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Abstract

A major issue in Irish economic history is the lack of historical national accounts before the interwar period. This paper addresses the gap with new annual estimates of real GDP between 1842 and 1913 using an indirect estimation technique based on a set of macroeconomic variables and a dynamic factor model. Three major results emerge from the data. First, per capita growth was faster in this period than anywhere in Europe. Second, aggregate output contracted by more than a third during the Great Famine of the 1840s, but had recovered its level and closed the output gap by the end of the decade. Thirdly, the volatility of the business cycle fell by nearly three quarters in the second half of the sample.
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), 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 paucity of data for the underlying components of traditional HNAs. As a result, we

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know less about the macroeconomic impact of the Great Famine of 1845, for example, than we do of the Black Death in Britain 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 (Ritschl et al., 2016; Sarferaz and Uebele, 2009), we develop a two-step approach to estimate real GDP. In the first step, a dynamic factor model is estimated to identify the common movement in a set of key macroeconomic variables. From the co-movement, an estimate of GDP is obtained. Included in the data set are existing components of GDP (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, 2016) and share prices (Grossman et al., 2014; Hickson and Turner, 2008). A problem with dynamic factor models is that the resulting index is unitless. In the second step, we therefore normalize the index against existing benchmarks of real GDP. This normalization gives the index an economic interpretation.

A number of results emerge from the new estimates of real GDP. First, Irish economic growth on a per capita basis was impressive by international standards. Between the Famine and the First World War, living standards improved more quickly than in any other European country for which comparable data is available. Second, output collapsed by 38% during the Great Famine, but recovered relatively quickly. Third, the Irish business cycle was highly volatile in the first half of the sample but declined by three-quarters after.

Section 2 discusses the extant literature on Irish GDP prior to the First World War. Section 3 sets out the methodology, section 4 the data. 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 the United Kingdom in the nineteenth century, there are real limitations to the volume of statistics that can ever be collected in the future. 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.[1] Finally, on the output side, among other issues, 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 Irish velocity were known, then so would Irish GDP, as the former can only be calculated by dividing the latter by the money supply. Therefore, O'Rourke regresses a number of variables on velocity 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.[2] On the eve of the Famine, Mokyr (1985) placed income 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). 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.[3]

At the frontier of the literature are the point estimates for 1861, 1871, 1881, 1891, 1901 and 1911 produced by Geary and Stark (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 nominal GDP increased from £89.3 million in 1861 to £119.6 million in 1911.

3 Methodology

In this paper, the annual level of real GDP in Ireland is estimated using a dynamic

[1]See Begley et al. (2010) for details.
[2]See Cullen (1995) for an interesting discussion of contemporary estimates of national income.
[3]Ó Gráda (1994) reworks this figure and arrives at £130-40 million for pre-war GNP.

factor model. These models have been used previously in the estimation of business cycle fluctuations in both contemporary (Stock and Watson, 1989) and historical (Ritschl et al., 2016; Sarferaz and Uebele, 2009) 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 just the business cycle but also the level and growth rate of GDP.

To understand our approach, consider the dynamic factor model below,

$$x_{it} = \alpha_{xj} \sum_{j=1}^{J} f_{jt} + \varepsilon_{xt} \tag{1}$$

$$f_{jt} = \sum_{i=1}^{I} \beta_{ij} f_{jt-i} + \vartheta_t \tag{2}$$

where x_{it} is one of $i = 1, \ldots, I$ observed time series, $j = 1, \ldots, J$ are the number of common factors, f are the respective factors that are assumed to be independent of each other, α are the factor loadings, which gives the relationship of the respective variable to the respective factor, ε and ϑ 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 represents the 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 utilizing the Geary and Stark (2015) benchmarks, we neither have to assume that the first factor represents GDP nor to impose any ad hoc assumptions. Once we have estimated the factors, we then use the benchmark GDP estimates to identify the factors that represent GDP and to normalize the factors such that they obtain an economic interpretation.

The full procedure is carried out in 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. The estimation of the dynamic factor model requires that we specify the number of factors to be estimated. Estimating too few factors may cause biased estimates of the factors, while estimating too many quickly reduces the degrees of freedom and thus the precision of the estimates.

4. The dynamic factor model is estimated by maximum likelihood with a Kalman filter. It is possible to use alternative estimation methods. 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 an estimate of the level.

6. Alternative combinations of the indices are regressed on the deflated benchmark GDP 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 are multiplied by the respective annual indices to arrive at annual estimates of real GDP: $\ln(\hat{Y}_t) = \hat{\gamma}_0 + \sum_{j=1}^{J} \hat{\gamma}_j I_{jt}$.

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 deviation is zero. If the estimated level of GDP is close to the benchmarks, then this validates the quality of the benchmarks and our modelling approach.

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_{xt}, and not by the common factor, f_{jt}. Therefore, measurement error has a smaller effect on our GDP estimates compared to other methods.

4 Data

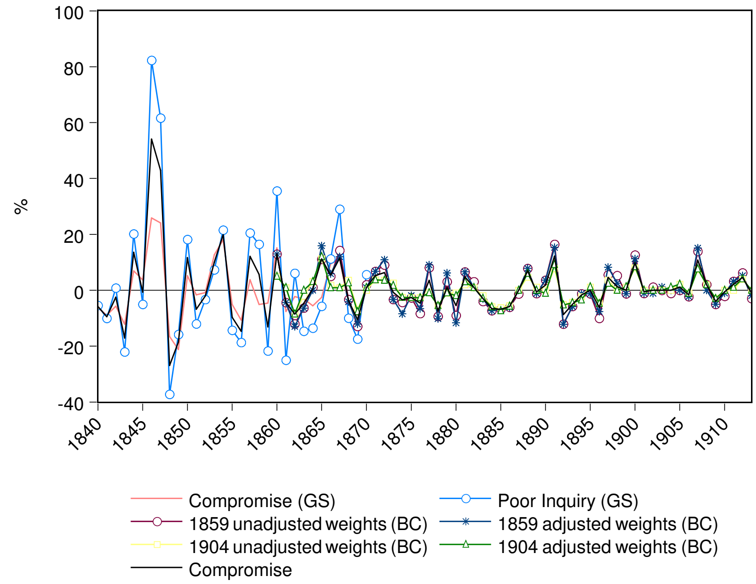
The dynamic factor model requires a balanced sample. Therefore, only variables that span the entire period are included in the estimations. The baseline model includes 19 time series covering six categories: macroeconomic, government, agriculture, construction and manufacturing and services (see table 1). The macroeconomic category includes population, real currency in the hands of the public, real interest rate, Poor Law recipients per capita, real stock prices and real wages. The government category includes real government revenue. The agriculture category includes oxen, pig and sheep exports. The construction category includes timber imports. The manufacturing category includes butter exports, distilling output, Guinness sales, linen cloth exports, shipbuilding and tobacco consumption per capita. The services category includes property transactions and real rail revenue. The sources and transformations involved for each variable are discussed in the appendix.

A number of variables are measured in nominal terms in the underlying sources, such as currency in the hands of the public, interest rate, 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 with alternative weights. For the years between 1860 and 1913, Brunt and Cannon (2004) have constructed four cost of living indices, each with different 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 advantages that it incorporates more information and results in a less erratic series. This method is also preferred over using 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.

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 cases, there are a small amount of missing observations, such as with Poor Law recipients per capita (1899), real 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

Figure 1: Existing and Compromise Estimates of Inflation, 1840-1913



Notes and sources: GS=Geary and Stark (2004), BC=Brunt and Cannon (2004).

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)." 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 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. This variable is included 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). Real currency in the hands of the public (Kenny and Lennard, 2016) is also included, based on the logic that real monetary aggregates should be related to real 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)."[4]

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 nominal GDP for these years are multiplied by Feinstein's (Mitchell, 1988) corresponding compromise estimate of UK nominal GDP, which are then deflated using the Irish compromise cost of living index discussed above.

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). 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), manufacturing production, such as linen cloth exports and distilling, and services, as measured by real rail revenue. The second factor, f_2, captures a significant co-movement between population, currency, Poor Law recipients per capita and pig exports.

Having obtained the dynamic factors, we then create an index for each factor and regress them on the six benchmark GDP estimates from Geary and Stark (2015). These regressions are only performed to normalize the indices and the estimated parameters have no economic interpretation. As the regressions are only based on six observations, one should be careful when interpreting the estimated standard errors and significance levels.

Three models are estimated to normalize the indices. The first model (M1) includes both indices ($\hat{I}_1$ and $\hat{I}_2$). The second model (M2) only includes index 1 ($\hat{I}_1$). The third model (M3) only includes index 2 ($\hat{I}_2$). According to the results in table 2, only the first factor is correlated with GDP. M2 is preferred over M1 due to objectively better performance in terms of the adjusted R^2 and information criteria.

The average deviation between our estimate (M2) and the benchmarks of GDP are 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 our estimates are close to all of the benchmarks. There is virtually no deviation in 1891, while the largest relative error was 4.7% in 1861. The close correspondence between our estimates and the benchmarks confirms the quality of both.

5.1 Irish Economic Growth

Figure 2 presents annual estimates of real GDP for Ireland between 1842 and 1913. The aggregate level is shown in the top panel while the bottom panel is expressed in per capita terms. Note that while the underlying data begins in 1840, two observations are

[4]Other examples in Irish economic history include Ollerenshaw (1987).

Table 1: Estimated Factor Loadings, 1841-1913

		Factor 1	Factor 2
Macroeconomic	Population	.04	-.44***
		(.14)	(.12)
	Real currency in the hands of the public	11.38***	-6.25***
		(2.38)	(3.42)
	Real interest rate	10.45***	2.62
		(2.05)	(2.19)
	Poor Law recipients per capita	.17	.60***
		(.17)	(.11)
	Real stock prices	10.82***	-4.12
		(1.65)	(3.21)
	Real wages	3.58***	-.38
		(.81)	(1.38)
Government	Real government revenue	9.20***	-2.52
		(1.33)	(2.36)
Agriculture	Oxen exports	-5.49*	1.07
		(2.87)	(2.90)
	Pig exports	-1.05	-11.9**
		(5.38)	(4.61)
	Sheep exports	-10.55***	.79
		(3.33)	(3.63)
Construction	Timber imports	1.08	-3.97*
		(2.56)	(2.29)
Manufacturing	Butter exports	.71	-1.62
		(1.16)	(1.09)
	Distilling output	3.82**	-1.93
		(1.59)	(1.84)
	Guinness sales	-.38	-.84
		(1.21)	(1.18)
	Linen cloth exports	3.73***	-.88
		(1.15)	(1.43)
	Shipbuilding	-9.59	-7.27
		(6.62)	(5.76)
	Tobacco consumption per capita	.28	-1.02
		(.73)	(.71)
Services	Property transactions	1.15	-.53
		(1.76)	(1.67)
	Real rail revenue	14.13***	1.68
		(1.75)	(3.68)
	Factor dynamics	.04	.50***
		(.13)	(.22)

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 (M1)	Model 2 (M2)	Model 3 (M3)
Constant	3.96***	3.96***	4.70***
	(0.16)	(0.06)	(0.50)
Factor 1	0.08***	0.08***	
	(0.01)	(0.01)	
Factor 2	0.00		-0.05
	(0.03)		(0.13)
Adjusted R^2	0.92	0.94	-0.21
Schwarz information criterion	-3.02	-3.32	-0.27

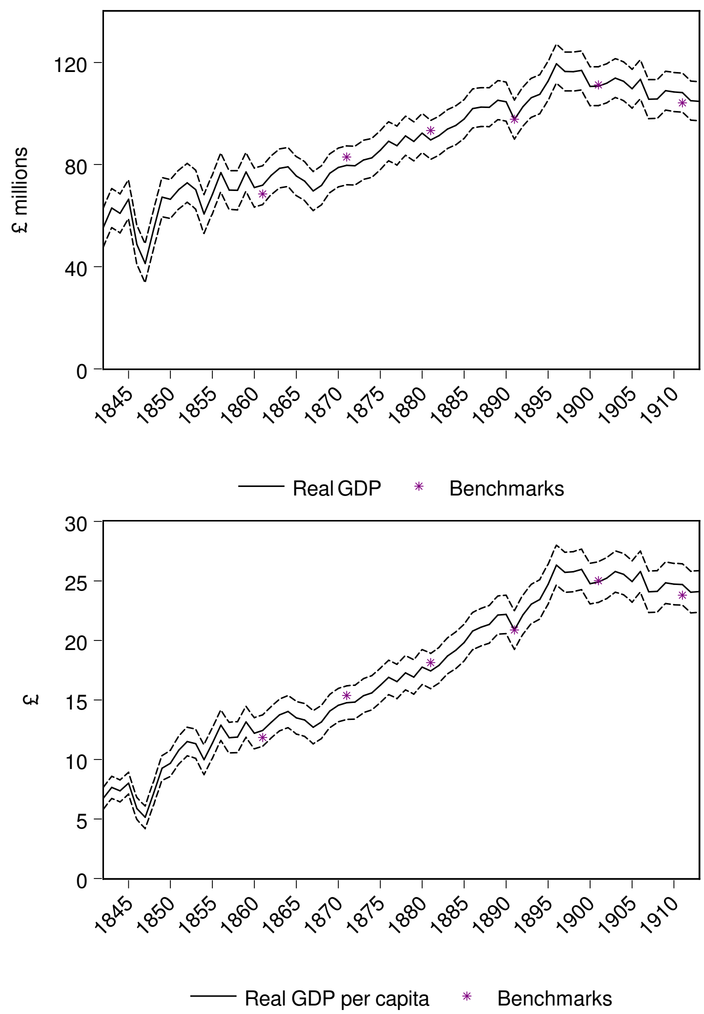
Table 3: Estimates of Real GDP and Benchmarks (£ millions), 1861-1911

	Benchmarks	M2 (F1)
1861	68.5	71.9
		(3.4)
1871	83.0	79.7
		(-3.3)
1881	93.3	89.7
		(-3.6)
1891	97.7	97.6
		(-0.1)
1901	111.2	110.7
		(-0.5)
1911	104.2	108.2
		(4.0)

Note: Absolute deviation from benchmark in parentheses.

lost in the process due to first differencing and the inclusion of a lag. The dashed lines are 95% confidence intervals. These are based on the standard deviation of the second stage regression.

Figure 2: Estimates of Real GDP and Real GDP Per Capita, 1842-1913



Note: Dashed lines are 95% confidence bands.

The pace of Irish economic growth was impressive between the Famine and the First World War. On an aggregate basis, the average rate of growth was 0.9% per year, which over the full period saw the size of the economy almost double. On a per capita basis, the average rate of growth was 1.8%, which meant that living standards more than tripled. The measured increase in living standards is consistent with the literature. Ó Gráda (1994) 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) 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. Per capita GDP growth in Ireland was faster than anywhere in Europe for which data is available. The relative pace of post-Famine growth has been hitherto underappreciated.

Table 4: Average Growth of Real GDP Per Capita in Europe (%), 1842-1913

	Average Growth Rate
Ireland	1.8
Sweden	1.6
Denmark	1.5
Norway	1.3
France	1.3
United Kingdom	1.0
Netherlands	0.8
Italy	0.5
Greece	-0.1
Average	1.1

Source: Bolt and van Zanden (2014).

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). The link between major population shocks and higher steady state incomes per capita has been emphasized in recent work by Voigtländer and Voth (2013). 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). Part of the increase in living standards is thus due to a falling population.

Table 5 shows the average growth of real GDP and real GDP per capita by sub-period. The periodization allows for comparisons with the rate of growth between existing benchmark estimates. Economic growth was uneven throughout the sample, with periods of faster and slower growth. The average rate of growth, in both aggregate and per capita terms, was highest around the years of the Famine. That is not to say that there were not output losses during the Famine itself, which will be discussed in the next section. The new estimates point to a slower rate of growth in the 1860s, but slightly faster growth in the 1880s and 1900s, while there is no difference in the other decades. Overall, the new estimates of economic growth are equal to the existing benchmarks for the common period of 1861 to

1911.

Table 5: Average Growth of Real GDP and Real GDP Per Capita by Sub-period (%), 1842-1913

	GS Real GDP	Real GDP	Real GDP Per Capita
1842-61		1.4	3.3
1861-71	1.9	1.0	1.7
1871-81	1.2	1.2	1.7
1881-91	0.5	0.9	1.8
1891-1901	1.3	1.3	1.8
1901-1911	-0.6	-0.2	-0.1
1861-1911	0.8	0.8	1.4
1842-1913		0.9	1.8

Note: GS=Geary and Stark (2015).

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 cycles are estimated using 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.[5] 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 6.

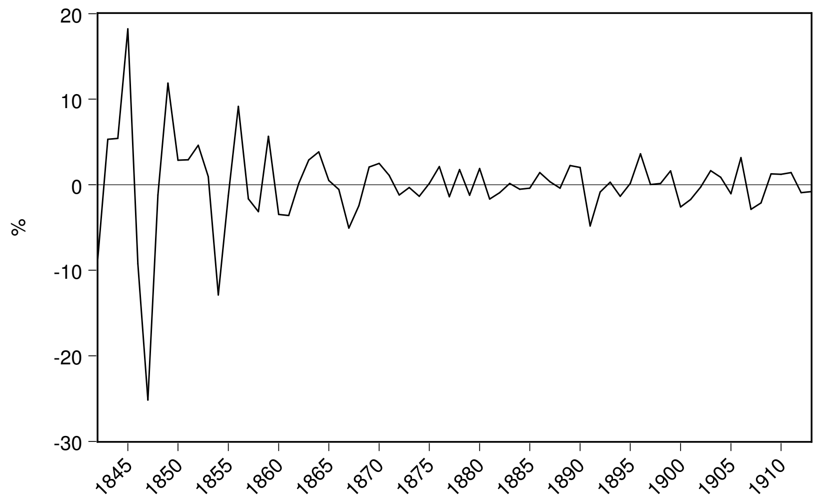
Table 6: Chronology of the Business Cycle (Real GDP), 1842-1913

Peak	Trough	Peak	Trough
1845	1847	1883	1884
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	1912
1880	1881		

The major event of the 1840s was, of course, the Great Famine. The macroeconomic

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

Figure 3: The Business Cycle (Real GDP), 1842-1913



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 38%. The lion's share of the decline operated through the business cycle, but there was also a permanent reduction in trend output as well (-4%). 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, such as the Great Famine in England in the 1310s (-15% (Broadberry et al., 2015a)). The result confirms Solar's (1989) view that this was no ordinary subsistence crisis.

The 1850s were rocked by a number of major events. 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 14%. This was the largest decline between the Famine and the First World War. The compromise cost of living index increased by 20%, which Lynch and Vaizey (1960) 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 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 of roughly 2.5% 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). The level of GDP fell by 8% 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). 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.

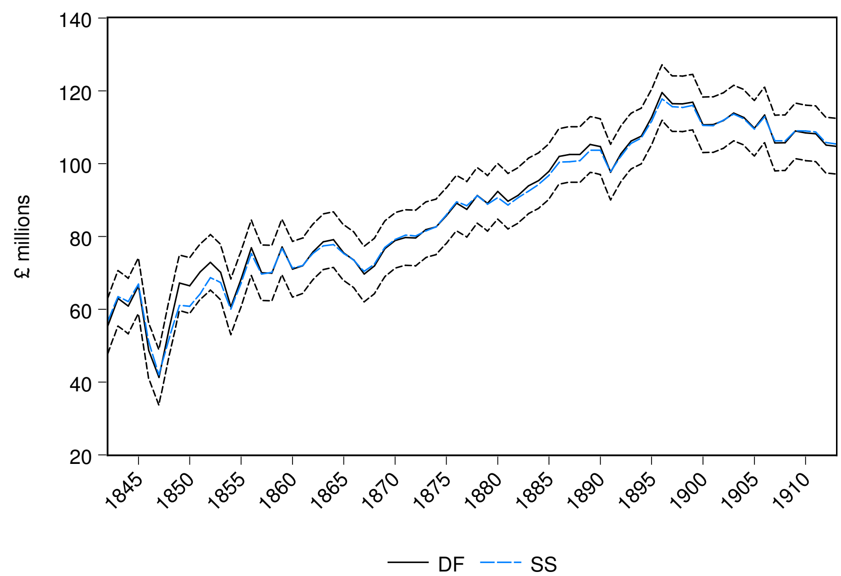
The 1870s marked the emergence of the first industrial crisis. According to Cullen (1972), a global industrial boom collapsed in 1874, which saw the Irish market flooded with British manufactured goods. In the data, the bubble burst a little earlier, in 1872, and remained roughly 1% below trend until the trough in 1874. Agricultural crisis returned after the bad seasons of 1877-9. However, in combination with a decline in agricultural output (Turner, 1996) was an increase in real wages (Williamson, 1995) and in the consumption of Guinness (Hughes, 2006), tobacco (Bielenberg and Johnson, 1998) and the number of letters sent (Mitchell, 1988). On balance, the economy grew by nearly 2% in these years, albeit with a negative output gap of 1-2% in 1877 and 1879. The results are supportive of Donnelly's (1976) view that this agricultural depression had less macroeconomic significance than that of 1859.

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. 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 two 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). The Bank's response was potentially the source of reduced output as opposed to the panic itself.

6 Robustness

In this section, the sensitivity of the baseline estimates to a number of reasonable permutations is investigated. The first is to an alternative econometric method. 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 4 shows that the results are not materially sensitive to the choice of econometric method. The state-space (SS) estimates lie within the 95% confidence interval of those of the dynamic factor model (DF). The correlation between the two in first differences is 0.99. There is, however, a slight difference around the Famine, with the DF model pointing to a stronger recovery than the SS.

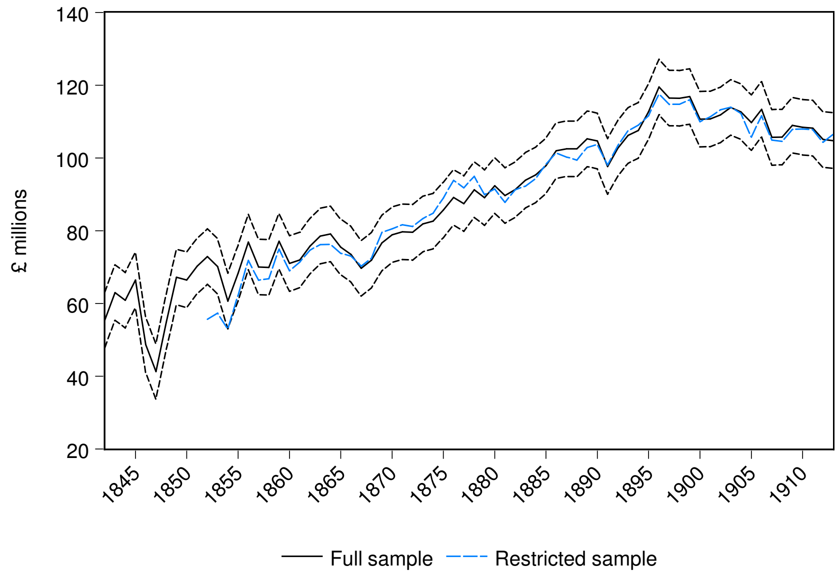
Figure 4: Sensitivity of Estimates of Real GDP to Econometric Method, 1842-1913



An important issue in time series is the role of outliers and structural breaks. Figure 5 shows the results for a model estimated over a slightly shorter sample, 1850-1913, which omits the volatile years of the Famine. The correlation between changes in the two series for the common sample is 0.92. The level of GDP is somewhat lower prior to 1855, but thereafter lies comfortably within the 2 standard error bands.

Agriculture was important to the Irish economy in this period with roughly half of the labour force employed in the sector (Geary and Stark, 2002; Geary, 1998). In the baseline model, three components of agricultural output are included. However, from 1850 the gross output of the aggregate agricultural sector is available. Figure 6 shows the results from a model with the volume of agricultural output included in place of the proxies plotted alongside the baseline estimates. Again, the results are very similar to the baseline with a correlation over the common sample of 0.94. The small difference is more a function of the changing sample than of the inclusion of agricultural output. The correlation in first differences between the baseline model estimated over the period 1850 and 1913 and the

Figure 5: Sensitivity of Estimates of Real GDP to Sample Period, 1842-1913



model inclusive of agricultural output is 1.00.

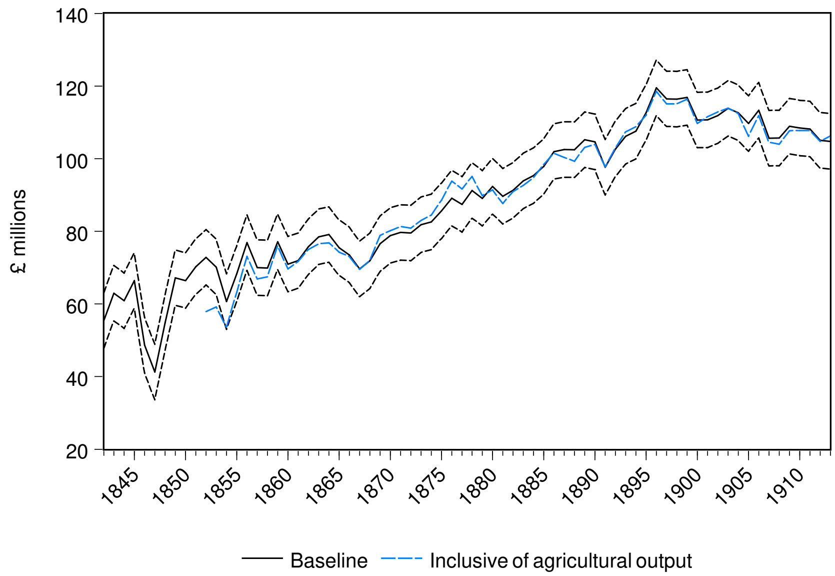
In summary, the baseline results are robust to a number of alternative specifications, including an alternative econometric model, a shorter sample period and the inclusion of agricultural output instead of agricultural proxies.

7 Conclusions

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 an alternative econometric estimation technique.

The new annual estimates of real GDP point to three stylized macroeconomic facts. Firstly, the increase in living standards was greater than anywhere in Europe between the

Figure 6: Sensitivity of Estimates of Real GDP to Inclusion of Agricultural Output, 1842-1913



Famine and the First World War. The period for which existing estimates of growth exist, 1861-1911, was an era of more moderate growth, while the previously uncharted decades before saw rapid growth. In this sense, the stimulus to per-capita incomes after the Famine has parallels with the Black Death. Secondly, the 38% contraction in output during the Famine is the largest in the known economic history of Ireland. The recovery was equally impressive with double digit growth in 1848 and 1849, which meant that output was back to its pre-Famine level by the end of the decade. Thirdly, the volatility of the Irish business cycle fell by three-quarters in the period 1880-1913 relative to 1842-79. This fact has been neglected in the literature so far.

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 extrapolating a constant fraction of Irish to UK GDP for a benchmark year so that a nominal variable can be normalized or on focusing on a single time series on blind faith that it is a bellwether of wider economic activity, as has been the case the case in recent research. Even if the "tantalizing dream" (Kennedy, 1997) is realized 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 real wages, prices, trade, government revenue etc., it is possible to construct estimates of the level of annual GDP using the two-step method developed in this paper. This approach may also be valuable for modern developing economies, for which existing GDP data is unreliable (Jerven, 2013).

Table A.1: Data Description

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 (2016). Deflated using compromise 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 compromise 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 compromise 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 compromise cost of living index
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 compromise cost of living index
Compromise cost of living index (1841=1)	1840-70: Geary and Stark (2004), 1860-1913: Brunt and Cannon (2004)
Agricultural output (1850=100)	Turner (1996). Chained Laspeyres quantity index

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