\Delta \ln h}$ is about eight times larger, $\Delta \ln h_{Min} = 16.5$ occurs (in 1919), $\Delta \ln h_{Max}$ equals three percent (in 1937), and $\widehat{\rho}_{\Delta \ln h}(1) = -0.05$. These observations are bolstered by the plot of $\Delta \ln h_t$ in figure 2. However, interpreting the sample statistics of $\Delta \ln h_t$ requires caution because trends and a structural break are built into h_t.

3. Applications

This section contain two applications. The first is a growth accounting exercise that exploits h_t to produce an uninterrupted TFP residual from 1916 to 1938. Next, we add combinations of $\tau_{K,t}$, $\tau_{N,t}$, and $\tau_{C,t}$ to the Benjamin and Kochin (1979) regression to conduct a Bayesian evaluation of the hypothesis that increased unemployment benefits drove the UK interwar unemployment rate higher.

[9]Sample means of $[\tau_{K,t} \;\; \tau_{C,t}] = [0.162 \;\; 0.079]$. Associated standard deviations are 0.069 and 0.015.

3.1 *World War I and Interwar UK Growth Accounting*

The growth accounting exercise decomposes output growth into contributions made by capital, labour, and TFP conditional on a production function. We adopt the constant return to scale (CRS) production technology

$$(1) \qquad Y_t = K_t^{\theta}[Z_t N_t]^{(1-\theta)}, \quad 0 < \theta < 1,$$

where Y_t, K_t, Z_t, and N_t denote output, the capital stock, labour-augmenting TFP, and labour input, respectively. Labour input equals total hours worked, $N_t = E_t \times h_t$, where E_t is the employment rate. We set capital's share, θ, at 0.35. The CRS production technology (1) is standard in macroeconomics. For example, Cho and Cooley (1994) use a similar production function to study the roles adjustment along the extensive margin, E_t, and the intensive margin, h_t, play in aggregate fluctuations.[10]

The growth accounting exercise requires data on UK output, capital, employment, hours worked, and population to compute TFP. We obtain UK output and capital from Feinstein (1972) and Mitchell (1988). Appendix A.1 summarizes the data, which appears in table A1. Section 2.2 discusses UK employment and population, along with construction of h_t. Note that E_t is per capita as are Y_t and K_t, which are also in constant 1913 pounds. The TFP residual is computed by passing the log through production function (1) and rearranging terms to generate $\ln Z_t$ and its growth rate, $\gamma_{Z,t}$ $(= \ln Z_t - \ln Z_{t-1})$.

Results of the growth accounting exercise are found in table 4. This table contains sample statistics for the 1916–1938, 1920–1938, and 1922–1938 samples in its top, middle, and bottom panels. We study these samples to gauge the robustness of the growth accounting exercise across the McKenna rule regime and interwar samples. The 1922–1938 sample is included to examine the impact of the post-World War I depression

[10] Cole and Ohanian (2002a) employ the CRS technology $[h_t K_t]^{\theta}[Z_t N_t]^{(1-\theta)} = K_t^{\theta}[Z_t E_t]^{(1-\theta)} h_t$ in a growth accounting exercise. Their technology equates the workweeks of E_t and K_t. We avoid this restriction with the production function (1), which instead holds fixed the capital utilization rate.

on interwar UK economic outcomes. On these samples, table 4 reports the sample mean $\overline{y}_X$, standard deviation $\hat{\sigma}_{y_X}$, maximum $y_{Max,X}$, minimum $y_{Min,X}$, and first-order autocorrelation coefficient $\hat{\rho}_{y_X}(1)$ of the growth rates $y_{X,t}$, $X_t = Y_t,\ K_t,\ N_t$, and Z_t.

The sample means of $\overline{y}_Z$ and $\overline{y}_K$ exhibit little change across the three samples. Table 4 shows that $\overline{y}_Z$ is about one percent no matter the sample. Likewise, $\overline{y}_K$ changes by only 0.2 percent from the longest sample to the two interwar samples.

There are larger shifts in $\overline{y}_Y$ and $\overline{y}_N$ moving from the McKenna rule regime to the interwar samples. Output growth increases from 0.6 to one percent by ignoring the 1916–1919 observations and rises to two percent after dropping 1920 and 1921. Much of the increase in $\overline{y}_Y$ is generated by $\overline{y}_N$ moving from negative, to zero, to about 1.4 percent as the World War I and early interwar years are eliminated from the samples.

Table 4 also shows that there is little change in volatility, $\hat{\sigma}_y$, and persistence, $\hat{\rho}_y(1)$, of $\overline{y}_Y,\ \overline{y}_K,\ \overline{y}_N$, and $\overline{y}_Z$ on the 1916–1938 and 1920–1938 samples. Across these samples, $\hat{\sigma}_{y_N}$ and $\hat{\sigma}_{y_Z}$ are close and about 50 percent larger than $\hat{\sigma}_{y_Y}$ and $\hat{\sigma}_{y_K}$. Persistence is similar on the McKenna rule regime and 1920-1938 sample with small positive $\hat{\rho}_{y,Y}(1)$, slight negative $\hat{\rho}_{y,K}(1)$ and $\hat{\rho}_{y,Z}(1)$, and near zero $\hat{\rho}_{y,N}(1)$.

The shorter 1922–1938 sample yields shifts in $\hat{\sigma}_y$ and $\hat{\rho}_y(1)$. The bottom panel of table 4 contains smaller $\hat{\sigma}_y$ for output, capital, labour, and TFP compared to those produced by the longer samples. Also $\hat{\sigma}_{y_Y},\ \hat{\sigma}_{y_N}$, and $\hat{\sigma}_{y_Z}$ are about equal. It is also striking that y_Y exhibits small negative first-order serially correlation on the 1922–1938 sample, but on this sample the same statistics for $y_K,\ y_N$, and y_Z are positive.

Figure 3 plots the growth accounting exercise for the UK from 1916 to 1938. The top row of windows in figure 3 gives two perspectives on movements in $Y_t,\ K_t$, and N_t. Growth rates appear in the top left window of figure 3. We report a low frequency or trend measure in the top right window, which is $\Gamma_{X,t} = \ln X_t - \ln X_{1916},\ X_t = Y_t, K_t, N_t$, and $t = 1916, \ldots, 1938$. The top row of windows of figure 3 represent $Y_t,\ K_t$, and N_t

plots with (blue) solid, (red) dashed, and (green) dotted lines, respectively.

The volatility message of table 4 is reinforced by the plots of $\gamma_{Y,t}$, $\gamma_{K,t}$, and $\gamma_{N,t}$ in the top left window of figure 3. These plots are visual evidence that $\gamma_{Y,t}$, $\gamma_{K,t}$, and $\gamma_{N,t}$ are more volatile from 1916 to 1922 than during the 1923–1938 period.

The top right window of figure 3 focuses attention on lower frequency movements in Y_t, K_t, and N_t. Lower frequency fluctuations appear as peaks, troughs, and long-run growth paths. For example, plots of $\Gamma_{Y,t}$ and $\Gamma_{N,t}$ peak in 1918 followed by a steep drop. The cumulative loss in Y_t is over 22 percent by 1921 and for N_t it is more than 40 percent by 1922. The path $\Gamma_{K,t}$ takes sees it fall during World War I before peaking with a cumulative gain of almost 13 percent in 1920. From the mid-1920s to 1938, there is growth in $\Gamma_{Y,t}$, $\Gamma_{K,t}$, and $\Gamma_{N,t}$ with the early 1930s being about the only exception.

The growth and trend growth rates of TFP are displayed in the bottom left and right windows of figure 3, respectively. These plots reveal that the UK had a productivity boom toward the end of World War I. However, the bottom left window of figure 3 shows $\gamma_{Z,1919} = -0.5$ percent and $\gamma_{Z,1920} = -20.1$ percent, which indicates that the fall in UK TFP subsequent to World War I turned into a collapse by 1920. There is an immediate recovery in TFP the next year, $\gamma_{Z,1921} = 18.9$ percent, but there are five years in which $\gamma_{Z,t}$ is negative from 1923 to 1938 (*i.e.*, 1927, 1932, 1934, 1937, and 1938) with an average of -1.48 percent. Nonetheless, the average of $\gamma_{Z,t}$ is 3.09 percent after 1922 when $\gamma_{Z,t} > 0$. This helps to explain the economic recovery of the mid-1920s and the reduced volatility in $\gamma_{Z,t}$ on the 1923–1938 sample (because on this sample $\sigma_{\gamma_Z} = 3.6$ percent is smaller than on the longer 1920–1938 and 1916–1938 samples).

The bottom right window of figure 3 maps $\gamma_{Z,t}$ into $\Gamma_{Z,t}$. This trend measure of TFP appears in the bottom right window of figure 3. In this window, $\Gamma_{Z,t}$ depicts a peak in TFP during World War I, its steep post-war decline, and a recovery in TFP that levels off by 1925. Thus we close this section by noting that, without the uninterrupted hours worked series h_t, it is not possible to observe the collapse in TFP from 1919 to 1921 was wedged between a small boom during World War I and a recovery beginning in 1922.

3.2 The Benjamin-Kochin Regression Revisited

Benjamin and Kochin (1979) contend that generous unemployment insurance benefits produced a higher UK unemployment rate, UR_t, in the interwar period. Their analysis relies on an ordinary least squares (OLS) regression of the UR_t on the ratio of benefits to wages, the replacement ratio RR_t, detrended log real net national product, y_t, and a constant.[11] We refer to it as the BK regression. The BK hypothesis is that there is a positive, economically large, and statistically significant response of UR_t to RR_t. On the McKenna rule regime of 1916–1938, the estimated BK regression is

$$UR_t = \underset{(1.77)}{1.12} + \underset{(4.04)}{23.55}\, RR_t - \underset{(6.44)}{26.83}\, y_t, \tag{2}$$

where standard errors are in parentheses and the standard deviation of the regression residuals is 3.05. There is solace for Benjamin and Kochin (1979, 1982) in these estimates because the elasticity of UR_t with respect to RR_t is 0.90 at the sample means.

This section studies the robustness of the BK regression and hypothesis. There are several critiques of the BK regression and hypothesis. Rather than repeat those here, the interested reader is directed to Nason and Vahey (2006). Instead Bayesian model averaging (BMA) methods are used to address robustness of the BK hypothesis by modifying the BK regression to include different combinations of $\tau_{K,t}$, $\tau_{N,t}$, and $\tau_{C,t}$ on the McKenna rule regime of 1916 to 1938. We apply BMA to compute the probability that RR_t should be excluded from the modified BK regression. Figure 4 plots the UR_t, RR_t, and y_t to reintroduce the reader to these time series. The average tax rates are included in figure 4 to cover all the relevant variables.

[11] Appendix A2 discusses construction of UR_t, RR_t, and y_t. Table A2 lists the series.

The most general version of the modified BK regression is

$$UR_t = \beta_0 + \beta_{RR}RR_t + \beta_y y_t + \beta_{\tau_K}\tau_{K,t} + \beta_{\tau_N}\tau_{N,t} + \beta_{\tau_C}\tau_{C,t} + e_t, \tag{3}$$

where e_t is a mean zero error term with homoscedastic variance, σ_e^2. Besides regression (2), we estimate three models with two of the three tax rates and three models with only one of the three tax rates. These seven models are $M_1, \ldots, M_7$, where regression (3) is M_7. Our BMA evaluation of the BK hypothesis adds seven more regressions that are identical to $M_1, \ldots, M_7$, but restrict $\beta_{RR} = 0$. These regressions are labeled $M_{1,\mathcal{R}}, \ldots, M_{7,\mathcal{R}}$. Model space $\mathcal{M} = \left\{M_1, M_{1,\mathcal{R}}, \ldots, M_7, M_{7,\mathcal{R}}\right\}$ contains the 14 regressions. We include levels regressions in $\mathcal{M}$ to be consistent with Benjamin and Kochin (1979).

Table 5 reports OLS estimates of $\mathcal{M}$ on the 1916–1938 sample. These estimates suggest uncertainty about the regression pairs in $\mathcal{M}$. However, it is not a surprise that M_7 and $M_{7,\mathcal{R}}$ produce the smallest (and nearly identical) estimates of σ_e.

Uncertainty about the regression specifications is tied to fragility in the BK hypothesis of $\widehat{\beta}_{RR}$ across $M_1, \ldots, M_7$. There are three modified BK regressions, M_2, M_3, and M_6, that produce $\widehat{\beta}_{RR} > 0$ with $t-$ratios greater than two. These modified BK regressions include $\tau_{N,t}$ and $\tau_{C,t}$, but $\tau_{K,t}$ is absent. There is less support for the BK hypothesis when $\tau_{K,t}$ appears in the modified BK regressions M_1, M_4, M_5, and M_7. These modified BK regressions yield $\widehat{\beta}_{RR}$ that are small compared to $\widehat{\beta}_{RR} = 25.6$ of the estimated BK regression (2). Thus, the BK hypothesis appears to be compromised by adding $\tau_{K,t}$ to the BK regression.[12]

The modified BK regressions $\mathcal{M}$ are a platform for gauging the vulnerability of the BK hypothesis. Although standard $t-$ratios might suggest that adding $\tau_{K,t}$ negates the BK hypothesis, we do not take that position. Instead, we view the OLS estimates

[12] Nason and Vahey (2006) report Bayesian Monte Carlo Markov chain estimates for the BK regression with $\tau_{K,t}$, $\tau_{N,t}$, and $\tau_{C,t}$ and obtain qualitatively similarly results for the BK hypothesis.

and standard errors of table 5 as evidence that there is substantial uncertainty across the 14 regressions $\left\{M_1, M_{1,\mathcal{R}}, \ldots, M_7, M_{7,\mathcal{R}}\right\}$. By ignoring this uncertainty, a researcher may overstate the precision of estimated coefficients and place insufficient concern on the fragility of the hypothesis under review.

We employ BMA to study the impact of model uncertainty on the fragility of the BK hypothesis. The BMA approach to model selection exploits rules of conditional probability to make inferences about the parameter of interest, β_{RR}. Our BMA application follows Koop (2003) and an example in Garratt, Koop, and Vahey (2008).

The posterior model probability is a central focus of Bayesian model evaluation. Define $\Pr\left(M_i \middle| \mathcal{D}\right)$ for the BK regression, where $\mathcal{D} = \left[UR_t \;\; 1 \;\; RR_t \;\; y_t \;\; \tau_{K,t} \;\; \tau_{N,t} \;\; \tau_{C,t}\right]$ is the data vector. The posterior model probability is found using Bayes rule

$$\Pr\left(M_i \middle| \mathcal{D}\right) \propto \Pr\left(\mathcal{D} \middle| M_i\right) \Pr\left(M_i\right),$$

where $\Pr\left(\mathcal{D} \middle| M_i\right)$ is the marginal likelihood and the prior model probability is $\Pr\left(M_i\right)$. Our prior is non-informative such that each model receives equal weight, $\Pr\left(M_i\right) = 7^{-1}$. The post-data probability of M_i is approximated with the Schwarz or Bayesian Information Criterion (BIC). This approximation is

$$\Pr\left(M_i \middle| \mathcal{D}\right) = \frac{\text{BIC}_i}{\sum_{i=1}^{7} \text{BIC}_i}, \tag{4}$$

where $\text{BIC}_i = \widehat{\mathcal{L}}_i - 0.5 k_i \ln T$, $\widehat{\mathcal{L}}_i$ is the log likelihood function computed at the maximum likelihood estimates (*i.e.*, OLS) of M_i, k_i is the number of parameters in M_i, and T $(= 23)$ is sample size.

Our interest is in the probability that the data supports the restriction $\beta_{RR} = 0$, $\Pr\left(\beta_{RR} = 0 \middle| \mathcal{D}\right)$. The rules of conditional probability imply

$$(5) \qquad \Pr\left(\beta_{RR} = 0 \,\middle|\, \mathcal{D}\right) = \sum_{i=1}^{7} \Pr\left(\beta_{RR} = 0 \,\middle|\, \mathcal{D}, M_i\right) \Pr\left(M_i \,\middle|\, \mathcal{D}\right),$$

where $\Pr\left(\beta_{RR} = 0 \,\middle|\, \mathcal{D}, M_i\right)$ is the probability that RR_t has no predictive content for UR_t conditional on $\mathcal{D}$ and M_i. We calculate the probability that RR_t has no predictive content for UR_t in M_i as

$$(6) \qquad \Pr\left(\beta_{RR} = 0 \,\middle|\, \mathcal{D}, M_i\right) = \frac{\exp\left(\mathrm{BIC}_{i,\mathcal{R}}\right)}{\exp\left(\mathrm{BIC}_{i,\mathcal{R}}\right) + \exp\left(\mathrm{BIC}_i\right)}, \quad i = 1, \ldots, 7,$$

where BIC_i and $\mathrm{BIC}_{i,\mathcal{R}}$ represent the BICs for the unrestricted M_i and restricted $M_{i,\mathcal{R}}$ ($\beta_{RR,i} = 0$), respectively. Thus, $\Pr\left(\beta_{RR} = 0 \,\middle|\, \mathcal{D}, M_i\right)$ relies on the posterior model probabilities of the ith unrestricted and restricted modified BK regressions. Note that the non-informative prior requires the probability that RR_t is included or excluded from the elements of $\mathcal{M}$ to equal 0.5.

We assess the predictive content of RR_t using evidence from $\mathcal{M}$ given $\mathcal{D}$. This is the probability $\Pr\left(\beta_{RR} = 0 \,\middle|\, \mathcal{D}\right)$ of (5). It is computed using the conditional probability (6), weighted by the posterior probability of (4), summed from $i = 1, \ldots, 7$. Given the McKenna rule regime 1916–1938 sample, $\Pr\left(\beta_{RR} = 0 \,\middle|\, \mathcal{D}\right) = 0.79$. Thus, there is little support for the BK hypothesis during the McKenna rule regime.

4. Conclusion

This paper fills in gaps in the World War I and interwar UK times series. We construct UK per capita hours worked and average capital income, labour income, and consumption tax rates from 1913 to 1938. Details about data sources and construction methods are discussed in the first part of the paper.

The rest of the paper displays some of the uses to which per capita hours worked and the UK average tax rates can be put. We test for a unit root in the average tax rates and report samples statistics of the average labour income tax rates, first differences of the average capital income and consumption tax rates, and growth rate of per capita hours worked. There are also growth accounting exercises for the UK on 1916–1938, 1920–1938, and 1922–1938 samples and a Bayesian evaluation of the Benjamin and Kochin (1979) regression and hypothesis on the 1916–1938 sample.

The results point future research in several new directions. For example a unit root is rejected for the average labour income tax rate on the 1916–1938 sample, but not for the average capital income and consumption tax rates. Optimal tax theory predicts that the labour income tax rate is stationary when markets are complete, but this appears at odds with most views of the state of the UK economy from 1916 to 1938. Duanton (2002) finds that UK fiscal policy relied on capital income taxation during the McKenna rule regime which suggests a research agenda that compares this fiscal policy to the predictions of optimal tax theory.

Our UK growth accounting exercise finds that capital and productivity growth supported average positive output growth in the face of negative average total hours worked growth during the McKenna rule regime. These results are consistent with Cole and Ohanian (2002a) who report a growth accounting exercise that shows a drop in average labour input growth coincides with low average UK output growth during the interwar period. However, this leaves unexplained why capital grew during World War I and the interwar period contributing to output growth when the McKenna rule regime aimed to tax capital heavily.

Our last empirical example studies the Benjamin and Kochin (1979) regression that contends generosity of unemployment benefits spurred an increase in the unemployment rate in the UK during the the interwar period. We employ Bayesian model averaging (BMA) to examine the uncertainty and fragility of the Benjamin and Kochin (BK) regression and hypothesis on the McKenna rule regime of 1916 to 1938 by adding various combinations of the average capital income, labour income, and consumption tax rates. The Bayesian approach exposes a weakness in the hypothesis that increased unemployment benefits drove the UK unemployment rate higher on the McKenna rule regime.

Our view is that the growth accounting exercise and the BMA applications to the BK regression raises more questions about the impact of fiscal policy on the UK economy during World War I and the interwar period. Future analysis of these data from Keynesian and non-Keynesian perspectives will yield more insight into the UK economy from World War I through the interwar period. Although these questions are left for future research, Cole and Ohanian (2002a,b) and Nason and Vahey (2007) are good starting points.

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Table 1: UK Per Capita Hours Worked and Average Tax Rates, 1913–1938

	$\tau_{K,t}$	$\tau_{N,t}$	$\tau_{C,t}$	$\tau_{EPD,t}$	h_t
1913	0.0538	0.0388	0.0444	–	1175.0249
1914	0.0601	0.0389	0.0434	–	1158.8584
1915	0.0510	0.0527	0.0529	–	1185.3950
1916	0.0390	0.0700	0.0577	0.1314	1195.8753
1917	0.0345	0.0982	0.0453	0.2185	1199.1299
1918	0.0304	0.0910	0.0469	0.2669	1205.3611
1919	0.0339	0.1106	0.0611	0.2557	1022.0481
1920	0.0934	0.0971	0.0665	0.2539	1040.8534
1921	0.2641	0.1069	0.0795	0.1527	908.6391
1922	0.2263	0.1277	0.0862	0.0382	898.5255
1923	0.2011	0.1139	0.0842	0.0309	903.2405
1924	0.1756	0.1094	0.0750	0.0255	907.9546
1925	0.1708	0.1058	0.0745	0.0172	917.7429
1926	0.1884	0.0980	0.0764	0.0081	916.8186
1927	0.1913	0.0882	0.0795	0.0013	942.7299
1928	0.1794	0.0913	0.0815	–	944.5552
1929	0.1774	0.0896	0.0796	–	958.5370
1930	0.2179	0.0938	0.0783	–	939.0188
1931	0.2286	0.1108	0.0820	–	915.0793
1932	0.2491	0.1222	0.0945	–	916.5186
1933	0.2295	0.1057	0.0936	–	933.8593
1934	0.1696	0.0977	0.0960	–	960.0468
1935	0.1748	0.0889	0.0948	–	975.4359
1936	0.1505	0.0842	0.0971	–	1004.1981
1937	0.1423	0.0908	0.0963	–	1035.9207
1938	0.1604	0.0987	0.0945	–	1036.6234

The average capital income, labour income, consumption, and excess profits duty (EPD) tax rates are denoted $\tau_{K,t}$, $\tau_{N,t}$, $\tau_{C,t}$, and $\tau_{EPD,t}$, respectively. Per capita hours is represented by h_t.

Table 2: Dickey-Fuller Regressions of UK Average Tax Rates, 1916–1938

DF: $\tau_{i,t} \;=\; \alpha_{\tau_i} \,+\, \delta_{\tau_i}\tau_{i,t-1} \,+\, \xi_{\tau_i,t}, \;\; i = K, N, C, \;\; T = 23.$

	$\tau_{K,t}$	$\tau_{N,t}$	$\tau_{C,t}$
$\hat{\alpha}$	0.040	0.049	0.011
	(0.021)	(0.013)	(0.006)
$\hat{\delta}$	0.774	0.516	0.887
	(0.115)	(0.127)	(0.079)
$\hat{\sigma}_\xi$	0.040	0.010	0.006
DF t-ratio	−1.970	−3.811	−1.430
$\hat{\delta}_{MU}$	0.849	–	1.022
	[0.553 1.088]	–	[0.737 1.123]

The regressions are estimated by ordinary least squares (OLS). OLS standard errors appear in parentheses. The DF t-ratio has MacKinnon (1996) finite-sample one, five and ten percent critical values of −3.753, −2.998, and −2.639, respectively. The brackets contain lower and upper values of 90 percent confidence intervals of the Andrews and Chen (1994) approximate median-unbiased estimates of the first-order autoregressive coefficient, $\hat{\delta}_{MU}$.

Table 3: Sample Statistics of UK Average Tax Rates and Per Capita Hours Worked, 1916–1938

	$\Delta\tau_K$	τ_N	$\Delta\tau_C$	$\Delta \ln h$
$\overline{X}$	0.005	0.100	0.002	−0.006
$\hat{\sigma}_X$	0.043	0.013	0.006	0.048
X_{Max}	0.171	0.128	0.014	0.031
X_{Min}	−0.060	0.070	−0.012	−0.165
$\hat{\rho}_X(1)$	0.148	0.646	0.189	−0.051

The sample mean, standard deviation, maximum, minimum and first-order autocorrelation coefficient are denoted $\overline{X}$, $\hat{\sigma}_X$, X_{Max}, X_{Min} and $\hat{\rho}_X(1)$, respectively.

Table 4: UK World War I and Interwar Growth Accounting Summary Statistics

Sample		Y	K	N	Z
1916–1938					
	$\overline{y}$	0.006	0.009	−0.006	0.010
	$\hat{\sigma}_y$	0.045	0.046	0.074	0.066
	y_{Max}	0.074	0.141	0.060	0.189
	y_{Min}	−0.103	−0.115	−0.269	−0.201
	$\hat{\rho}_y(1)$	0.220	−0.185	−0.034	−0.246
1920–1938					
	$\overline{y}$	0.010	0.011	0.000	0.010
	$\hat{\sigma}_y$	0.043	0.045	0.071	0.072
	y_{Max}	0.074	0.141	0.060	0.189
	y_{Min}	−0.093	−0.115	−0.269	−0.201
	$\hat{\rho}_y(1)$	0.300	−0.233	−0.025	−0.245
1922–1938					
	$\overline{y}$	0.020	0.011	0.014	0.011
	$\hat{\sigma}_y$	0.033	0.019	0.032	0.036
	y_{Max}	0.074	0.141	0.060	0.189
	y_{Min}	−0.057	−0.013	−0.054	−0.063
	$\hat{\rho}_y(1)$	−0.128	0.232	0.373	0.299

The sample mean, standard deviation, maximum, minimum and first-order autocorrelation coefficient of the growth rates are denoted $\overline{y}$, $\hat{\sigma}_y$, y_{Max}, y_{Min} and $\hat{\rho}_y(1)$, respectively.

Table 5: Modified BK Regressions, 1916–1938

Dependent Variable: UK Unemployment Rate, UR_t

	$\widehat{\beta}_0$	$\widehat{\beta}_{RR}$	$\widehat{\beta}_y$	$\widehat{\beta}_{\tau_K}$	$\widehat{\beta}_{\tau_N}$	$\widehat{\beta}_{\tau_C}$	$\widehat{\sigma}_e$
M_1	−3.73	6.62	6.46	77.59	–	–	2.28
	(1.74)	(5.37)	(9.18)	(18.21)			
$M_{1,\mathcal{R}}$	−4.03	–	13.78	96.14	–	–	2.36
	(1.78)		(7.21)	(10.57)			
M_2	−12.28	26.70	−15.82	–	129.82	–	2.79
	(6.51)	(3.73)	(7.84)		(61.09)		
$M_{2,\mathcal{R}}$	4.91	–	−29.09	–	66.72	–	5.01
	(10.86)		(13.68)		(108.55)		
M_3	−6.06	14.35	−22.30	–	–	148.45	2.86
	(4.37)	(7.36)	(6.56)			(83.66)	
$M_{3,\mathcal{R}}$	−11.26	–	−19.17	–	–	288.22	3.09
	(3.73)		(6.86)			(46.46)	
M_4	−13.48	8.89	12.29	71.82	97.95	–	2.09
	(4.88)	(5.03)	(8.84)	(16.88)	(46.31)		
$M_{4,\mathcal{R}}$	−12.13	–	20.65	96.63	80.47	–	2.23
	(5.13)		(7.96)	(9.98)	(48.21)		
M_5	−9.60	−2.13	9.04	74.69	–	125.21	2.10
	(3.30)	(6.56)	(8.54)	(16.83)		(61.62)	
$M_{5,\mathcal{R}}$	−8.93	–	7.43	71.60	–	112.10	2.11
	(2.58)		(6.97)	(13.90)		(46.60)	
M_6	−17.71	16.58	−12.57	–	120.18	132.92	2.63
	(6.89)	(6.84)	(7.62)		(57.76)	(77.11)	
$M_{6,\mathcal{R}}$	−21.45	–	−10.83	–	98.22	293.31	2.94
	(7.52)		(8.50)		(63.91)	(44.36)	
M_7	−18.14	0.68	14.23	69.58	90.60	115.09	1.92
	(5.04)	(6.14)	(8.19)	(15.58)	(42.79)	(56.57)	
$M_{7,\mathcal{R}}$	−18.25	–	14.66	70.58	89.57	119.23	1.92
	(4.95)		(7.20)	(12.70)	(41.79)	(42.68)	

Mnemonics β_0, RR, y, $\widehat{\sigma}_e$, τ_K, τ_N, and τ_C denote the intercept, replacement ratio, linear detrended log net national product, standard deviation of regression residuals, and average capital income, labour income, and consumption tax rates, respectively. Models $M_1, \ldots, M_7$ ($M_{1,\mathcal{R}}, \ldots, M_{7,\mathcal{R}}$) are modified BK regressions that include different combinations of $\tau_{K,t}$, $\tau_{N,t}$, and $\tau_{C,t}$, and (exclude) RR_t. Regressions are estimated with OLS on the 1916–1938 sample, $T = 23$. Parentheses contain OLS standard errors.

Fig. 1: Average Tax Rates, 1913--1938

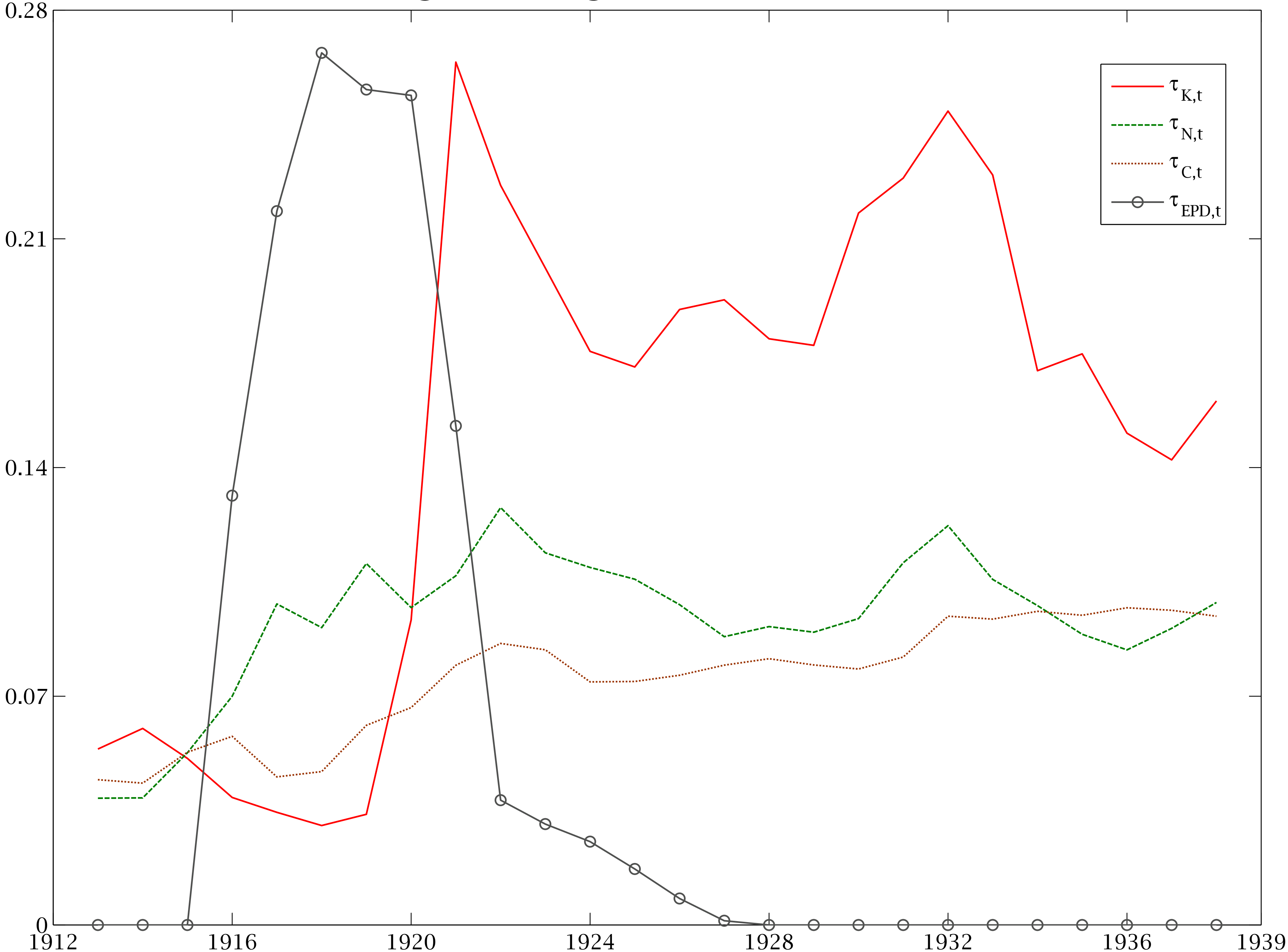


Fig. 2: Average Tax Rate Changes and Per Capita Hours Worked Growth, 1914-1938

Fig. 3: U.K. WWI and Interwar Productivity Accounting, 1916-1938

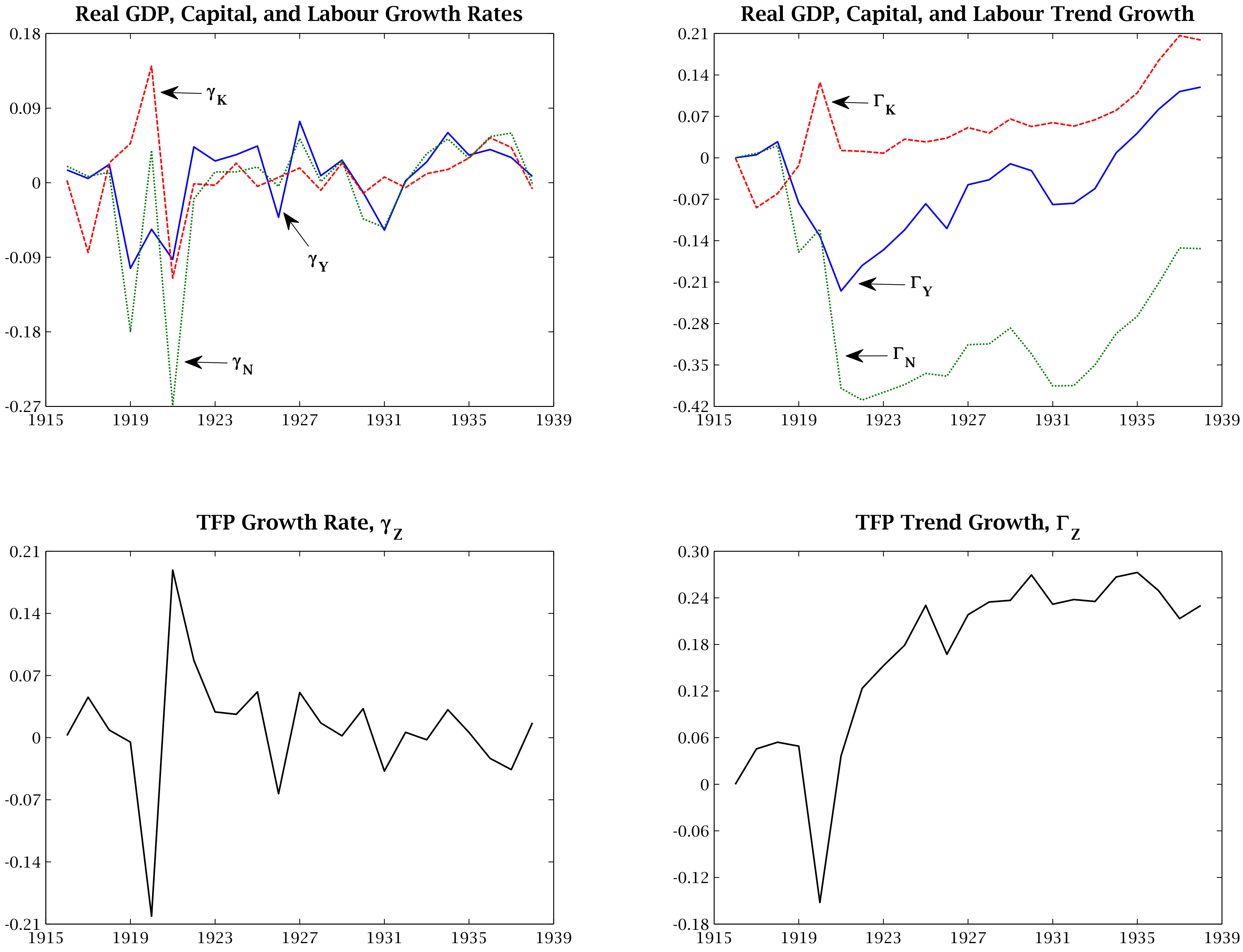
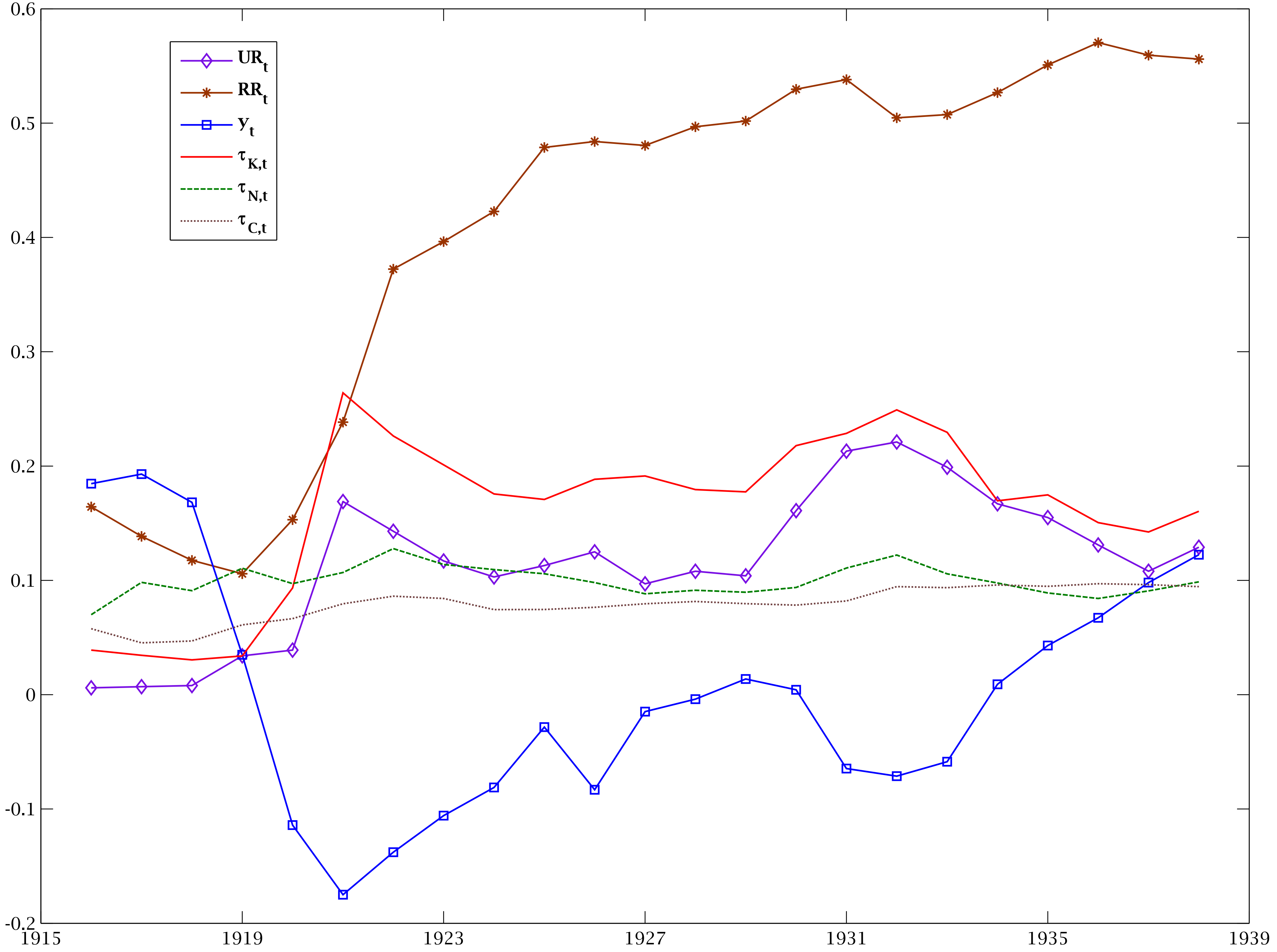


Fig. 4: Unemployment Rate, Replacement Ratio, Detrended Output, and Average Tax Rates, 1916-1938



Appendix

This appendix describes the sources and construction of the income growth accounting and Benjamin and Kochin (1979) regression time series.

A.1 UK Growth Accounting Data

Feinstein (1972) and Mitchell (1988) are the primary sources of our U.K. national income, tangible capital stock, per capita hours worked, and employment data. We obtain nominal national income from the "Compromise GDP" measure reported in Feinstein (1972, T12–T13). This nominal GDP series is in millions of current pounds at factor cost. The series is revised and extended by Mitchell (1988, p. 836). A real GDP index is reported by Feinstein (1972, T19) on a "compromise" basis with 1913 the base year 1913. Mitchell (1988, p. 836) revises and extends the nominal GDP and real GDP index. Our real output series is calculated by scaling the real GDP index with the 1913 nominal GDP observation. The real capital stock equals the net capital stock in million of current pounds found in Mitchell (1988, pp. 865–866), scaled up by the inverse of one minus a fixed depreciate rate (equal to 0.109), and adjusted to the 1913 base year using the implied "compromise GDP" deflator. As discussed in the section 2.2, per capita hours worked relies on the sum of civilian and armed services employment to measure total employment. The employment series are available in Feinstein (T126–7) measured in thousands of workers.

A.2 Benjamin and Kochin (1979) Regression Data

This appendix describes the Benjamin and Kochin (1979) regression variables. Benjamin and Kochin's unemployment rate series is found in Ormerod and Worswick (1982, table 1) from 1920 to 1938, which is taken from Feinstein (1972, T128). He provides unemployment rate data that is based on those workers covered by unemployment insurance. The 1919 observation is also given by Feinstein (1972, T126), whose data sources are trade union records. Mitchell (1988, p. 124) reports additional observations for the 1913–1918 period using similar sources and definitions. The 1913–1918, 1919, and 1920–1938 data are combined to obtain the unemployment rate, UR_t.

Ormerod and Worswick (1982) provide the replacement ratio series. Benjamin and Kochin calculate the series using average weekly wages of full-time employees from Chapman (1953) and benefit entitlements of an adult male with a spouse and two children from Burns (1941, table XI, p. 368). Benefits data prior to 1920 is also from Burns, but average weekly wages are from Feinstein (1972, T140) rather than Chapman. The pre-1920 data and Benjamin and Kochin's preferred series are spliced together to form the replacement ratio, RR_t, that the paper employs.

Benjamin and Kochin's output series is also found in Ormerod and Worswick (1982). They use real net national product at millions of 1938 pounds at factor cost that is available from Feinstein (1972, T15). This source also supplies observations from 1913 to 1919. Note that real net national product is not per capita. Subsequent to taking the log of real net national product from 1916 to 1938, it is regressed on an intercept and time trend. The regression residuals form y_t. The same procedure is used to create y_t on the 1920–1938 sample.

We use Benjamin and Kochin's preferred series in the regressions. This avoids issues of comparing our results to Benjamin and Kochin's and measurement problems discussed in the economic history literature. Nason and Vahey (2006) provide a summary and references of these problems. We experimented with alternative measures of UR_t, y_t, and RR_t that have been discussed in the literature. Our empirical results are robust across the alternative variable measures. Although there are a few differences in the levels across alternative variable measures, these variables exhibit qualitatively similar comovement with the UR_t in the 1920–1938 sample.

Table A1: UK GDP, Capital, Employment, and Population, 1913–1938

	Nominal GDP	Real GDP Index	Net Capital Stock	Civilian Employment	Military Employment	Population
1913	2244.0	100.0	4565.0	19910.0	400.0	45649.0
1914	2278.0	102.3	4642.0	19440.0	810.0	46049.0
1915	2746.0	108.8	5298.0	18400.0	2490.0	46340.0
1916	3218.0	110.9	6131.0	17700.0	3500.0	46514.0
1917	4082.0	111.7	7112.0	17100.0	4250.0	46614.0
1918	4920.0	114.1	8588.0	17060.0	4430.0	46575.0
1919	5202.0	102.8	10558.0	19030.0	2130.0	46534.0
1920	5439.0	91.3	13440.0	19537.0	760.0	43718.0
1921	4578.0	83.9	11060.0	17417.0	491.0	44072.0
1922	3995.0	88.2	9230.0	17483.0	392.0	44372.0
1923	3793.0	91.0	8510.0	17758.0	348.0	44596.0
1924	3877.0	94.8	8610.0	18032.0	346.0	44915.0
1925	4113.0	99.4	8700.0	18238.0	350.0	45059.0
1926	3870.0	95.7	8590.0	18244.0	349.0	45232.0
1927	4079.0	103.4	8560.0	18789.0	347.0	45389.0
1928	4103.0	104.7	8460.0	18868.0	336.0	45578.0
1929	4214.0	107.8	8660.0	19146.0	333.0	45672.0
1930	4185.0	107.0	8590.0	18788.0	327.0	45866.0
1931	3843.0	101.5	8410.0	18340.0	325.0	46074.0
1932	3746.0	102.3	8130.0	18430.0	323.0	46335.0
1933	3776.0	105.3	8080.0	18813.0	323.0	46520.0
1934	4016.0	112.2	8220.0	19360.0	325.0	46666.0
1935	4197.0	116.5	8560.0	19704.0	333.0	46868.0
1936	4389.0	121.8	9080.0	20321.0	349.0	47081.0
1937	4708.0	126.1	9860.0	20987.0	377.0	47289.0
1938	4959.0	127.6	10230.0	20986.0	432.0	47494.0

Nominal GDP is in millions of current year pounds, at factor prices. The net capital stock is also measured in millions of current year pounds. Civilian employment, military employment, and population are in thousands of individuals. Appendix A.1 contains details about the national income, employment, and population data.

Table A2: UK Unemployment Rate, Replacement Rate, and Real Net National Product, 1913–1938

	Unemployment Rate	Replacement Rate	Real Net National Product
1913	3.60	19.80	4085
1914	4.20	19.68	4118
1915	1.20	17.91	4469
1916	0.60	16.43	4515
1917	0.70	13.85	4579
1918	0.80	11.75	4492
1919	3.40	10.58	3954
1920	3.90	15.31	3426
1921	16.90	23.84	3242
1922	14.30	37.23	3384
1923	11.70	39.64	3514
1924	10.30	42.27	3622
1925	11.30	47.87	3840
1926	12.50	48.39	3656
1927	9.70	48.04	3937
1928	10.80	49.68	4003
1929	10.40	50.18	4097
1930	16.10	52.96	4082
1931	21.30	53.81	3832
1932	22.10	50.46	3828
1933	19.90	50.74	3899
1934	16.70	52.67	4196
1935	15.50	55.09	4365
1936	13.10	57.04	4498
1937	10.80	55.94	4665
1938	12.90	55.60	4807

The UK unemployment and replacement rates are in percentages. Real net national product is in millions of 1938 pounds at factor cost. Appendix A.2 discusses the sources of the unemployment rate (UR_t) and replacement rate (RR_t), along with estimating linear detrended output (y_t) as the residual of log real net national product on an intercept and time trend.