Irish GDP between the Famine and the First World War

Estimates Based on a Dynamic Factor Model

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Abstract

A major issue in Irish economic history is the lack of national accounts before the interwar period. This paper constructs new annual estimates of real GDP between 1842 and 1913 based on a novel two-stage econometric approach. Our results show that while living standards approximately tripled in this period, development was uneven with contractions in economic activity not only during the Great Famine but also between the late 1890s and the First World War. As a proof of concept, we also apply our methodology to Swedish data. The resulting estimates closely match existing historical national accounts.

Keywords: Ireland, GDP, Famine, Historical national accounts

JEL: C38, E01, N13

1. Introduction

Historical national accounts (HNAs) are a major input into important economic and historical debates, such as comparisons of living standards across time and space, and the causes and consequences of major macroeconomic events. In recent years there has been a wave of HNAs back to the Middle Ages for a number of European countries such as Britain (Broadberry *et al*. 2015a), Germany (Pfister 2011), Holland (van Zanden and van Leeuwen 2012), Italy (Malanima 2011), Portugal (Reis *et al*. 2013), Spain (Álvarez-Nogal and Prados de la Escosura 2013) and Sweden (Schön and Krantz 2012).

Ireland lies on the periphery of this development with no consistent HNAs before the 1930s (Gerlach and Stuart 2015) except for some scattered benchmark estimates for the nineteenth and early-twentieth centuries (Geary and Stark 2015). The fundamental problem is the scarcity of data for the underlying components of traditional HNAs. As a result, we know less about the macroeconomic impact of the Great Famine of 1845, for example, than we do of the Black Death in England 500 years before.

This paper proposes a solution to the standstill, which can be applied in other contexts in economic history for which similar conditions prevail. Building on the business cycle literature that identifies the cycle using factors models (Sarferaz and Uebele 2009; Ritschl *et al*. 2016), we develop a two-stage approach to estimate GDP. In the first stage, a dynamic factor model is estimated to identify the common movement in a set of key macroeconomic variables. The data set includes those sub-components of GDP that are available (on the expenditure, income and output sides), as well as the growing body of high-quality macroeconomic time series that are in theory correlated with GDP, such as monetary aggregates (Kenny and Lennard 2017) and share prices (Hickson and Turner 2008; Grossman *et al.* 2014). A problem with dynamic factor models is that the resulting index is unitless. In the second stage, we therefore normalize the index against existing benchmarks of GDP. This normalization gives the index an economic interpretation.

As a proof of concept, we apply the new method to Swedish data. Not only are the Swedish HNAs relatively accurate, but the two economies were similar in this period, consisting of large agricultural and external sectors. This experiment shows that the methodology captures both the short- and long-run movements in existing estimates of real GDP, which demonstrates that our method is a viable alternative to traditional HNAs.

A number of results emerge from the new estimates of Irish real GDP between 1842 and 1913. First, living standards effectively tripled between the Famine and the First World War.

Second, the volume of economic activity contracted by 21% during the Great Famine. This contraction is the largest in the known economic history of Ireland (Gerlach and Stuart 2015). Third, from the late 1890s to the Great War, the standard of living declined. This slump may have been related to the political uncertainty associated with the possibility of Irish independence.

Section 2 discusses the existing literature on Irish GDP prior to the First World War. Sections 3 and 4 set out the methodology and data respectively. Section 5 presents the new annual estimates of real GDP. Section 6 assesses the sensitivity of the results to a number of alternative specifications. The final section concludes.

2. Historical national accounts for Ireland

There are numerous, potentially irreconcilable, challenges in constructing HNAs for Ireland. The fundamental issue is that, whether calculated on either the expenditure, income or output side, HNAs require a critical mass of time series data. Although a great deal of work has gone into the production of such data, the critical mass has seemingly not been reached. In fact, as a consequence of the integration of Ireland and Great Britain in the nineteenth century, there are real limitations to the volume of statistics that can ever be collected in the future.[1] On the expenditure side, for example, comprehensive trade data is lacking between 1825 and 1904 (Solar 1990a). Not only is this a component of GDP, probably an important one in the Irish case, it is also used to calculate consumption. In terms of income, while the income tax returns are a promising source of information, there are serious issues relating to their reliability and consistency over time.[2] Finally, on the output side, among other issues,

[1] The United Kingdom consisted of the kingdoms of Great Britain and Ireland between 1800 and 1921. In this paper, references to the United Kingdom relate to both kingdoms, while references to Great Britain relate to that kingdom alone.

[2] See Begley *et al.* (2010) for details.

progress is limited by the lack of an input-output table, which has been used in the case of Britain, for example, to establish sectoral weights (Broadberry *et al*. 2015a).

In the absence of HNAs, two approaches have typically been followed in the literature. The first approach has been to construct proxies of GDP. O'Rourke (1998) multiplied estimates of velocity by a measure of the broad money supply to give nominal "GDP" for the years between 1845 and 1913. However, if velocity were known, then so would GDP, as the former can only be calculated by dividing the latter by the money supply. Therefore, O'Rourke regresses velocity on a number of variables for other European countries, and plugs in Irish data to get an out-of-sample forecast of Irish velocity. The exercise showed that GDP fell in nominal terms by a quarter during the Famine, but was three times as high on a per capita basis by the First World War. However, O'Rourke notes that "it would be foolish to use such numbers to track annual variations in GDP, or even to estimate growth rates over the period as a whole."

The second approach has been to produce a number of point estimates of national income and expenditure.[3] Mokyr (1985, p. 11) placed income on the eve of the Famine at £75-85 million, or £9-10 per capita. However, the calculations involved rest upon the assumption that the income of the poorest two-thirds of the population, which can be approximately measured, "received about a third of total income" (Mokyr 1985, p. 11). The next point estimates relate to the twentieth century. Bielenberg and O'Mahony (1998), making use of the first census of production, valued GDP on the expenditure side at market prices at £144 million in 1907. Cullen (1995), also making use of the 1907 census of production in addition to the 1911 census of population, estimated that GNP on the income side at market prices amounted to £139 million in 1911.[4]

[3] See Cullen (1995) for an interesting discussion of contemporary estimates of national income.

[4] Ó Gráda (1994, pp. 379-82) reworks this figure and arrives at £130-40 million for pre-war GNP.

At the frontier of the literature are the point estimates for 1861, 1871, 1881, 1891, 1901 and 1911 produced by Geary and Stark (2002, 2015). This too is a proxy or "short-cut" approach relative to HNAs because it distributes UK GDP on the basis of regional sectoral productivity (as measured by wages) and employment. The estimates are limited to every tenth year because they rely on employment information contained only in the census returns of those years. The numbers show that real GDP increased from £97.2 million in 1861 to £123.5 million in 1911.

3. Methodology

This paper develops a new two-stage methodology to estimate the level of real GDP. The first stage estimates a dynamic factor model for a set of time series representing a wide range of economic activity. However, the factors are unitless and have no economic interpretation. The second stage, therefore, normalizes the factors using existing benchmarks of GDP, which gives the factors an economic interpretation.

Dynamic factor models have been used previously in the estimation of business cycle fluctuations in both contemporary (Stock and Watson 1989) and historical (Sarferaz and Uebele 2009; Ritschl *et al*. 2016) contexts. The basic idea is that a time series is likely to be influenced by one or potentially more common factors as well as an idiosyncratic component. For example, consider the money supply and construction. The series might be driven by a number of common components such as economic activity and interest rates. In addition, each series might also be made up of idiosyncratic shocks, such as the introduction of a new payments technology in the case of the money supply and a land-use planning reform in the case of construction. Factor analysis enables the estimation of these unobserved common factors from which the business cycle is then identified. We extend this approach to estimate not only the business cycle but also the level of GDP.

To make the discussion more concrete, consider the following dynamic factor model:

$$x_{it} = \sum_{j=1}^{J} \alpha_{ij} f_{jt} + \varepsilon_{it} \quad (1)$$

$$f_{jt} = \sum_{k=1}^{K} \beta_{jk} f_{jt-k} + \vartheta_{jt} \quad (2)$$

where x_{it} is one of $i = 1, \dots, I$ time series. f_{jt} is one of $j = 1, \dots, J$ common factors that are assumed to be independent of each other. The α's are the factor loadings, which gives the relationship of the respective variable to the respective factor. ε_{it} and ϑ_{jt} are independent and normally distributed idiosyncratic error terms.

Two key issues arise relating to identification. First, if there is more than one factor, which factor or combination of factors represents GDP? To return to the example, it is not clear which of the two common factors is related to economic activity and which to interest rates. This problem is usually solved in the business cycle literature by assuming that the first factor, i.e. the factor that accounts for the most variability in the data, represents the business cycle (Breitung and Eickmeier 2006).

Second, the factors are never identified independent of the factor loadings. This implies that the size and sign of the estimated factor(s) can be large or small depending on the assumption imposed on the loadings. Changing the loading assumptions changes the estimates of the factors. This problem is often solved by imposing various (ad hoc) identifying assumptions to normalize the factors such that they can be interpreted as representing the business cycle.

In the second stage, the factors are cumulated into an index, which are then regressed on existing benchmarks of GDP. This stage agnostically identifies which factor or factors are correlated with GDP, but also helps to scale the indices, which are unitless, to the same units as the benchmarks. The identification issues are therefore resolved without resorting to ad hoc assumptions.

The estimates are based on the following steps:

1) All nominal variables are deflated into real terms.
2) The first difference of the log of non-stationary variables is taken: $\Delta x_{it} = \ln(X_{it}) - \ln(X_{it-1})$. This transformation is necessary since the factor model requires that the data is stationary.
3) A principal component (PCA) model is estimated to identify the number of significant factors in the data. Dynamic factor models require that the number of factors to be estimated is specified. Estimating too few factors may cause biased estimates of the factors, while estimating too many quickly reduces the degrees of freedom and the precision of the estimates. The sensitivity of the results to the number of factors included in the dynamic factor model is shown in section 6.
4) The dynamic factor model is estimated by maximum likelihood with a Kalman filter. In section 6, we show that the results are robust to the choice of estimator.
5) As the model is estimated in log-growth rates, the factors also represent growth rates. To obtain an estimate of the level, an index is constructed by cumulating the respective factor: $\hat{I}_{jt} = \hat{I}_{jt-1} + \hat{f}_{jt}$, where $I_{-1} = 0$. Our estimation of the level using growth rates is similar to the approach of Bai and Ng (2004) who estimate non-stationary common factors using stationary growth rates, before cumulating them into levels.
6) Alternative combinations of the indices are regressed on the benchmark estimates from Geary and Stark (2015): $\ln(Y_t) = \gamma_0 + \sum_{j=1}^{J} \gamma_j \hat{I}_{jt} + \omega_t$.

7) The vector of coefficients of the model that minimizes information criteria is multiplied by the respective annual indices to arrive at annual estimates of GDP: $\ln(\hat{Y}_t) = \hat{\gamma}_0 + \sum_{j=1}^{J} \hat{\gamma}_j \hat{I}_{jt}$.

It is worth making two points on the methodology at this point. First, the annual estimates of GDP, and growth rates between various points, are not fixed to the benchmarks in the second-stage regression. The estimates are free to take on any value in any given year. The only restriction imposed is that the average (log) deviation is zero. If the results are close to the benchmarks, then this validates the quality of the benchmarks and our model.

Second, time series are often measured with error, particularly in a historical context. As GDP is the sum of its underlying components, error in their measurement will affect the estimate of GDP, with the bias given by the ratio of the error to the true value of GDP. In a dynamic factor model, the measurement error is likely to be captured by the idiosyncratic component, ε_{it}, not by the common factor, f_{jt}. Therefore, measurement error has a smaller effect on our estimates compared to other approaches.

4. Data

A new balanced data set, constructed from primary and secondary sources, is used to estimate GDP. The baseline model includes 20 time series covering seven categories: macroeconomic, government, agriculture, construction, manufacturing, private consumption and services (see table 1). The macroeconomic category includes population, currency in the hands of the public, interest rates, Poor Law recipients per capita, stock prices and wages. The government category includes government revenue. The agriculture category includes grain imports and oxen, pig and sheep exports. The construction category includes timber imports. The manufacturing category includes butter exports, distilling output, Guinness sales, linen cloth exports and shipbuilding. The private consumption category includes tobacco consumption per capita. The services category includes property transactions and rail revenue. The sources and transformations involved for each variable are discussed in table A1.[5]

A few variables are measured in nominal terms in the underlying sources, such as currency in the hands of the public, interest rates, stock prices, government revenue and rail revenue. In the absence of annual GDP estimates, it follows that a GDP deflator is also missing. To construct a deflator we calculate the median inflation rate across existing price indices. For the years up until 1870, Geary and Stark (2004) have constructed two cost of living indices: a Poor Inquiry index and a compromise index. The former is based on expenditure shares derived from official inquiries in the 1830s, while the latter is based on a "best guess at a typical budget for a household of four to six persons of the urban and rural waged labouring class" (Geary and Stark 2004). For the years between 1860 and 1913, Brunt and Cannon (2004) have constructed four cost of living indices: an unadjusted and adjusted series based on 1859 consumption weights and an unadjusted and adjusted series based on 1904 consumption weights. The inflation rates of these indices are plotted in figure 1. The median is preferred over splicing one series from Geary and Stark and another from Brunt and Cannon because it is not clear which of their series should be preferred. The median also has the advantage that it incorporates more information.[6]

FIGURE 1 ABOUT HERE

All variables are transformed into log first differences except the number of Poor Law recipients per capita and the real interest rate, which are first differenced. In a handful of

[5] While the data set captures a large share of economic activity, a number of other series would be useful such as agricultural output before 1850, output of bread and biscuits, clothing production and migration.

[6] This is also preferred to Kennedy's (2003) index that spans the entire period, as the basket of goods is comparatively light, while some of the prices are interpolated or proxied by their British counterparts.

cases, there are a small amount of missing observations, such as Poor Law recipients per capita (1899), government revenue (1889-91), oxen exports (1873) and tobacco consumption per capita (1871-5). In these instances, the gaps have been linearly interpolated.

All series are either important components of GDP, on the expenditure, income or output side, or are, in theory, correlated with it. In terms of the components of GDP, the data set covers the output of a number of major industries, such as linen, which "from the eighteenth century to the First World War, […] took centre stage as Ireland's premier industry and primary industrial export" (Bielenberg 2009, p. 177). Textiles and clothing accounted for a third of value added when the first census of production was taken in 1907 (Bielenberg 2008). Other important industrial sectors are also included, such as construction (proxied by timber imports); food, drink and tobacco; and iron, engineering and shipbuilding, which together accounted for half of value added in industry. In addition, wages, which were the largest component of factor incomes in the wider United Kingdom in this period (Mitchell 1988), are captured as well.

In terms of correlates of GDP, we have included an index of stock prices, among others, based on the efficient market hypothesis that these prices contain information about economic fundamentals. Hickson and Turner (2008) argue, "as stock-market performance is widely regarded as a bellwether for real economic activity, our indices can serve as a measure of the levels and fluctuations of real economic activity in Ireland during an important period in its economic development." A measure of equity prices was also used in Ritschl *et al*. (2016). Currency in the hands of the public (Kenny and Lennard 2017) is also included, based on the logic that monetary aggregates should be related to GDP through the quantity equation, given stable velocity. Bank notes, a large component of this aggregate, have been used in previous studies “as a good barometer of the level of economic activity” for this period in Irish history (Ó Gráda 1994, p. 178).[7]

The benchmark estimates used in step 6 for every tenth year between 1861 and 1911 are calculated as follows. Geary and Stark’s (2015) estimates of the Irish share of UK real GDP for these years are multiplied by Feinstein’s (Mitchell 1988) corresponding compromise estimate of UK real GDP.

5. Results

The estimated factor dynamics and factor loadings are shown in table 1. Following initial testing using PCA, two common factors are estimated: factor 1 (f_1) and factor 2 (f_2).[8] Also shown in the table is the variance of the idiosyncratic components. The first factor, f_1, captures a significant positive co-movement between the macroeconomic variables (with the exception of population and Poor Law recipients per capita), government revenue, manufacturing production, such as distilling output and linen cloth exports, and services, as measured by rail revenue, and a significant negative co-movement with grain imports and sheep exports. The second factor, f_2, captures a significant co-movement between population, currency in the hands of the public, Poor Law recipients per capita, grain imports, pig exports, timber imports and rail revenue.

TABLE 1 ABOUT HERE

Having obtained the dynamic factors, we then create an index for each factor and regress them on the six benchmark GDP estimates. These regressions are only performed to normalize the indices and the estimated parameters have no economic interpretation. As the

[7] Other examples in Irish economic history include Ollerenshaw (1987, pp. 82-3).

[8] The results of the PCA are shown in table C1.

regressions are only based on six observations, one should be careful when interpreting the parameters, standard errors and significance levels.

Three models are estimated to normalize the indices. The first model includes index 1 ($\hat{I}_1$). The second model includes index 2 ($\hat{I}_2$). The third model includes both indices ($\hat{I}_1$ and $\hat{I}_2$). Based on the results in table 2, the first model is preferred due to better performance in terms of information criteria.

TABLE 2 ABOUT HERE

The average (log) deviation between our estimate and the benchmarks of GDP is by construction zero. However, there is no guarantee that the deviations are small for each benchmark year. Nevertheless, the results in table 3 show that the estimates are close to all of the benchmarks. There is virtually no deviation in 1861, 1871, 1901 and 1911, while the largest relative error was -4.0% in 1881. This error is relatively small. For example, Feinstein's (Mitchell 1988) income and expenditure estimates of UK nominal GDP at factor cost differ by as much as 25% in a single year.

TABLE 3 ABOUT HERE

5.1 Irish economic growth

Figure 2 presents annual estimates of real GDP for Ireland between 1842 and 1913.[9] Expressed in constant 1913 prices, the aggregate level is plotted in the top panel, while the bottom panel is shown in per capita terms. The dashed lines are 95% confidence intervals,

[9] See table B1 for the underlying annual estimates.

which are based on the standard deviation of the residuals from the second-stage regression. Although there is some deviation between our estimates and the benchmarks, the latter lie within the 95% confidence intervals.

FIGURE 2 ABOUT HERE

The pace of Irish economic growth was impressive between 1842 and 1913. On an aggregate basis, the average rate of growth was 0.6% per year, which over the full period saw the size of the economy expand by 50%. On a per capita basis, the average rate of growth was 1.5%, which meant that living standards almost tripled. The measured increase in living standards is consistent with the literature. Ó Gráda (1994, p. 250) notes that "a whole series of proxies for living standards – wages, consumption, literacy, life-span, height, birth weight, argue for betterment between the Famine and the First World War." Cullen (1972, p. 138) efficiently summarized, "living standards rose" during this time.

As a result of the recent upsurge in the construction of HNAs, data for GDP per capita is available for nine European countries for the years 1842 and 1913. The average growth rate over this interval is displayed in table 4, descending in order from the fastest to slowest growing economies. In an international perspective, the increase in Irish living standards was high. Only in Sweden was per capita GDP growth in Europe greater.

TABLE 4 ABOUT HERE

The rapid increase in living standards following the Famine resembles the experience of European countries following the Black Death in the fourteenth century (Pamuk 2007). However, the success of the Irish economy to deliver higher living standards must be balanced by its failure to do so for a growing population, which declined from 8.3 million in 1845 to 4.3 million in 1913 (Mitchell 1988). Boyer *et al.* (1994) calculate that emigration raised per capita income by as much as 25%. Part of the increase in living standards is thus due to a falling population.

A striking feature of figure 2 is the slowdown in growth at the tail end of the nineteenth century. From the peak in 1896, output growth was -0.4% per year, relative to 0.8% after the recovery from the Famine. At the heart of the stagnation may be political uncertainty linked to the growing prospect of Irish independence. Hickson and Turner (2005) argue that "political economy led to an unexpected rise in the real discount rate", while Grossman *et al.* (2014) suggest that it may have also led to capital flight.

5.2 Business cycle fluctuations

Estimates of the Irish business cycle are presented for the first time in figure 3. Business cycles are of interest as they inflict welfare losses on society. The estimates are based on the new series of real GDP and a band pass filter. Specifically, a Maximum Overlap Discrete Wavelet Transform (MODWT) with a Daubechies (4) wavelet filter is used to retain cyclical components lasting 2 to 8 years.[10] The MODWT combines time and frequency resolution and can therefore estimate the cyclical component of GDP even in the presence of structural breaks, outliers and other non-recurring events. A chronology of turning points based on the business cycle is shown in table 5.[11]

FIGURE 3 ABOUT HERE

[10] For more information about the MODWT, see Percival and Walden (2006) and Andersson (2016).

[11] Note that the results are not sensitive to the filtering method. The correlation between the wavelet and Hodrick-Prescott estimates of the business cycle is 0.99.

TABLE 5 ABOUT HERE

The major event of the 1840s was, of course, the Great Famine. The macroeconomic consequence of this ecological disaster was severe. From the arrival of the potato blight in the autumn of 1845 to its passing in Black '47 (Ó Gráda 2007), real GDP declined by 21%. The lion's share of the decline operated through the business cycle, but there was also a reduction in trend output as well. In a comparative perspective, the output losses in the Great Famine in Ireland were far larger than those in the other major famines in the history of the British Isles. For example, output declined by little more than 1% during the Great European Famine that struck England between 1315 and 1317 (Broadberry *et al*. 2015a, p. 228). This confirms Solar's (1989) view that the Irish Famine was no ordinary subsistence crisis.

The estimates suggest that there was a strong recovery from the Famine. In 1848 and 1849 output grew by 14% and 9% respectively. This is perhaps hard to reconcile with the existing narrative, which suggests that 1848 was not a year of recovery but of continued hardship. The crude death rate was still particularly high, although less so than in 1847 (Vaughan and Fitzpatrick 1978; Mitchell 1988). Our approach, like all national accounts, measures market-based economic activity. It is possible that the recovery in non-market activity may have been somewhat different. If this was the case, then there would have also been implications for the distribution of income. In any case, the results show that output had returned to trend in 1849, while the level of GDP recovered in 1851.

The 1850s were hit by a number of major shocks. After the 1840s it was the most volatile decade of the period, as measured by the standard deviation of the cycle. The first shock came in 1854 when the real value of Irish output fell by 5%. This was the largest decline between the Famine and the First World War. The median cost of living index increased by 20%, which Lynch and Vaizey (1960, p. 146) associate with the Crimean war.

The inflation was not fully compensated for by nominal variables, such as currency, stock prices, interest rates and railway revenue, so that the real value fell. In addition, the quantity of real variables, such as distilling output and linen cloth exports also declined significantly. The trough was also associated with a bout of migration, with more than 2% of the population emigrating (Vaughan and Fitzpatrick 1978; Mitchell 1988). The next shocks were the financial crises of 1856 and 1857. The first of which saw the failure of the Tipperary Bank, while the second was associated with the international crisis. A negative output gap emerged in 1857 and 1858. Lastly, the extreme weather that began in the summer of 1859 and ended in 1864 led to a major agricultural depression (Turner 1996, pp. 30-2). The level of GDP fell by 4% between 1859 and 1860, while a negative output gap persisted into 1861.

The outbreak of the American Civil War coincided with the beginning of a short expansionary cycle. The linen industry, in particular, was stimulated by the subsequent cotton famine across the Atlantic – the value of Irish linen exports increased by 71% between 1861 and 1865 (Solar 2005). The trough in 1867 was associated with a sudden 17% collapse in the value of agricultural output (Turner 1996, pp. 108, 124). Interestingly, the Fenian Rising, a rebellion organised by the Irish Republican Brotherhood, flared during this depression. The link between economic hard times and the rise of Irish nationalism is a promising area for future research, which is now possible given the new estimates.

Agricultural crisis returned after the poor harvests of 1879-81 (Ó Gráda 1994, p. 250), leading to a spike in emigration (Vaughan and Fitzpatrick 1978). Yet the economy contracted by just 0.1% in this period, which supports Donnelly's (1976) view that this agricultural depression had less macroeconomic significance than that of 1859.

The major macroeconomic events are consigned to the history of the earlier period as opposed to the latter, but there are some further events of interest that are evident in the new series. The failure of the Munster Bank in 1885, the last major bank to do so before 2008 (Ó

Gráda 2012), was associated with below-trend output several years before the crisis. Its failure may have had its origin in the weak fundamentals of the time. Interestingly, the international crisis of 1907 emerges as a trough. In response to the crisis, the Bank of Ireland increased its discount rate from 4.5% in the spring to 7% in the autumn (Hall 1949, p. 389). As monetary policy had large real effects in the United Kingdom in this period (Lennard 2017), the Bank's response was potentially the source of reduced output as opposed to the panic itself.

There was a moderation of the business cycle after the 1870s. The standard deviation of the cycle fell by nearly three quarters in the period 1880-1913 relative to 1842-79. A possible cause of the decline in macroeconomic volatility is that agricultural output became much less variable from the 1880s. Grossman *et al.* (2014) find that equity price volatility also declined substantially between the 1880s and the Great War. Previous research has identified a link between macroeconomic volatility and stock market volatility (Beltratti and Morana 2006).

6. Robustness

In this section, we carry out a number of exercises to gauge the reliability of the new estimates. We first apply the method to Swedish data and compare the results to existing HNAs. Returning to Ireland, we then consider a number of alternative specifications, including estimating fewer factors, using a state-space model, including agricultural output instead of agricultural proxies and normalizing with both factors.

6.1 A proof of concept: estimates of Swedish GDP, 1842-1913

We first investigate whether our two-stage methodology works well for an economy with existing HNAs. While there are many possible candidates, we opt for Sweden for two reasons. First, as small, open economies, comparisons between Sweden and Ireland are well established (Kenny 2016). Second, a dynamic factor model has been estimated for the

Swedish economy in this period to estimate business cycles (Enflo and Morys 2013). As a result, we include exactly the same data, which constrains us from cherry-picking variables to match the existing estimates. The data set includes 15 variables that cover similar categories, such as macroeconomic, government, agriculture, construction and manufacturing, but is narrower in that it does not include private consumption or services. Using this data, we re-follow steps 1 to 7, again using the CPI instead of the GDP deflator in the first step, and using benchmarks of real GDP (Schön and Krantz 2012) in 1861, 1871, 1881, 1891, 1901 and 1911 in step 6.

FIGURE 4 ABOUT HERE

Figure 4 plots the estimates from the dynamic factor model along with the existing series of Swedish GDP. The figure shows that the model captures the broad contours of economic activity. There is a period between the late 1880s and 1900 when our estimates are consistently higher than the existing HNAs. However, the average deviation is only 3.8%. Beyond visual inspection, it is useful to measure how the model captures the short and long-run dynamics. In terms of the short-run, the correlation coefficient in first differences is 0.49, which is statistically significant at the 1% significance level. In terms of the long-run, if the two series share similar trends, any difference between the two should be temporary with the implication that the series are cointegrated. An Engel-Granger test of cointegration points to a significant $(p < 0.01)$ cointegrating relationship between the estimates from the dynamic factor model and the existing series. Thus, this example is a proof of concept that the two-stage methodology captures both the short and long-run movements in GDP.

6.2 *Alternative first- and second-stage regressions*

The next step is to test how sensitive the Irish estimates are to alternative first- and second-stage stage regressions.

Number of factors

In the first stage, we estimate a dynamic factor model with the number of factors determined by PCA. As a result, we included two factors in the baseline model. An alternative is to estimate a model assuming only one factor. Figure 5 plots the results from the baseline model and the associated confidence intervals, along with the estimates based on a single factor. Both estimates are similar with a correlation in first differences of 0.99 ($p < 0.01$). The results are, therefore, robust to an alternative number of factors included in the dynamic factor model.

FIGURE 5 ABOUT HERE

Econometric method

The results might also be sensitive to the econometric method used in the first-stage regression. The dynamic factor model was used as the baseline as it has become the standard in business cycle applications (Ritschl *et al*. 2016). However, a reasonable alternative is a state-space model, as used in Gerlach and Gerlach-Kristen (2005). Figure 6 shows that the results are not materially sensitive to the choice of econometric method. The state-space estimates lie within the 95% confidence interval of those of the dynamic factor model. The correlation between the two in first differences is 1.00 ($p < 0.01$).

FIGURE 6 ABOUT HERE

Choice of data

The variables included in the first-stage regression are carefully chosen to represent a wide range of economic activity. Agriculture was a major sector of the Irish economy, employing roughly half of the labour force (Geary 1998; Geary and Stark 2002). In the baseline model, four components of agricultural output are included. However, from 1850 the gross output of the aggregate agricultural sector is available, which is a broader indicator than we use in the main specification. Figure 7 shows the results from a model with the volume of agricultural output included in place of the proxies, alongside the baseline estimates. Again, the results are very similar to the baseline with a correlation in first differences of 0.96 ($p < 0.01$) over the common sample.

FIGURE 7 ABOUT HERE

Normalizing with two factors

In terms of the second-stage regression, only the first factor was used in the normalization. However, it is useful to explore whether using both factors leads to markedly different estimates of GDP. Figure 8 shows that this is not the case. The two estimates are much the same, except that normalizing with both factors suggests a slightly lower level before the Famine and a stronger recovery. Nonetheless, the correlation in first differences is 0.87 ($p < 0.01$).

FIGURE 8 ABOUT HERE

Summary

In summary, the baseline results are robust to a number of alternative specifications, including estimating fewer factors, using a state-space model, including agricultural output instead of agricultural proxies and normalizing with both factors.

7. Conclusion

A major issue in Irish economic history is the lack of historical national accounts prior to the 1930s. The fundamental issue is a lack of data on either the expenditure, income or output side. This paper introduces an alternative methodology, based on a dynamic factor model, to make use of the available time series evidence. The included series cover the five largest industrial sectors, which together accounted for more than 80% of industrial output when the first census was taken in 1907. The agricultural sector was captured by a series of proxies as agricultural output was not available for the full sample. However, its inclusion for a restricted sample has no bearing on the results. The estimates are also robust to a number of other specifications.

The new annual estimates of real GDP point to three major findings. First, living standards improved by 1.5% per year between 1842 and 1913. Second, output declined by almost a quarter during the Famine, which is the largest contraction in recorded Irish economic history. Third, economic activity fell from a peak in 1896 to the First World War. The decline was associated with the rising possibility of Home Rule, which has been linked to a rise in the real discount rate and capital flight.

Historical national accounts for the nineteenth century are the holy grail of Irish economic history. While the approach of this paper does not reach those heights by traditional means, it is surely an improvement on focusing on a single time series on blind faith that it is a bellwether of wider economic activity. Even if the “tantalizing dream” (Kennedy 1997) is achieved in the future by standard means, an alternative indicator of economic activity, with well-measured inputs from other sectors such as finance, would surely be a complement to, as opposed to a substitute for, HNAs.

The approach is potentially useful in other contexts where the construction of HNAs is held back by a lack of data. Benchmarks are available, for example, for colonial India (Broadberry *et al*. 2015b) and for Japan between the eighth and nineteenth centuries (Bassino *et al*. 2015). In combination with annual data that are commonly available, such as wages, prices, trade, government revenue etc., it is possible to construct estimates of the level of annual GDP using the two-stage method developed in this paper. This approach may also be valuable for modern developing economies, where existing GDP data is unreliable (Jerven 2013).

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Appendix A

Table A1. *Data and sources*

Variables and units	Sources and notes
Population (number)	Mitchell (1988). Mid year
Real currency in the hands of the public (£)	Nominal series from Kenny and Lennard (2017). Deflated using median cost of living index
Real interest rate (%)	Nominal series from Hall (1949). Weighted annual average of discount rate on 3 month Irish bills. Deflated using median cost of living index
Poor Law relief recipients per capita (number)	Number of indoor recipients from Thom's Irish Almanac (various years). 1899 linearly interpolated due to missing observation. Population from Mitchell (1988)
Real stock prices (1825=100)	1840-64: Hickson and Turner (2008), 1865-1913: Grossman *et al*. (2014). Multiplicatively spliced. Year end. Weighted by market capitalization. Deflated using median cost of living index
Real wages (1900=100)	Williamson (1995). PPP-adjusted for unskilled labour
Real government revenue (£)	1840-81: House of Commons (1886), 1882-1913: Thom's Irish Almanac (various years). Sum of customs, excise and stamp duties and income tax revenues. 1889-1891 linearly interpolated due to missing observations. Deflated using median cost of living index
Grain imports (1,000 hundredweight)	Brunt and Cannon (2004)
Oxen exports (100 head)	1840-4: Solar (2006), 1845-1913: Solar (1987). Multiplicatively spliced. 1873 linearly interpolated due to missing observation
Pig exports (100 head)	1840-4: Solar (2006), 1845-1913: Solar (1987). Multiplicatively spliced
Sheep exports (100 head)	1840-4: Solar (2006), 1845-1913: Solar (1987). Multiplicatively spliced
Timber imports (loads)	Bielenberg (2009). Total imports spliced backwards from 1904 using growth rate in imports from foreign
Butter exports (hundredweights)	Solar (1990a)
Distilling output (proof gallons)	Bielenberg (2003)
Guinness sales (bulk barrels)	Hughes (2006). Porter and extra stout
Linen cloth exports (1,000 yards)	1840-52: Solar (1990b), 1853-1913: Solar (2005)
Shipbuilding (tonnage)	Bielenberg (2009). Capacity of new ships built
Tobacco consumption per capita (pounds)	Bielenberg and Johnson (1998). On which duty was paid. 1871-5 linearly interpolated due to missing observations
Property transactions (number)	O'Rourke and Polak (1994)
Real rail revenue (£)	Thom's Irish Almanac (various years). Deflated using median cost of living index
Median cost of living index (1913=1)	1840-70: Geary and Stark (2004), 1860-1913: Brunt and Cannon (2004)
Agricultural output (1850=100)	Turner (1996). Chained Laspeyres quantity index

Appendix B

Table B1. *New estimates of real GDP and real GDP per capita (1913 prices), 1842-1913*

Year	Real GDP (£ millions)	Real GDP per capita (£)	Year	Real GDP (£ millions)	Real GDP per capita (£)
1842	80.96	9.85	1878	112.36	21.27
1843	87.04	10.56	1879	110.70	21.02
1844	86.04	10.39	1880	111.75	21.48
1845	89.55	10.80	1881	110.54	21.48
1846	78.89	9.52	1882	111.97	21.95
1847	70.78	8.82	1883	112.83	22.46
1848	80.38	10.52	1884	114.37	22.99
1849	87.77	12.10	1885	116.02	23.49
1850	87.98	12.79	1886	118.55	24.16
1851	90.46	13.89	1887	118.46	24.39
1852	94.29	14.88	1888	118.95	24.78
1853	93.46	15.08	1889	120.65	25.36
1854	88.51	14.55	1890	120.63	25.57
1855	94.17	15.66	1891	117.18	25.04
1856	100.64	16.85	1892	119.77	25.85
1857	96.77	16.35	1893	122.24	26.53
1858	97.05	16.47	1894	123.04	26.81
1859	102.11	17.42	1895	125.93	27.62
1860	98.09	16.85	1896	129.70	28.56
1861	98.36	16.99	1897	128.52	28.37
1862	100.80	17.45	1898	128.23	28.38
1863	102.29	17.89	1899	128.54	28.55
1864	102.79	18.22	1900	125.26	28.03
1865	101.16	18.08	1901	125.03	28.11
1866	99.72	18.05	1902	126.09	28.43
1867	97.79	17.82	1903	126.91	28.73
1868	99.20	18.15	1904	125.96	28.58
1869	102.62	18.83	1905	124.31	28.26
1870	104.18	19.22	1906	126.27	28.71
1871	105.10	19.47	1907	122.36	27.88
1872	104.78	19.50	1908	122.35	27.90
1873	105.60	19.82	1909	123.93	28.25
1874	106.52	20.10	1910	123.93	28.26
1875	108.85	20.62	1911	123.58	28.21
1876	111.17	21.06	1912	121.70	27.86
1877	110.65	20.93	1913	121.25	27.90

Appendix C

We use a PCA to determine the number of factors to be estimated in the dynamic factor model. It is possible to estimate the PCA either using the covariance matrix or the correlation matrix. The principal components are ranked such that the first component explains most of the variation in the data set, the second component explains the second most variation and so on. Table C1 shows that the first principal component explains 31.8% of the variation if the PCA is estimated using the covariance matrix (second column) and 23.6% if it is estimated using the correlation matrix (third column). The second component explains either 25.3% (covariance) or 14.0% (correlation). The remaining components account for a smaller share of the variation. The differences in results between the covariance and the correlation based estimates are explained by some of our variables having a higher variation compared to other variables.

Table C1. *Variance explained by principal components (%)*

	Covariance	Correlation
PC1	31.8	23.6
PC2	25.3	14.0
PC3	14.6	8.9
PC4	6.8	7.3
PC5	5.3	6.5
PC6	4.1	5.8

The estimation of the dynamic factor model includes up to two factors given the PCA results. We also allow the variance of the idiosyncratic components to vary to account for differences in volatility.

Table 1. *Estimated factor loadings and variance of idiosyncratic component, 1842-1913*

		Factor 1	Factor 2	Variance of idiosyncratic component
Macroeconomic	Population	0.12 (0.08)	0.35*** (0.07)	0.16*** (0.04)
	Real currency in the hands of the public	11.78*** (1.74)	3.57* (2.03)	109.04*** (21.57)
	Real interest rate	9.10*** (1.72)	-2.44 (1.76)	135.71*** (25.59)
	Poor Law recipients per capita	0.08 (0.13)	-0.62*** (0.09)	0.37*** (0.10)
	Real stock prices	10.82*** (1.16)	1.47 (1.70)	27.76*** (8.01)
	Real wages	3.81*** (0.75)	-0.37 (0.79)	29.71*** (5.23)
Government	Real government revenue	8.77*** (1.18)	0.70 (1.45)	55.02*** (10.65)
Agriculture	Grain imports	-19.61*** (4.44)	-9.49** (4.28)	948.32*** (170.33)
	Oxen exports	-4.28 (2.77)	-2.30 (2.40)	486.54*** (81.85)
	Pig exports	2.65 (3.88)	8.73** (3.45)	797.78*** (140.24)
	Sheep exports	-8.96*** (3.22)	-1.71 (2.98)	637.40*** (107.81)
Construction	Timber imports	2.01 (2.45)	3.97** (2.02)	357.89*** (60.69)
Manufacturing	Butter exports	1.19 (1.02)	1.12 (0.87)	64.80*** (10.90)
	Distilling output	4.50*** (1.44)	1.08 (1.33)	123.40*** (20.94)
	Guinness sales	0.19 (1.11)	0.13 (0.96)	79.86*** (13.31)
	Linen cloth exports	3.90*** (1.10)	0.22 (1.03)	72.05*** (12.26)
	Shipbuilding	-7.15 (6.14)	6.20 (5.03)	2359.80*** (396.62)
Private consumption	Tobacco consumption per capita	0.65 (0.62)	0.63 (0.54)	23.55*** (3.96)
Services	Property transactions	1.16 (1.74)	-0.03 (1.43)	198.24*** (33.06)
	Real rail revenue	13.39*** (1.79)	-4.18* (2.21)	91.12*** (22.33)
	Factor dynamics	0.06 (0.13)	0.63*** (0.12)	

Notes: Standard errors in parentheses. *** Statistically significant at 1% level, ** statistically significant at 5% level, * statistically significant at 10% level.

Table 2. *Normalization of indices, 1861-1911*

	Model 1	Model 2	Model 3
Constant	4.374*** (0.047)	4.211*** (0.121)	4.309*** (0.079)
Factor 1	0.037*** (0.005)		0.028** (0.010)
Factor 2		-0.04** (0.010)	-0.012 (0.012)
Adjusted R^2	0.923	0.779	0.924
Schwarz information criterion	-25.140	-18.832	-25.122

Table 3. *Estimates of real GDP and benchmarks (£ millions), 1861-1911*

	Benchmarks	New estimates	Difference (%)
1861	97.21	98.36	1.18
1871	105.02	105.10	0.08
1881	115.20	110.54	-4.04
1891	113.41	117.18	3.32
1901	125.58	125.03	-0.44
1911	123.51	123.58	0.05

Table 4. *Average growth of real GDP per capita in Europe (%), 1842-1913*

	Average growth rate
Sweden	1.6
Ireland	1.5
Denmark	1.5
Norway	1.3
France	1.3
Great Britain	1.1
Netherlands	0.8
Italy	0.5
Greece	-0.1
Average	1.1

Source: British data from Thomas and Dimsdale (2017). Other data from Bolt and van Zanden (2014).

Table 5. *Chronology of the business cycle, 1842-1913*

Peak	Trough	Peak	Trough
1845	1847	1880	1881
1849	1854	1886	1888
1856	1858	1889	1891
1859	1861	1893	1894
1864	1867	1896	1900
1870	1874	1903	1905
1876	1877	1906	1907
1878	1879	1911	

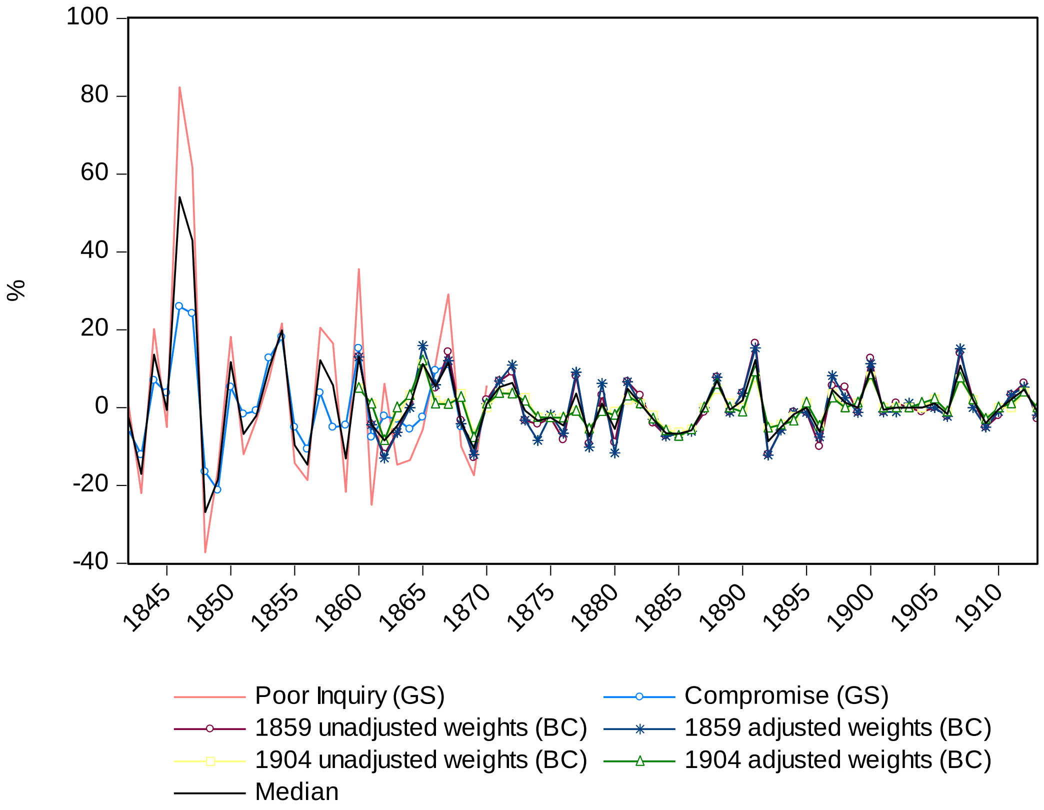

Figure 1. *Comparison of inflation estimates, 1842-1913*
Notes and sources: *BC = Brunt and Cannon (2004), GS = Geary and Stark (2004).*

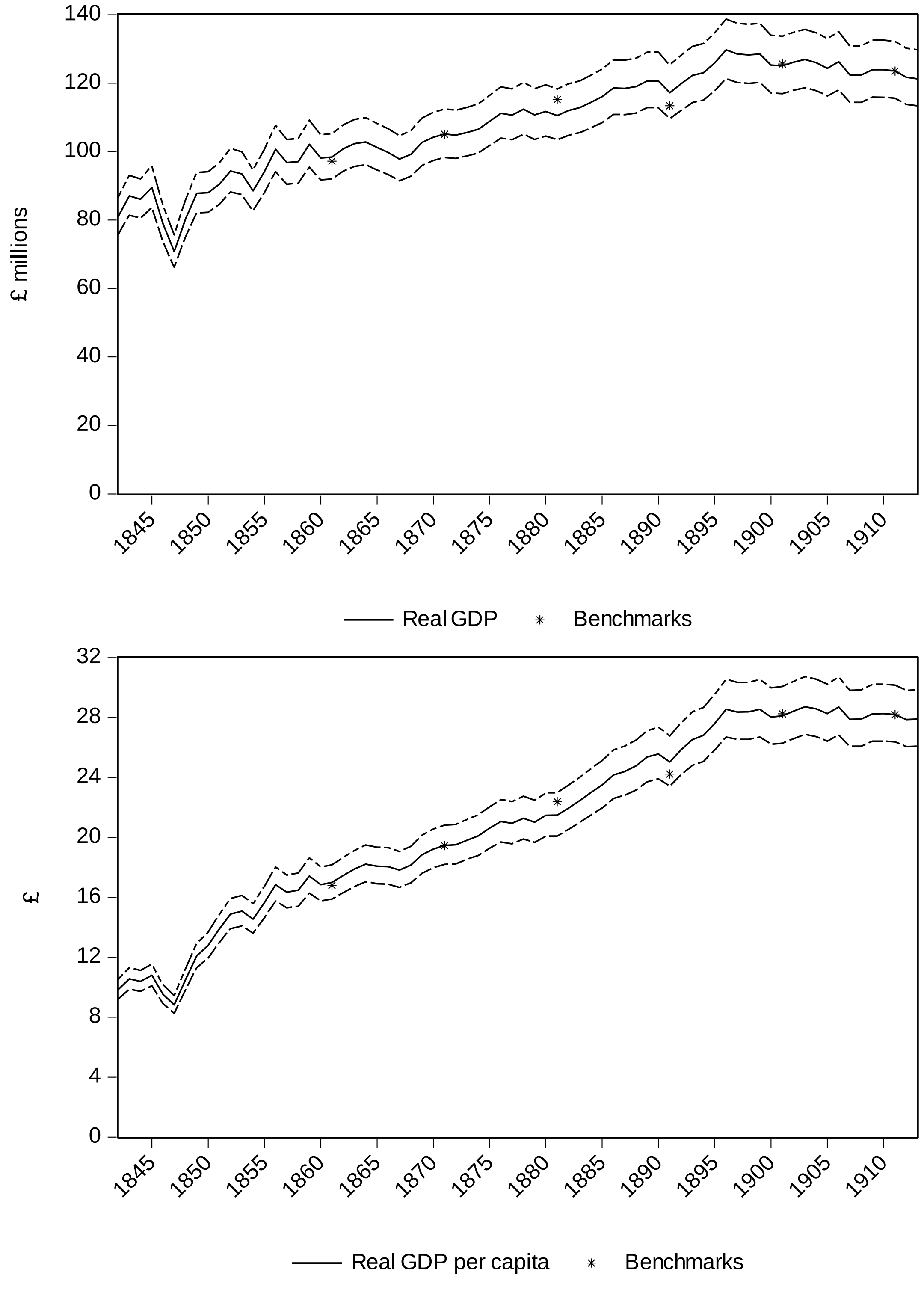

Figure 2. *Estimates of real GDP and real GDP per capita, 1842-1913*
Note: *Dashed lines are 95% confidence bands.*

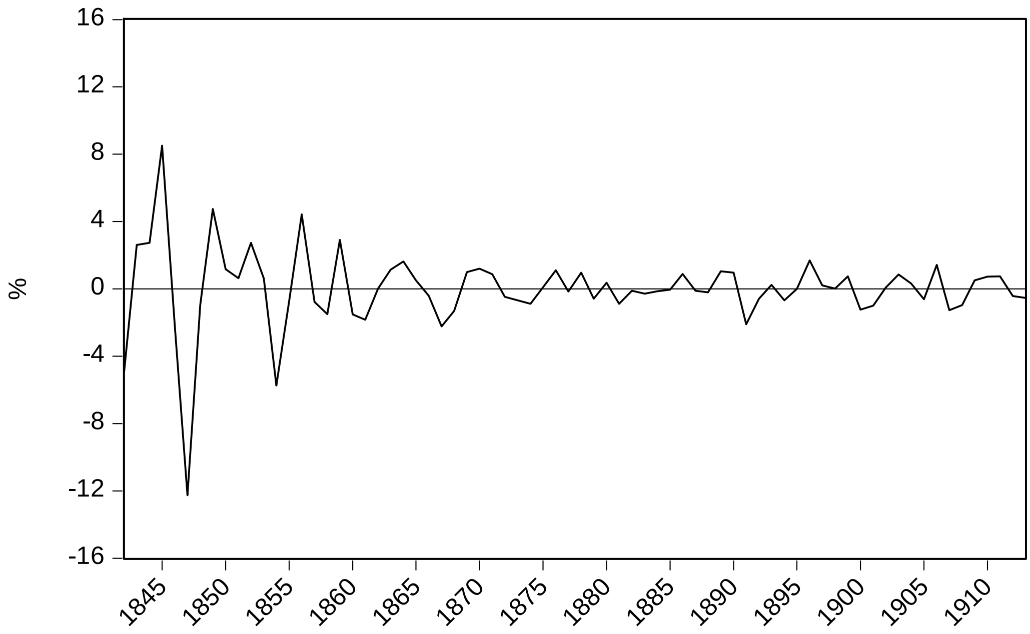

Figure 3. *The business cycle, 1842-1913*

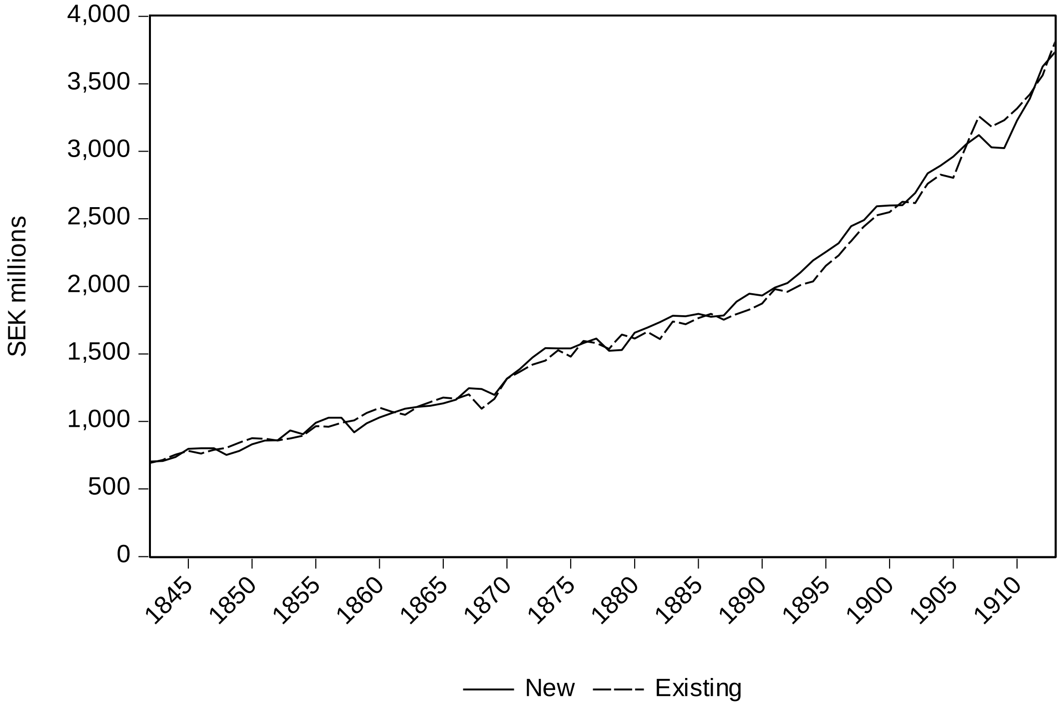

Figure 4. *New and existing estimates of Swedish real GDP, 1842-1913*

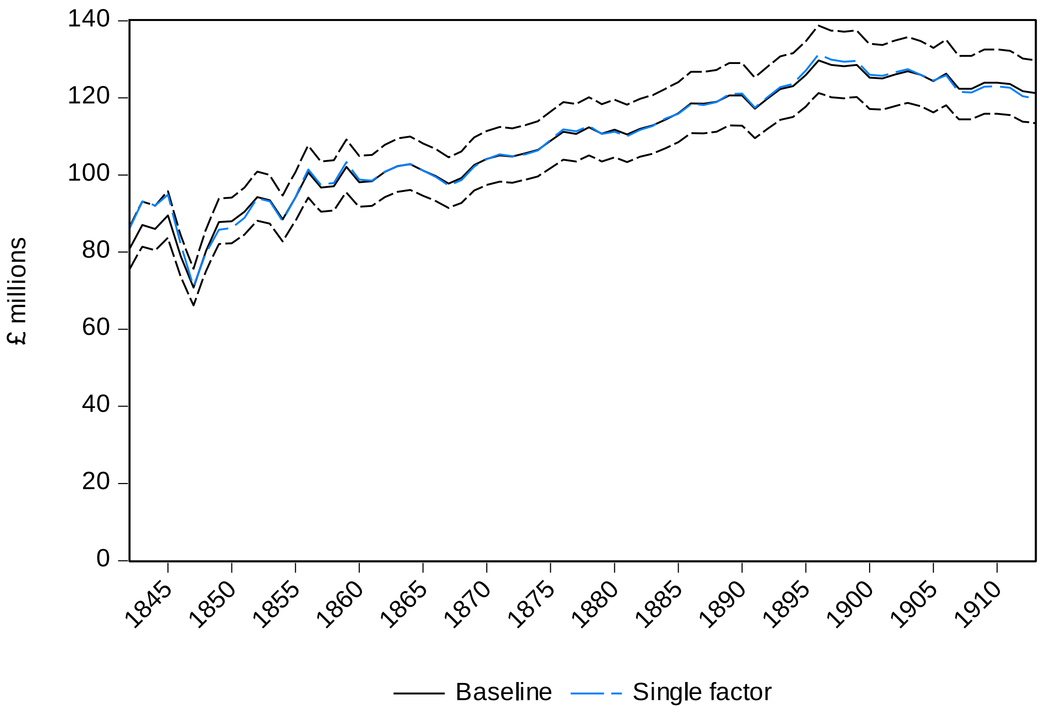

Figure 5. *Sensitivity of estimates of real GDP to number of factors, 1842-1913*

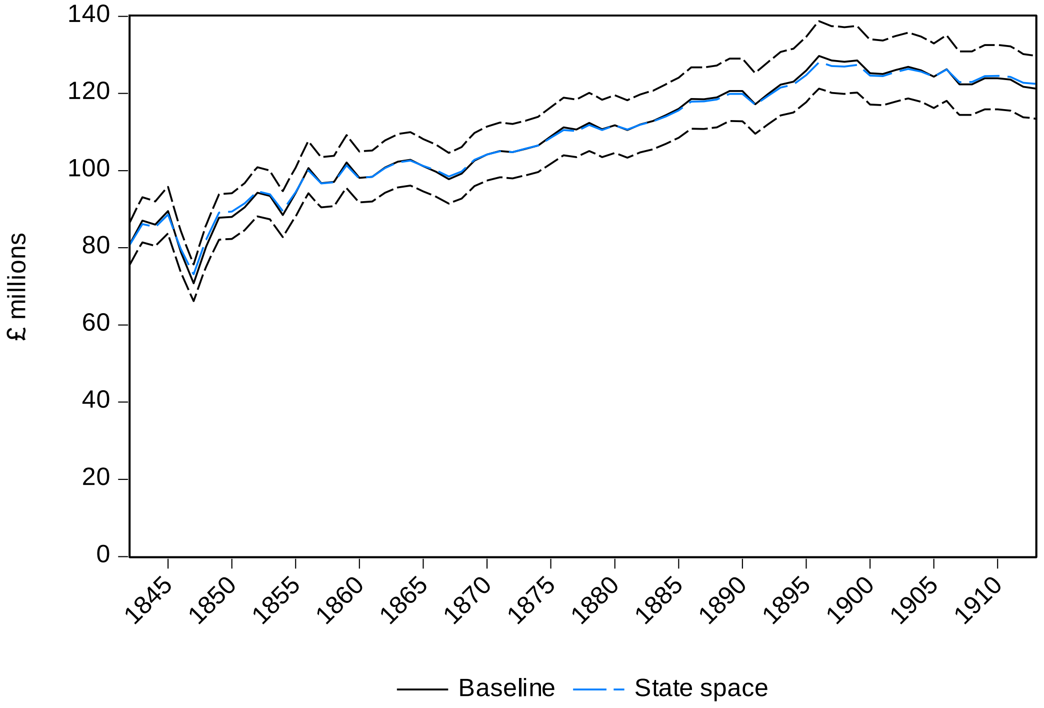

Figure 6. *Sensitivity of estimates of real GDP to econometric method, 1842-1913*

Figure 7. *Sensitivity of estimates of real GDP to inclusion of agricultural output, 1842-1913*

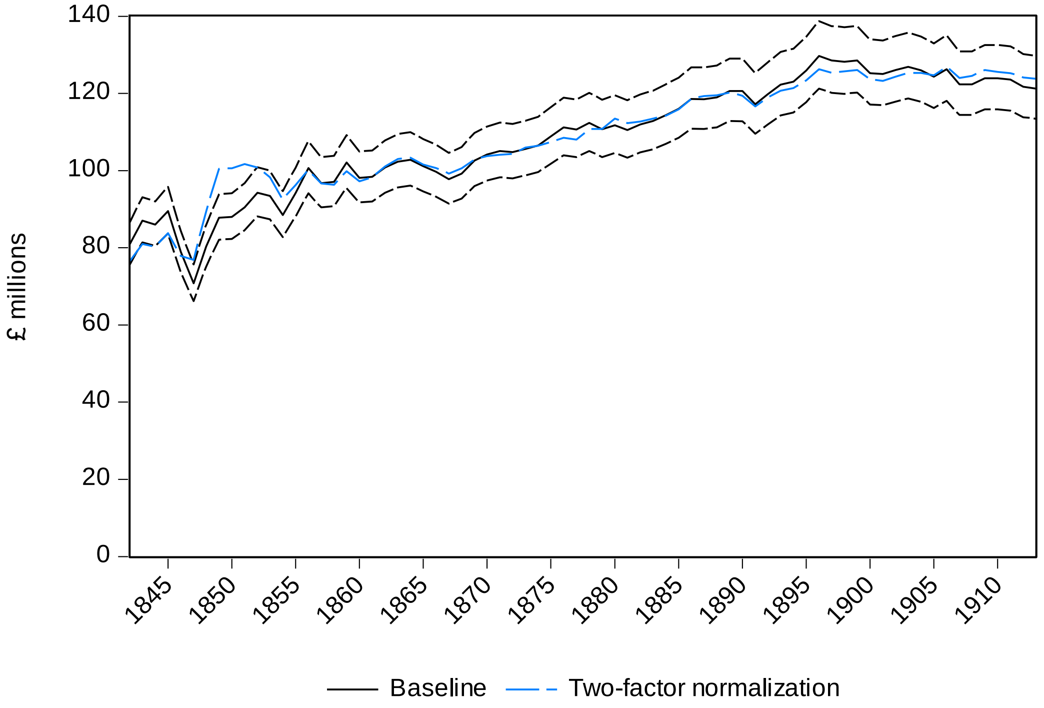

Figure 8. *Sensitivity of estimates of real GDP to two-factor normalization, 1842-1913*