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Testing for long-run "sustainability": Genuine Savings estimates for Britain, 1760-2000[¶]

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Abstract

Genuine Savings has been proposed as an economic indicator of sustainable development, and has been the focus of World Bank sustainability assessments for countries globally. However, whilst the theoretical basis for Genuine Savings is well-established (Arrow et al, 2011; Hamilton and Withagen, 2007; Pezzey, 2004), its ability to forecast long-run trends in well-being remains un-tested. In this paper, we take a first step towards such an assessment by constructing a time series of estimates for produced, natural and human capital for Britain over the period 1760-2000, and use them to derive estimates of Genuine Savings. The next step in the project will be to compare these Genuine Savings estimates with a range of well-being indicators to answer the question: does positive Genuine Savings predict improvements in average well-being?

[¶] We thank the Leverhulme Trust for funding this research under the project "History and the Future". We also thank Kirk Hamilton for comments on our calculations.

1. Introduction.

How to define "sustainable development", and then how to measure it, is a question which has attracted much attention from economists since around the early 1990s. Sustainable development has been defined as a pattern over time where per capita utility for an economy is non-declining and as a '*pattern where an economy's total stock of capital is maintained over time in value terms'*. This latter definition focuses on the concept of weak sustainability (Neumayer, 2010), whereby an economy's total capital stock is defined as the sum of produced, natural, human and social capital stocks (World Bank, 2006; Hanley, Shogren and White, 2006). In the weak sustainability model, a sufficient degree of substitutability is assumed between these different elements of a nation's total wealth so that no particular constraint needs to be placed on the time path of any particular element of the overall capital stock. This assumption has proved controversial, particularly the implication that natural capital can be run down without limit, so long as "enough" of the rents from natural capital extraction are re-invested in other forms of capital, when valued at correct shadow prices – the Hartwick Rule (Hartwick, 1977; d'Autume and Schubert, 2008).

Given the assumption of weak sustainability, a macro level test of sustainable development is then to examine whether, year-on-year, an economy's overall capital stock is falling, rising, or remaining constant. Beginning with Pearce and Atkinson (1993), the Genuine Savings[1] measure has emerged as the theoretically-correct measure of changes in this overall capital stock (Hamilton and Clemens, 1999, Pezzey, 2004). Genuine Savings (GS) adds up the value of year-on-year changes in each individual element of the capital stock of a country, valuing these changes using shadow prices which reflect the marginal value product of each stock to welfare, defined as the present value of aggregated utility over time. Changes in the stock of certain pollutants (such as CO_2) are also added (for example in the World Bank estimates) to the index, valued using their marginal damage costs, although there are doubts that pollution necessarily equates to disinvestment, whilst many problems exist in valuing pollution changes in monetary terms. Changes in human capital can be approximated using expenditures on education, or as a measure based on discounted lifetime earnings by skill level (Arrow et al, 2010; Le et al, 2006; Escosura and Roses, 2010). Changes in social capital are measured by the World Bank (2006, 2011) as a residual. The effects of technological change, resource price appreciation (capital gains/losses) for resource exporters and population change can also be incorporated into the GS indicator (Arrow et al, 2004; Pezzey et al, 2006). GS is typically reported either as an absolute amount, or as a percentage of Gross National Income.

The intuition of Pearce and Atkinson (1993) was that countries with positive levels of GS would satisfy a requirement of weak sustainability, since by implication their aggregate capital stocks would not be declining in value. Similarly, countries with negative GS values would be experiencing un-sustainable development. Hamilton and Withagen (2007) showed that, under certain conditions, a country with a positive GS would experience increasing consumption into the future; although Pezzey (2004) argues that GS is a one-sided indicator which can only prove un-sustainability, due to

[1] Also refereed to as Adjusted Net Savings or Comprehensive Investment.

the failure to use what have been termed "sustainability prices" to price changes in capital stocks. The World Bank (2006, 2011) report GS calculations for nearly 200 countries and find on this criterion that a number of sub-Saharan countries appear to be unsustainable.

However, whilst the theoretical underpinnings of GS are well-established (if much debated), empirical tests of the extent to which a positive GS in a particular year is a good indicator of improving (or at least of non-declining) well-being over time remain very limited. In the only studies to date, Hamilton and colleagues have used World Bank data back to 1970 to examine the link between GS and changes in per capita GDP as a wellbeing measure. Ferreira and Vincent (2005) find mixed results on the correlation between changes in the capital stock and future consumption, depending on whether OECD or non-OECD countries are considered. World Bank (2006) show that GS does a "reasonable job" of predicting changes in future consumption over the period 1970-2000. Ferreira, Hamilton and Vincent (2008) use the same data to examine whether allowing for population growth changes these conclusions. They find that for developing countries, genuine savings measures were positively and significantly related to changes in the present value of future consumption over the period 1970-1982.

Theory says nothing about the particular time period within which GS can act as a sustainability indicator, the theoretical models from which it is constructed being set in continuous, infinite time. However, a very important empirical and indeed policy-relevant question to ask is over what kinds of future periods GS can predict future wellbeing trends? "Sustainable development" is a concept, which has been interpreted as being of relevance over the much longer term than merely 40 years, the longest period over which GS has been "tested" to date.

In this paper, we make use of the historical record for the UK back to 1750 to develop a much longer time series for GS than has been published to date.[2] By constructing aggregate (produced, natural and human) capital data series along with price and cost data, we can back-cast a series for GS, and then test the extent to which is can predict a range of well-being indicators – not just traditional economic measures like real wages or real GDP per capita, but also alternative indicators infant mortality, life expectancy at birth and stature (Deaton, 2007).

In what follows, we first of all describe data collected on capital stock changes for Britain, before outlining the calculation of Genuine Savings from these data.

2. <u>Stock Levels</u>

This section outlines the data and methodology used in compiling stocks of British reproducible and natural capital. Natural capital for the UK is measured as consisting of non-renewable resources such as coal and iron ore, and renewable resources such as forests. Changes in pollution levels over time are also reported. These stock estimates along with measures of net investment are then used to calculate the different elements of GS in Section 3. Estimates of human capital stock are on-going. Examining changes in different components of the aggregate capital stock (human, produced, and natural) is of interest since economic development can be seen as a process whereby a country re-arranges its capital stock, running down an initial stock of natural capital, and accumulating stocks of human and produced capital. Indeed, World Bank (2006) show that this pattern exists across countries at present, with low-income countries holding a much higher fraction of their total wealth as natural capital than middle- or high- income countries.

2.1 Reproducible *capital*

There are two sets of reproducible capital stock data to choose from: gross and net. Matthews, Feinstein and Odling-Smee (1982, p. 120) outline the distinction: 'gross capital stock is defined as accumulated gross investment minus retirements. The net capital stock is defined as accumulated gross investment minus depreciation.[3]'

Both gross and net capital stock measure capital in use, but they use different accounting procedures to estimates that part of the produced capital stock which falls from use in any year. The net stock measure gives higher weight to newer assets, and so it is a better measure when there is strong physical deterioration or technological obsolescence (Matthews et al, 1982, p. 206). The NCS and capital price indices are taken from Feinstein & Pollard (1988), Feinstein (1972) and UK National Accounts, 1966-2000.

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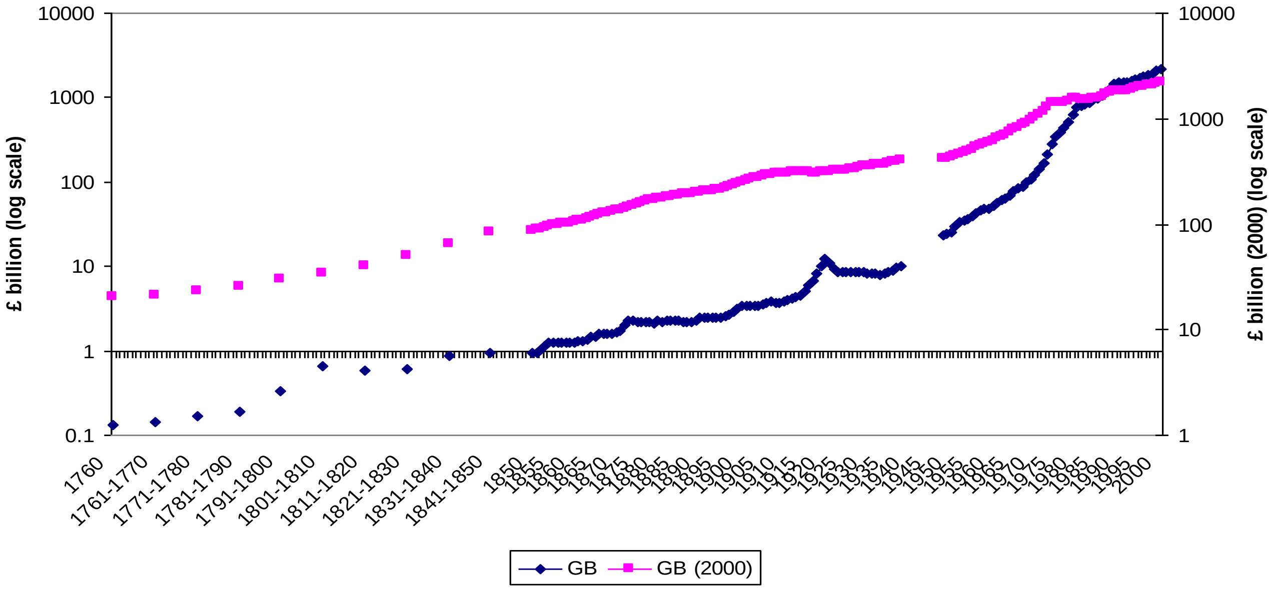
[2] Similar work is being undertaken for Sweden by Magnus Lindmark.

[3] Further clarification of the distinctions is given by Feinstein & Pollard (1988, p. 259) which state that:

Gross stock of fixed assets $_{\text{(end of year)}}$ = Gross stock of fixed assets at the beginning of the year + gross domestic fixed capital formation during the year – fixed assets retired during the year.

Net stock of fixed assets $_{\text{(end of year)}}$ = Net stock of fixed assets at beginning of year + gross fixed capital formation during the year – depreciation during the year – depreciated value of assets retired during the year.

Figure 1: Net reproducible capital stock, current prices and constant (2000) prices, 1760-2000



2.2. *Forestry*

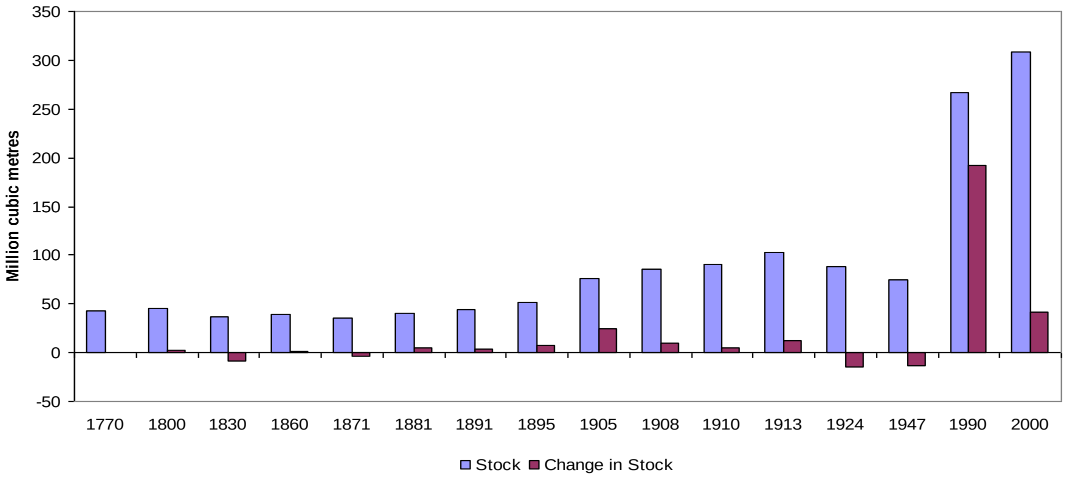
The overall approach taken to calculating stocks of forests in Britain was to estimate the volume of timber (m^3) per hectare. We obtained estimates of British forestry stocks from the 1947 woodland census, and for the 1990s and 2000s from Eurostat and Forestry Commission (2002). We then calculated historical timber stock estimates using data from the 1924 census of woodlands combined with yield estimates from Schlich (1904).[4]

The 1924 census of woodlands gave figures for the area of felled woodland during the First World War. Using Stamp & Beaver (1954)'s view that one third of the 1914 standing volume was used during the War, we estimated the timber volume for 1913 by adding 16.16 % of the area of felled woodland in the 1924 woodland census, to the 1924 estimate. There were no contemporary estimates of woodland stocks

[4] An alternative to our estimate is Stamp & Beaver (1954).

before the 1920s. We obtained returns of forestry area from British agricultural returns and from Feinstein & Pollard (1980). We then made estimates of forestry stock by assuming 40 m^3 per hectare between 1750 and 1890 and gradually rising thereafter.

Figure 2: Standing volume of timber and change in standing volume of timber, 1750--2000



2.3 Coal

Coal reserves are subject to the distinction between what is technologically feasible and what is economically viable. As technology progresses, deeper and otherwise less-accessible schemes become more accessible. However, at any moment in time, the measure of economic reserves will depend on current prices and extraction costs. Cumulative production over time exerts an upward influence on costs, even as technological progress pushes costs down (Slade, 1982).

What is the best guess to use to estimate an annual economic reserve of UK coal? The estimates published in the 1905 Royal Commission give the most detailed assessments of what total reserves were at that point in time, but this is not equivalent to an economic reserve. The data from the 1940s give us estimates of reserves that are recoverable and proven at that point in time. They exclude much of the reserve estimates made by the 1905 Committee. Ashworth (1986, p. 17) believed that the 1940s estimates were more reliable than the 1905 estimates. However Beacham (1946), writing contemporaneously to the publication of the 1940s surveys, argued that:

> *It would appear to the layman that the basis upon which coal reserves have been estimated varies from one report to another, and that the resulting estimates should be handled with care; also, that knowledge of coal reserves outside those areas which are being actively exploited at the present time is very sketchy indeed. It follows that, especially in view of our ignorance of future technical developments in mining, the Committees' estimates of future outputs, the life of pits, and the locational trend of future development should be treated as intelligent guesses rather than confident prophecies (p.319).*

We have chosen the 1905 reserve estimates as a benchmark, as these provide the greatest amount of detail. Furthermore, as the issue involved is not the amount of discovery, but the amount of workable reserves those reserves deemed workable in 1905 we assume would be workable in the future, even if uneconomic now. The proven reserves from the 1905 coal commission (B.P.P. 1905) were used as a benchmark to obtain estimates of British coal reserves over the period 1750-2000 by adding annual coal extracted pre-1905 to this benchmark and subtracting annual extraction post-1905 as follows:

$$\textit{Coal reserve}_{1750\text{-}1904} = (\text{reserve}_t + \text{annual extraction}_{t-1})$$

$$\textit{Coal reserve}_{1905\text{-}2000} = (\text{reserve}_t - \text{annual extraction}_{t+1})$$

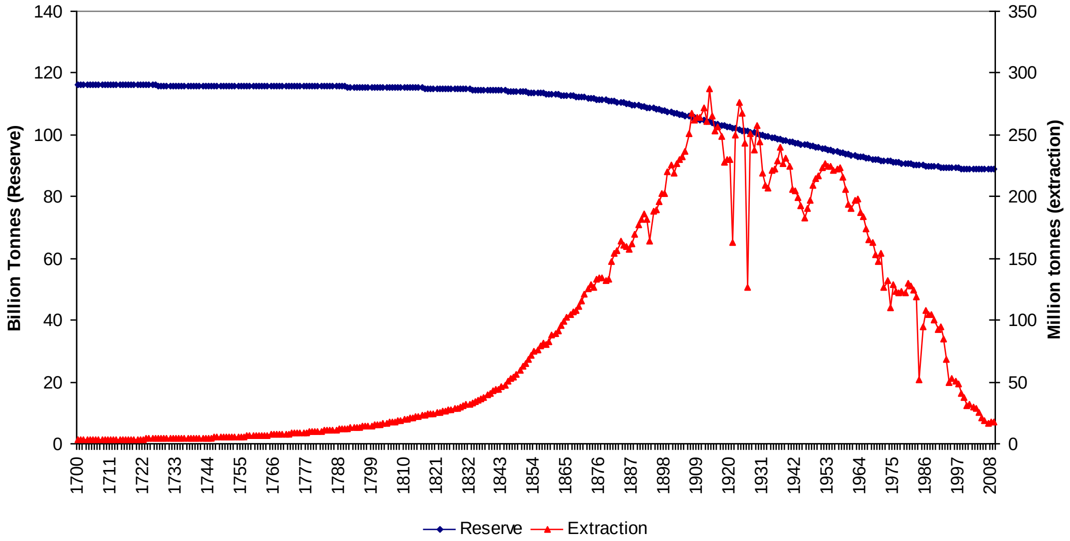
Table 1 outlines spot estimates of coal reserves from 1866 to 2010. There is a large discontinuity from 1905 to 1940 despite the fact that coal extraction had stagnated since the early 1900s, averaging 240 million tonnes per year between 1906 and 1940. There is also a large fall from 1940s to 2010. WEC (2010) stated that 'the decline of the British coal industry has been accompanied by a sharp decrease in economically recoverable reserves.' (WEC, 2010, p.38) However, WEC also stated that 'the UK's known resources of coal are dwarfed by its undiscovered resources, with nearly 185 billion tonnes estimated to be in place, of which about 41 billion is deemed to be recoverable' (2010, p.39).

Table 1: Coal reserves and extraction between dates, 1866-2010

	Known	***Possible***	***Reserve (total)***	***Extraction to date of reserve***	***Extraction at date as % of reserve***
			(million tonnes)	**(million tonnes)**	**%**
c.1866			85,544	3,381	3.95
c. 1870	97,526	100,917	198,433	3,822	1.93
c. 1905	106,153	40,721	146,874	9,881	6.73
c. 1912			186,494	11,721	6.29
c. 1915			235,000	12,528	5.33
c. 1940	20,500	13,376	33,877	18,265	53.92
c. 1945-46			54,604	19,441	35.60
c. 1947			49387	19,639	39.76
2010			386	27,302	
1750-2010				27,302	

Sources: Jevons (1866); B.P.P (1871); B.P.P. (1905); Strahan (1912); Jevons (1915); Stamp (1946); PEP (1947); WEC (2010).

Figure 3: Coal stock (Billion tonnes) and annual change in stock (million tonnes) 1700-2008



2.4 *Iron Ore*

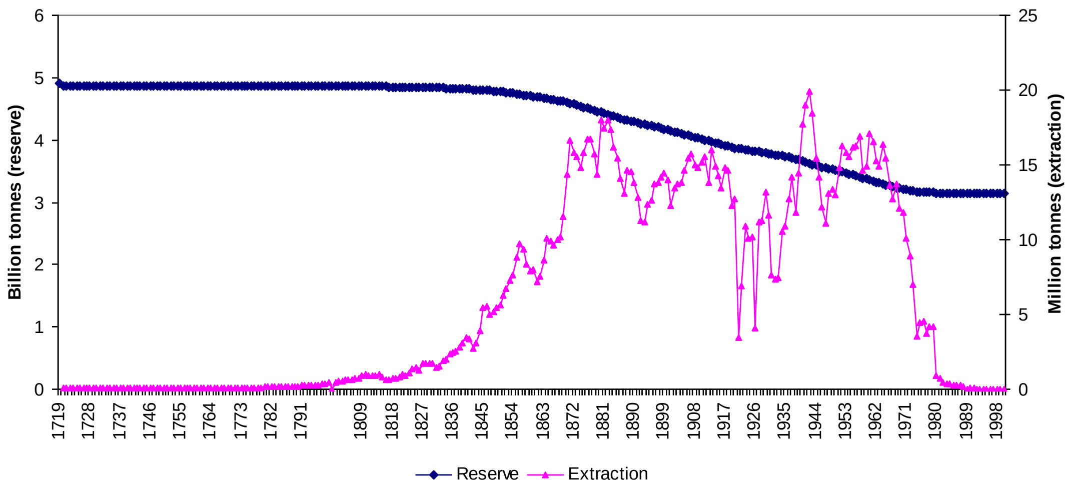
There have been a number of differing estimates of iron ore reserves, 13,000 million tons in 1910 (Louis, 1910), 3870 million tons (Hatch, 1920), 3528 million tons c. 1940 (Burn, 1940) and 12,000 million tons c. 1943 (Burnham & Hoskins, 1943). The benchmark estimate used to estimate an annual iron ore reserve was the 3870 million ton estimate from 1920. Previous iron ore extraction was added to this reserve and subsequent extraction subtracted from the figure as follows:

$$\textit{Iron Ore reserve}_{1750\text{-}1904} = (\text{reserve}_t + \text{annual extraction}_{t-1})$$

$$\textit{Iron Ore reserve}_{1920\text{-}2000} = (\text{reserve}_t - \text{annual extraction}_{t+1})$$

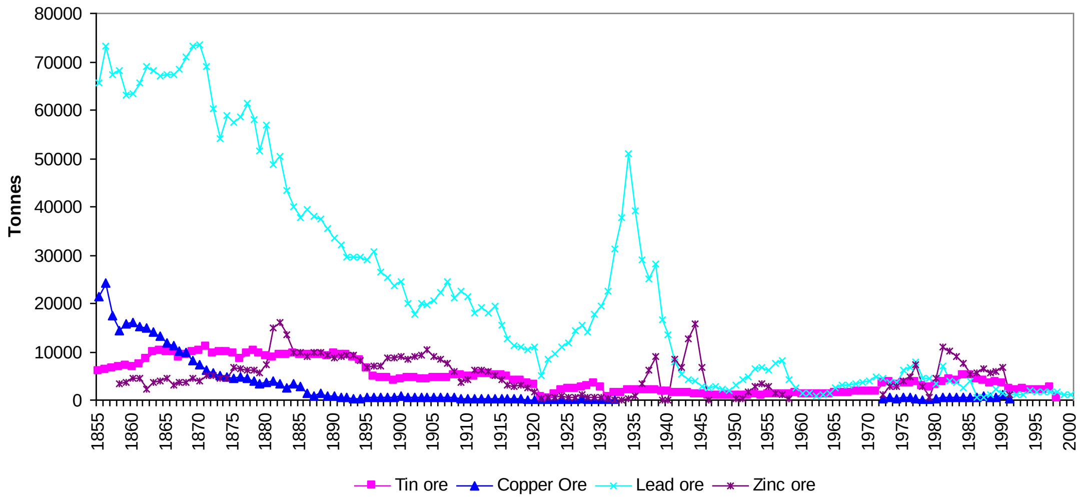
What we find is that prior to 1850 the amount of ore extracted was relatively small and that it made very little difference to the reserve, although the accessible reserve in 1750 was much smaller because of technological limitations.

Figure 4: Iron ore reserve (billion tonnes) and change in reserve (million tonnes), 1700-1914



UK mineral statistics also recorded the output of non-ferrous minerals such as copper, lead, tin and zinc over the period 1855 to 2000. However, unlike coal and iron, these mining industries have not received the same amount of historical attention.

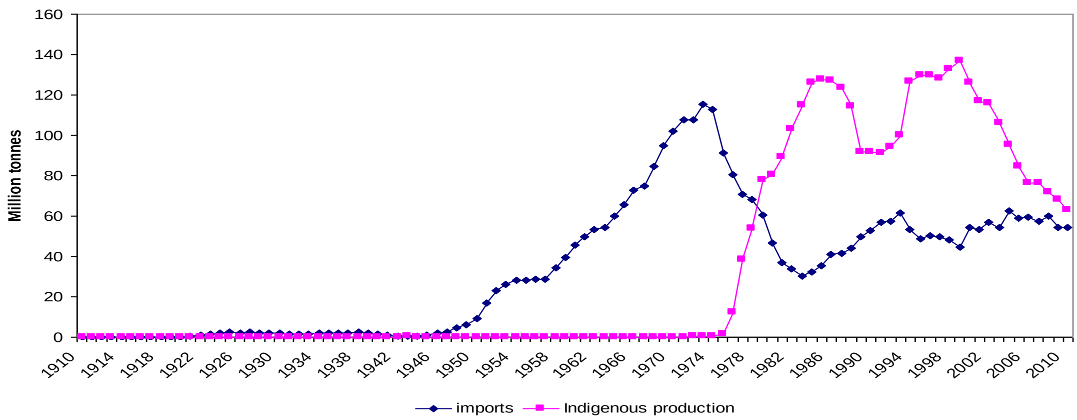
Figure 5: Lead, copper, tin and zinc extraction (million tonnes) 1855-2000



2.5 Oil *and Gas*

Oil and gas enter the story with the extraction from the North Sea. Oil and gas data were obtained from Mitchell (1988), *UK secretary of mines annual reports*, *Ministry of power statistical digest, Digest of UK Energy statistics, UK Mineral Statistics* and *UK Minerals Yearbooks*. In DUKES (1975) it was reported that there were 1,060 million tons proven reserves of oil, 1,205 million tons of probable reserves, 835 million tons of oil possible reserves, giving a total of 3,100 million tons (DUKES, 1975, p.91). Reserves of Gas were estimated to have been 44.4 trillion cubic feet in 1975 (DUKES, 1975, p.91).

Figure 6: Imports and indigenous extraction of oil (million tonnes), 1920-2000



2.6 *Pollutants*

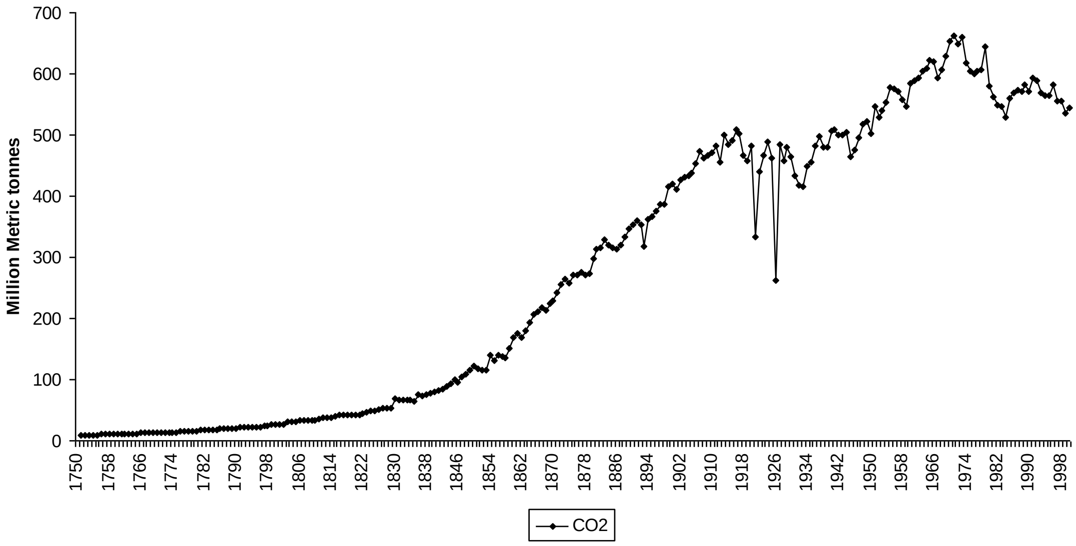
The World Bank Manual for Calculating Adjusted Net Savings expands the notion of a national "asset" to include its unpolluted air, although only stock pollutants such as carbon dioxide fit neatly into the capital stocks accounting framework of Genuine Savings.[5] As a first approximation World Bank use the damage from a single stock

[5] Damage costs from flow pollutants such as NOx can be directly included in other weak sustainability measures, or measures such as Green Net National Product.

pollutant, Carbon Dioxide, using a constant damage of $20 per ton of Carbon. They also report health damages associated with particulates. At the moment we are not convinced that a constant damage cost per tonne for CO_2 should be used for the whole period under scrutiny. During much of our period, global CO_2 stocks were far below the concentrations at which significant damages are thought to emerge (around 450 ppm), whilst such damage costs as 1800 emissions could be associated with would be discounted back from a considerable period into the future. As a stock pollutant the effects of which depend on exceeding an (uncertain) assimilative capacity, the shadow price of CO_2 emissions should rise over time. However, in this paper CO_2 emissions are deducted from other elements of GS using a range of carbon prices. Flow pollutant damages are not included in GS calculations, although we are working on a methodology to include some of these impacts in a measure of human capital.

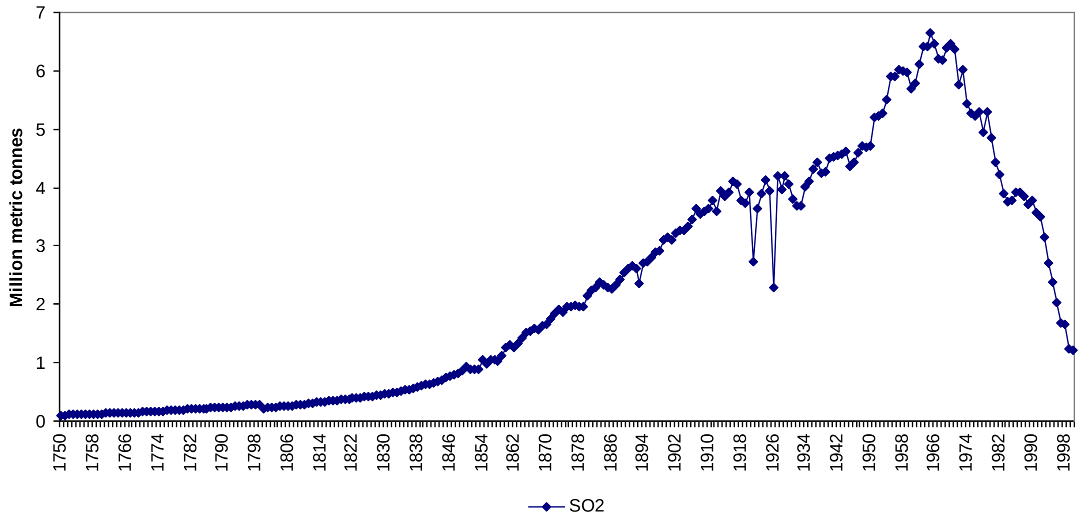
Historical estimates of CO_2 were made by Boden et al. (1995) and Andres et al. (1999) and the data are available on the website of the Carbon Dioxide Information Analysis Centre. In addition CO_2 emission values were estimated from conversion tables in Kunnas & Myllyntaus (2007) and applied to energy consumption data in Warde (2007).

Figure 7: UK CO_2 output, 1750-2000



For flow pollutants such as SO_2 the data are reported separately from the GS series, to allow some initial consideration of the relationship between pollution and economic growth. The historical series used for SO_2 estimates are Lefohn et al. (1999) and Smith et al. (2011), which provide estimates of SO_2 emissions from 1850 to 2005. There is a significant difference between the two estimated series with Smith et al. (2011) estimating a higher volume of SO_2 emissions. For the years prior to 1850 the volume of SO_2 was estimated by applying the formula cited in Smith et al. (2001): [Fuel use x Sulphur Content X (1- f_{ash}) X (1-$f_{control}$)]. Sulphur content estimates from Brimblecombe (1977) were used, these ranged from 2.5 - 2 % from 1750 to 1800 and 2 - 1.5 % from 1800 to 1900.

Figure 8: UK SO_2 output, 1750-2000



Other elements of natural capital depreciation and appreciation, which could be included in the GS indicator if sufficient data were available include commercial fisheries and (improved) agricultural land. We are currently working on such inclusions.

3. Genuine Savings

Based on the work of Hamilton and Clemens (1999), Pezzey et al (2006) and others, Genuine Savings for Britain have been calculated for the period 1760-2000 by the following formula:

GS = [Σ (Δ produced capital stock + expenditure on education + Δ forest stock -

Σ (extraction rents of non-renewables) - Σ (CO_2)]/GDP (Eq. 1)

All values in the GS calculation are converted into nominal monetary values and deflated by nominal GDP (1750-1870, Broadberry et al (2011), 1870-1965, Feinstein (1972), and 1966-2000, ONS (2006)). Shadow prices for each capital stock change are ideally calculated by subtracting the marginal cost from the price. Moreover, these prices are those that in optimal growth models from which the GS indicator is derived emerge along a PV-optimal growth path (Pezzey et al, 2006). In practice, we make use of market prices and, typically, average rather than marginal costs. This means that our numerical estimate of GS in any period does not correspond to its theoretical equivalent – as is true for all World Bank estimates.

Two measures are used for the change in the reproduced capital stock. Firstly, Net Fixed Capital Formation (NFCF) and these data were obtained from Feinstein & Pollard (1988), Feinstein (1972) and *UK National Income* publications. NFCF in current prices is not the same as the change in the nominal NCS in section 2. Feinstein & Pollard (1988, p. 259) outlined that 'for the identities to hold at current prices, it would be necessary to allow also for the change in price of the gross (or net) stock between the successive years.' Thus the gross (or net) capital formation only equals changes in the gross (or net) stock when they latter is measured in constant prices. Secondly, data on net foreign investment and inventories was included in an alternative measure of reproduced capital. Including net overseas investment may be important, for example if extracted natural resource rents are invested overseas. Additionally our estimates go back to 1750 when the ratio of circulating to fixed capital was higher, hence the inclusion of the value of increases in stocks and work in progress in the second measure of total net domestic and net overseas investment.

As with the World Bank methodology, we have incorporated public expenditure on schooling in our GS calculations as a proxy for investments in human capital. Data on public expenditure on education were derived from Carpentier (2001)[6] for the period 1833-1997, and UNESCO measures of educational expenditure were used for the remaining years of the series. There are advantages and limitations to the human capital by education expenditure representation. Investment in education fits naturally into GS framework, which articulates the varying components of investment. However, human capital formation may not simply equate to education investment. Our human capital formation estimates are on-going and we wish to complement education investment with new estimates of human capital using relative wages to measure skills. Wage-based measures of human capital formation have the possible disadvantage of reflecting wider influences on productivity.

Changes in the forestry stock were estimated in section 2.2. It has been difficult to locate prices on UK forestry. Sources used to construct a series from 1700 to 2000 were Schumpeter (1960); Hiley (1930); Aström (1988); Bulfin (1974/75); Howard (1997); MacGregor (1950*a*, 1950*b*, 1953, 1959). The prices used were UK import prices from 1700-1810 and 1847 to 1957, Finnish export prices from 1810 to 1847, and US export prices from 1965 to 2000. There are also UK domestic prices available from 1970 to 2000 from the Forestry Commission. According to MacGregor (1946, p.p.30), labour costs had the 'greatest direct influence on the cost of forestry operations'. MacGregor (1946, p. 38) highlighted that while prices were set in international markets labour costs were determined by conditions in the agricultural labour market. MacGregor (1946) collected agricultural wage data from 1824 to 1946, but he only recorded the agricultural wage rate and not the cost per m^3. In

[6] Carpentier (2003 & 2008) gives an English language overview of the methodology and findings of Carpentier (2001).

order to calculate a cost per m^3 we need to know the number of labourers involved in the forestry sector and the annual felling. It is difficult to exactly determine the number of forest labourers in the earlier period as agricultural labourers could double as forest labourers. Census data provides us with numbers of people who returned themselves as woodcutters from 1841 to 1911. Based on German statistics, it was estimated that forestry could provide employment for 1 person per 100 acres on woods work and 4 men in forest industries, 5 in total British Parliamentary Papers (B.P.P.) (1942-43).[7] The felling data used to construct estimates of wage cost per m^3 were from Iriarte-Goñi & Ayuda (2008), MacGregor (1953) and Forestry Statistics 2001. Estimates of productivity from 1770 to 1850 were based on a rolling 20 year moving average.

Data on coal extraction were taken from Pollard (1980), Flinn (1984), Church (1986), Mitchell (1984,1988) and UK mineral statistics and UK mineral yearbook. Coal extraction was multiplied by the pithead price minus the average cost of extraction to estimate the value of extracted rent. Pithead prices per tonne were taken from Clark & Jacks (2007), Church (1986), Mitchell (1984, 1988), Supple (1987), Ashworth (1986), NCB reports, *UK Mineral Statistics*, & *UK Mineral Yearbook*. Wage costs per tonne were used as the average wage cost, as mining was very labour intensive during the initial period 1760-1938. Wage estimates were taken from Flinn (1984), Church (1986), Mitchell (1984, 1988), Ashworth (1986), Supple (1987) and NCB reports. The 19th century data are wages estimates for Hewers, face workers, and were reported as daily wages in Flinn (1984) and shift rates in both Mitchell (1984) and Church

[7] These estimates were based on Heske (1938)'s claim that each 35 cubic foot of wood cut would equal a days work.

(1986). Labour force numbers were taken from the annual returns of mines from the 1874s onwards (Mitchell, 1988), from census returns (Taylor, 1961; Mitchell, 1988), and estimated based on assumed constant productivity of 250 per man year for the earlier periods.

Figure 9: Coal extraction (million tonnes) and value of coal extraction (coal extraction* (p – mc), 1750-2000

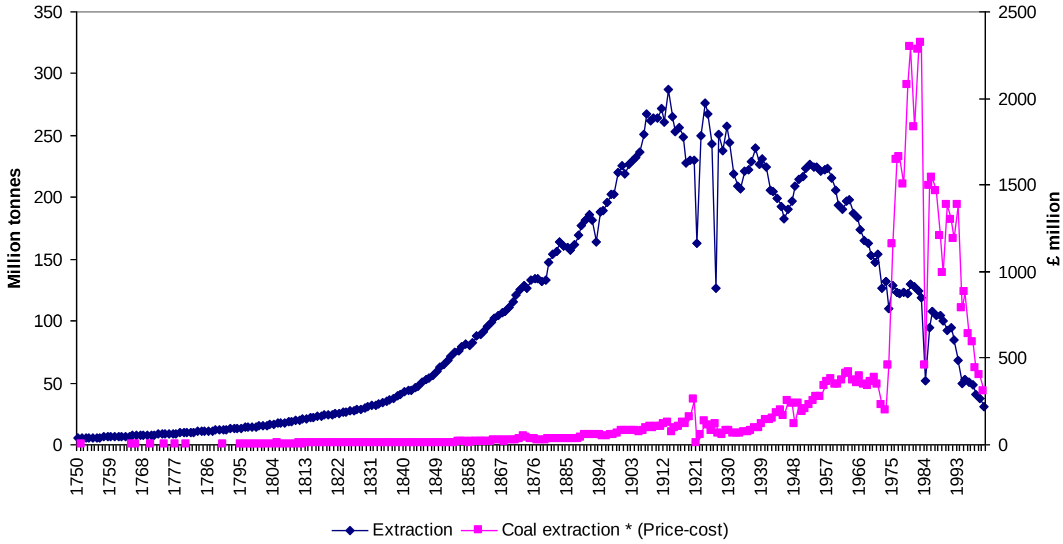
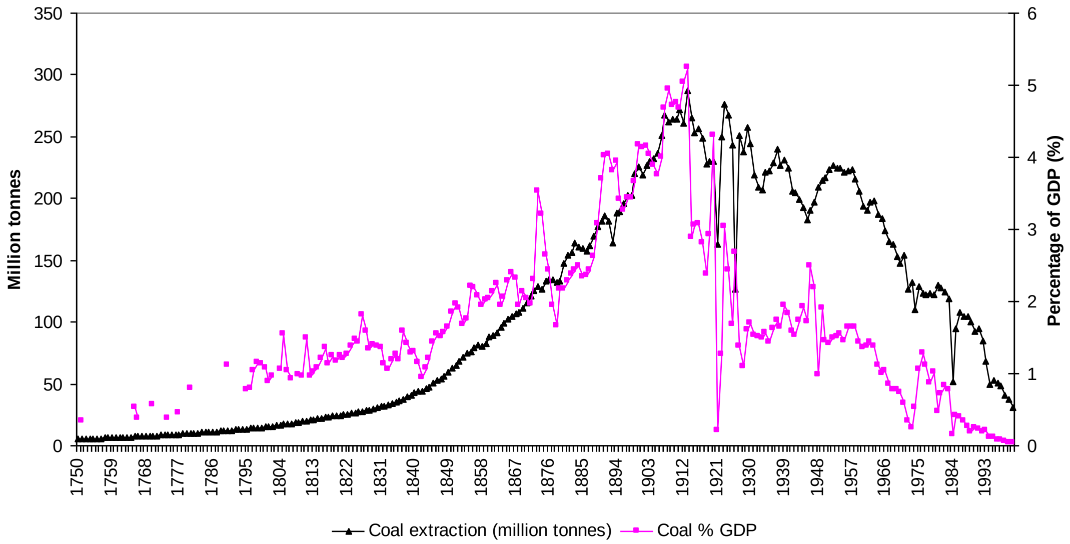


Figure 10: Coal extraction (million tonnes) and value of extracted coal as a percentage of GDP, 1750-2000



Data on iron ore extraction came from the official series beginning in 1854 and was estimated from pig iron production from Hyde (1977) and Riden (1977), as outlined in section 2.4. Extraction is multiplied by pithead prices minus average costs. Pithead prices from 1855 onwards are reported in the mineral statistics. Determining prices pre-1855 has proved to be more difficult as iron production had an integrated organisational structure. One solution would be to assume that the price of iron ore was a ratio of the price of pig iron prices. Using pig iron prices, we have estimated iron ore prices assuming that the iron ore price is a constant proportion of the pig iron price. An upper bound of 25 per cent (in line with (Hyde, 1977) & (King, 2011)), a mid point of 15 percent and a lower bound of 10 per cent were chosen (the average ratio of the pit head price to the pig iron price in the period 1857-1914 was 11 per cent). There are some scattered price data for the 20th century in the reports of the UK secretary of mines, Statistical digest, UK mineral statistics and UK mineral yearbook. We have used US prices for the period 1915-2000 obtained from Kelly et al. (2010).

As other mining industries are lacking in historical research it was difficult to estimate wage costs across mining industries. It is possible that the wage rates across all the mining industries were similar (Burt, 1984), but the wage costs per ton may well have differed. Using the 1907 census of production we see that Output per man year (OMY) for iron ore miners was 611 tons (B.P.P., 1910) versus an OMY of 321 tons for coal miners (B.P.P., 1909). This suggests that iron ore mining was approximately twice as productive and that therefore their costs would have been about half. Therefore if we divide the wage cost per ton estimate by 1.90 we arrive at a wage cost per ton estimate for iron ore mining.

Figure 11: Iron ore extraction (million tonnes) and value of iron ore extraction (coal extraction * (p – mc) value (1700-2000

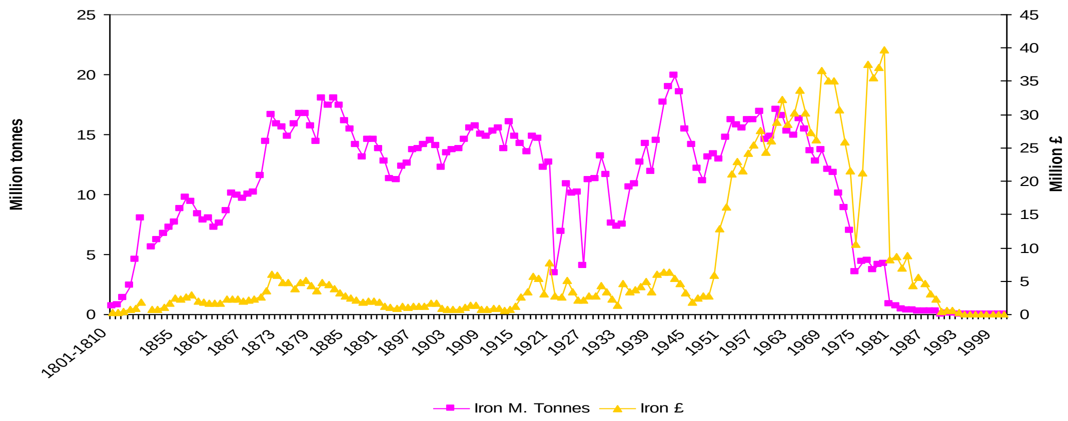
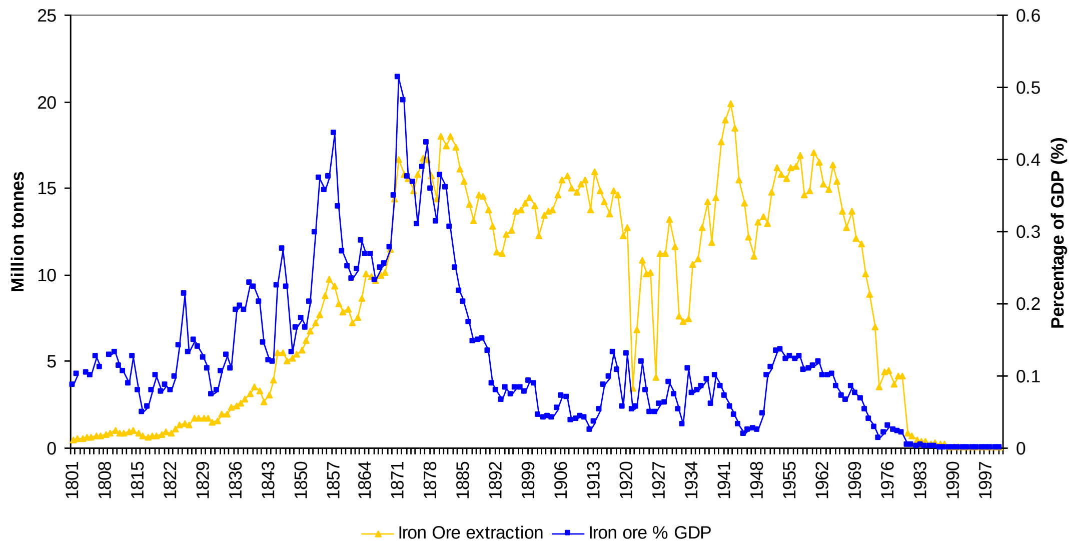


Figure 12: Iron ore extraction (million tonnes) and iron ore value as a percentage of GDP (%), 1700-2000



Data on tin, copper, lead and zinc extraction came from Mitchell (1988) and UK mineral statistics and mineral yearbook. As can be seen, non-ferrous minerals were not significant relative to UK GDP in this period.

Figure 13: Extraction of lead, copper, tin and zinc (tonnes) 1855-2000

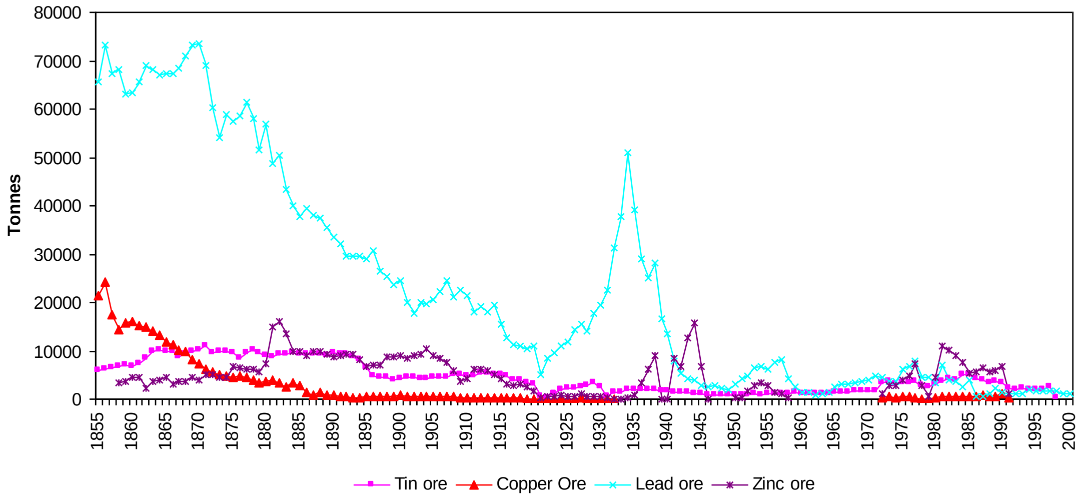
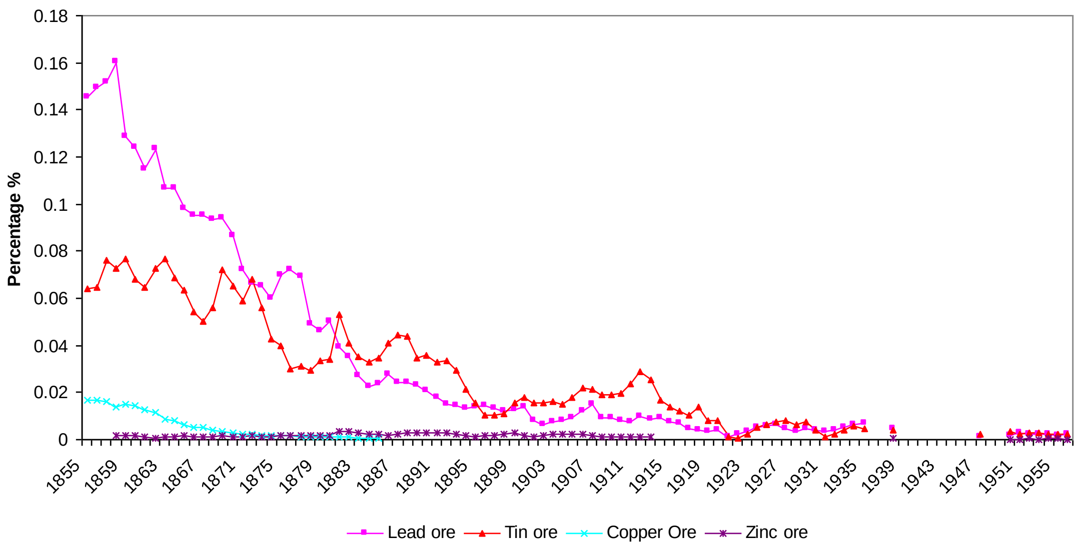
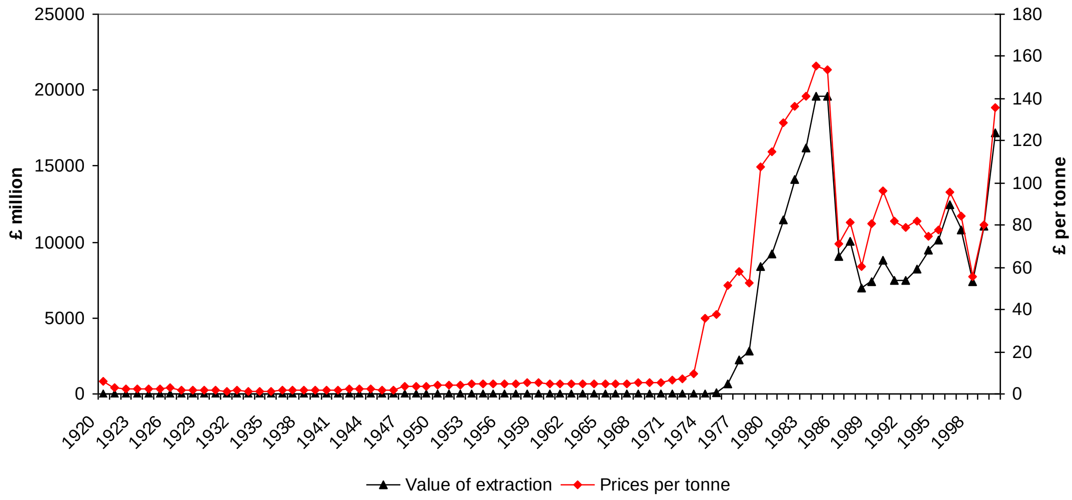


Figure 14: Value of lead, copper, tin and zinc extraction as a percentage of GDP, 1855-1956



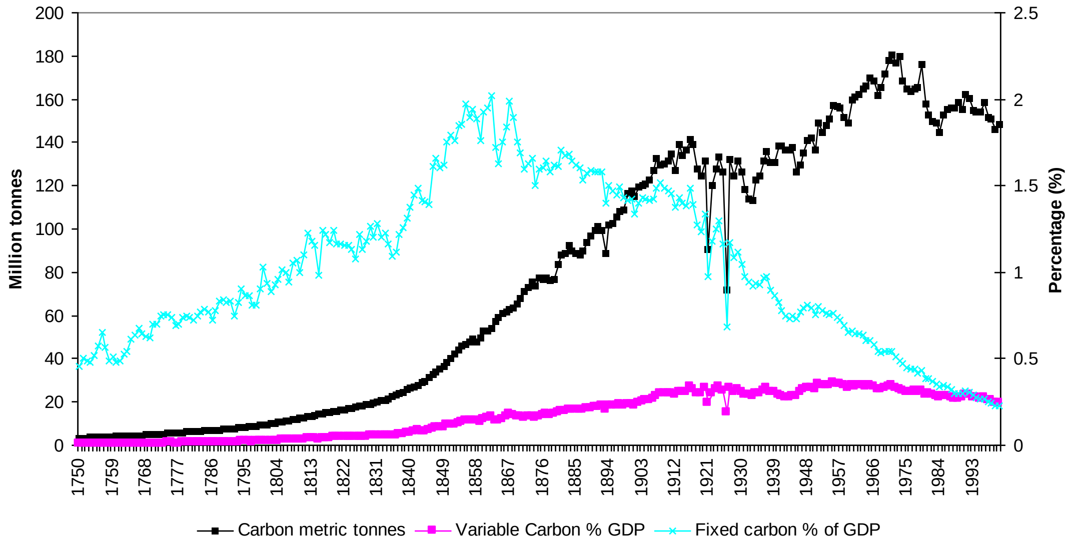
Oil and gas extraction was obtained from *Energy Trends* 2002. Historic oil prices used were from the BP *Statistical Review of World Energy* these were reported in price per barrel. These prices were converted to price per tonnes, assuming a barrel is equal to 0.136 tonnes. Dollar prices were then converted to pounds with the historic exchange rate series from Officer and Williamson (2010). The marginal costs of oil and gas extraction were assumed to be zero. The difference between crude oil prices and petrol prices arises due to refining or rents.

Figure 15: Value of UK oil extraction and current oil prices, 1920-2000



The provisional price of carbon used was \$20 (£12.66) per tonne in 1995 (Bolt, Matete, Clemens, 2002). The CO_2 output was converted to carbon by the factor of 12/44. The 1995 price was then deflated using the Officer and Williamson (2010) price index. Alternatively, we have shown the effect of a real price of carbon that rises over time. In the alternative the real price of carbon grows by 1.8 percent per annum, giving a value of £0.001 in 1750 and £12.66 in 1995.

Figure 16: Carbon output and carbon as a percentage of GDP, 1750-2000



4. Results and Discussion.

4.1 Genuine Savings and the Industrial Revolution

The estimates of GS are of particular interest over the period of the First Industrial Revolution. Economic Historians have long debated the importance of a rise in the savings (or investment) ratio during the Industrial Revolution. Rostow (1960) argued a necessary condition for sustained growth was a rise in the net investment to national income ratio from around 5% to 10%, for output to outstrip population growth when capital productivity was low. He tentatively dated the period of 'take-off' for Great Britain as 1783-1802.

Subsequent work, notably Feinstein (1978) denied a sharp rise in the investment ratio, instead arguing the gross domestic investment ratio had reached 12% by the 1780s and changed little over the next 50 years. Deane and Cole (1969) and Crafts (1985) are more sympathetic to the idea that the investment ratio rose, but they suggest this happened over a more extended period. For example, Crafts (1985) postulates a near doubling of gross domestic investment-national income from 6.0-

11.7%, 1760-1831. More recently, Crafts (1995) using revised estimates of gross domestic fixed capital formation from Feinstein (1988) reports a more modest rise in investment-GDP from 5.7% 1760-80 to 8.7% 1831-73. One curiosity of all these empirics is their focus on gross (total or fixed) investment whereas Rostow (1960, p.8 and p. 37) posits effective or net investment as the relevant ratio for sustained growth.

Our measures of GS incorporate estimates of net investment. Most importantly GS broadens the concept of net investment to include natural resource depletion. The GS estimates also include investment in education, although this was modest before 1860. One variant of the results includes estimates of environmental damage, but these are reported separately and later given the alternative views on whether or not pollution should be considered as net disinvestment, which reduced economic capacity. Accumulation associated with new technology will be incorporated into the estimates at a later stage.

For the period 1761-1860, the estimated GS essentially reflects the extent mineral resource depletion was offset by investments in produced capital. The GS estimates of Table 2 use the narrower measure of net domestic fixed investment, which averaged 1.1% of GDP in the 1770s and rose sharply to 4.3% of GDP during the 1830s and peaks at 5.31% during the 'railway age' of the 1840s. Most strikingly, the results of Table 2 show GS was negative 1760-80, as the extraction of coal and iron ore rents more than offset NFCF. This finding suggests the sustained economic growth, which followed the Industrial Revolution, was not assured in the 1760s and 1770s. Extraction rents, relative to GDP rose further in the first half of the nineteenth century, but GS was positive, and exceeded 2% of GDP during the manufacturing and railway investment expansions of the 1830s and 1840s. When railway investment fell in the 1850s so did GS, although at 1.6% it remained positive (note: real wages are discussed later on).

Table 2: Mean Genuine Savings rates (% GDP) and growth in real wages (% per annum), 1761-1860 (decade averages)

	NFCF [a]	*Educ*	*Forestry*	*Extraction*	*GS*	*real wages*
1761-1770	0.52			-1.10	-0.58	-0.68
1771-1780	1.12		0.05	-1.20	-0.04	1.05
1781-1790	1.38		0.04	-0.80	0.62	0.39
1791-1800	1.79		0.03	-0.65	1.17	-2.42
1801-1810	2.22		-0.02	-1.23	0.97	2.16
1811-1820	2.51		-0.03	-1.35	1.13	1.01
1821-1830	3.33		-0.05	-1.69	1.60	0.80
1831-1840	4.27	0.01	0.01	-1.35	2.94	-0.16
1841-1850	5.31	0.03	0.01	-1.75	3.61	1.67
1851-1860	3.95	0.10	0.02	-2.47	1.60	-0.18

Notes: a NFCF are table 1 column 6 (Net Fixed Capital Formation), Feinstein and Pollard (1988).

Within a GS framework the case for limiting net investment to fixed and domestic appears dubious. Inventories and work in progress (sometimes defined as circulating capital) were important elements of capital formation during the Industrial Revolution, and circulating capital increased in every decade 1761-1860. Countries can also hold wealth in the form of investments in other countries. Fixed investment grew more quickly than circulating, which largely explain why, given overseas investment was modest before the 1850s, the net domestic and overseas investment-GDP ratio, see Table 3, only doubled from the 1780s-1840s whereas NFCF (Table 2) more than quadrupled. Nevertheless, total net capital formation, once circulating capital is included, offset the effects of mineral extraction in the 1760s and 1770s to give a positive GS for these decades.

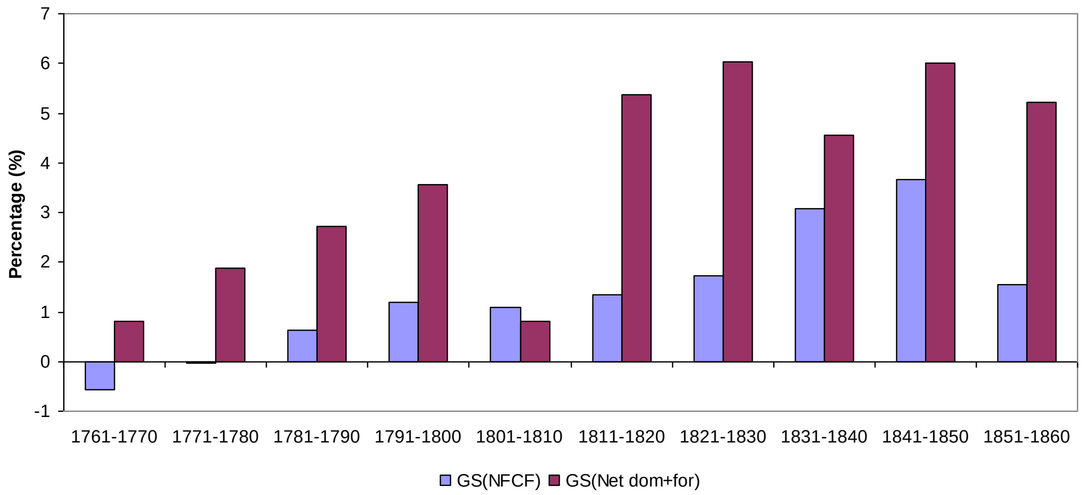
Table 3. Mean Genuine Savings rates (% GDP) and growth in real wages (% per annum), 1760-1860 (decade averages)

	Net domestic +overseas	*Educ*	*Forestry*	*Extraction*	*GS*	*real wages*
1761-1770	1.91			-1.10	0.82	-0.68
1771-1780	3.05		0.05	-1.20	1.90	1.05
1781-1790	3.44		0.04	-0.80	2.69	0.39
1791-1800	4.13		0.03	-0.65	3.50	-2.42
1801-1810	1.97		-0.02	-1.23	0.72	2.16
1811-1820	5.89		-0.03	-1.35	4.52	1.01
1821-1830	7.31		-0.05	-1.69	5.57	0.80
1831-1840	5.66	0.01	0.01	-1.35	4.33	-0.16
1841-1850	7.62	0.03	0.01	-1.75	5.92	1.67
1851-1860	7.77	0.10	0.02	-2.47	5.42	-0.18

Notes: a Net domestic and foreign investment are table 1 column 6 (Net Fixed Capital Formation), table 17 columns 3 (Value of physical increase in stocks and work in progress) and 4 (net investment abroad), Feinstein & Pollard (1988)

Other features of the GS estimates of Table 3 are worth highlighting. The GS ratio falls sharply 1801-10, though remains positive. The fall probably reflects the effects of the Napoleonic Wars. While NFCF rose, the increase in circulating capital in the first decade of the new century was lower than in the 1790s. Further, net overseas investment was negative 1801-10. Net overseas investment was relatively modest in the first half of the nineteenth century. In the 1840s it was less than one quarter the value of net domestic investment. Net overseas investment surged in the 1850s and amounted to around two-thirds the value of net domestic investment in that decade. The sharp fall in the GS ratio shown in Table 2 for the 1850s is not mirrored in the results of Table 3 (see also Figure 17), reflecting the heightened importance of overseas investment to the British economy in the 1850s. By the 1850s, natural resource depletion in the UK was being offset by overseas investment, a feature that would persist until the First World War.

Figure 17: Genuine Savings as a percentage of GDP: 1760-1860 (decade averages)



As may be seen in Figure 17, including the value of overseas assets held by British citizens considerably increases the GS measure, and results in it being positive over the entire time period.

4.2 Genuine Savings since 1850

Utilizing the narrow measure of produced capital, NFCF (Table 4) estimated GS has been positive since 1850 except during the two world wars. The war years apart, GS has been higher since 1860 than during the Industrial Revolution, by a factor of two from 1860-1938, and a factor of seven since 1946. The ratio of NFCF-GDP has been higher since 1860, but education investment also grew strongly, most especially in the twentieth century. Resource depletion is also higher after 1860, but the effects have been more than offset by other investment except during the world wars.

Table 4: Mean Genuine Savings rates (% GDP) and growth in real wages (% per annum), 1760-2000

	NFCF	*Education*	*Forestry*	*Extraction*	*Genuine Savings*	*Real wages*
1760-1860	2.64	0.05	0.01	-1.36	1.34	0.46
1860-1914	3.90	0.76	0.09	-2.10	2.65	1.39
1918-1938	2.39	2.15	-0.06	-1.96	2.53	2.37
1946-2000	7.06	4.31	0.17	-2.32	9.23	1.74
1914-1918	0.07	1.30	-0.16	-2.95	-1.74	-4.06
1939-1945	-0.91	1.58	-0.04	-1.82	-1.19	-2.18
1946-1968	7.42	3.44	0.17	-1.54	9.49	1.58

The decadal nuances of the NFCF version of GS are shown in Table 5. Domestic capital formation surges in the 1870s and in the first twentieth century decade are revealed, as is the lower NFCF ratio during the 1920s and 1930s. To an extent investment in education offset low NFCF between the world wars. The 1950s, 60s and 70s experienced both historically high NFCF and education investment, and concomitantly high GS. Natural resource extraction rose sharply in the 1980s and it was accompanied by lower NFCF and education investment, hence GS in the 1980s was around half of its peak 1960s ratio.

Table 5: Mean Genuine Savings rates (% GDP) and growth in real wages (% per annum), 1760-2000

	NFCF	*Education*	*Forestry*	*Extraction*	*Genuine Savings*	*Real wages*
1760-1860	2.64	0.05	0.01	-1.36	1.34	0.46
1851-1860	4.15	0.10	0.02	-2.59	1.68	-0.18
1861-1870	4.58	0.12	-0.08	-2.47	2.16	2.16
1871-1880	5.05	0.22	0.06	-2.80	2.53	2.64
1881-1890	2.80	0.58	0.05	-2.05	1.37	1.25
1891-1900	3.90	1.07	0.17	-1.59	3.55	1.67
1901-1910	4.00	1.50	0.22	-1.68	4.05	-0.37
1911-1920	1.02	1.40	-0.02	-2.65	-0.25	3.16
1921-1930	2.28	2.17	-0.06	-1.79	2.59	2.45
1931-1940	2.66	2.44	-0.03	-1.72	3.36	0.04
1940-1950	1.16	1.87	0.01	-1.81	1.23	0.77
1951-1960	7.04	3.17	0.20	-1.64	8.77	1.67
1961-1970	9.82	4.55	0.19	-1.16	13.41	3.26
1971-1980	8.29	5.32	0.23	-2.29	11.62	1.53
1981-1990	6.05	4.82	0.19	-4.58	6.47	2.29
1991-2000	5.45	4.64	0.09	-2.14	8.03	1.43

The consequences for GS of the broader measures of domestic and overseas investment are shown in Tables 6 and 7. The GS ratio was twice as high 1860-1914 compared to pre-1860 largely because of overseas investment, but education spending also rose. Similarly GS between the world wars fell to Industrial Revolution levels because of the overseas investment collapse. The severity of the GS collapse during World War 2 is accentuated by allowing for the dramatic overseas investment collapse. The rise in GS 1946-2000 arises from domestic investment, including that in education.

The decadal data of Table 7 chiefly serve to clarify the shifts of GS in the second half of the twentieth century. The 1950s, 60s and 70s are shown as decades of high GS because of high rates of domestic investment. The modest decline in the domestic investment ratio in the 1970s was partially offset by heightened education investment. Alternatively resource depletion also picked up during the 1970s, and then surged in the 1980s. Genuine savings halved in the 1980s compared to the previous decade, as resource depletion was accompanied both by lower domestic and overseas investment.

Table 6 : Mean Genuine Savings rates (% GDP) and growth in real wages (% per annum), 1760-2000

	Net domestic	***Net overseas***	***Educ***	***Forestry***	***Extract***	***G S***	*Real wages*
1760-1860	3.72	1.15	0.05	0.01	-1.36	3.57	0.46
1860-1914	4.48	4.70	0.89	0.12	-2.03	8.16	1.39
1918-1938	2.40	0.82	2.15	-0.06	-1.96	3.36	2.37
1946-2000	7.66	-0.22	4.31	0.17	-2.32	9.60	1.74
1914-1918	-0.55	0.21	1.30	-0.16	-2.95	-2.15	-4.06
1939-1945	-0.71	-7.56	1.58	-0.04	-1.82	-8.55	-2.18
1946-1968	8.38	0.01	3.44	0.17	-1.54	10.46	1.58

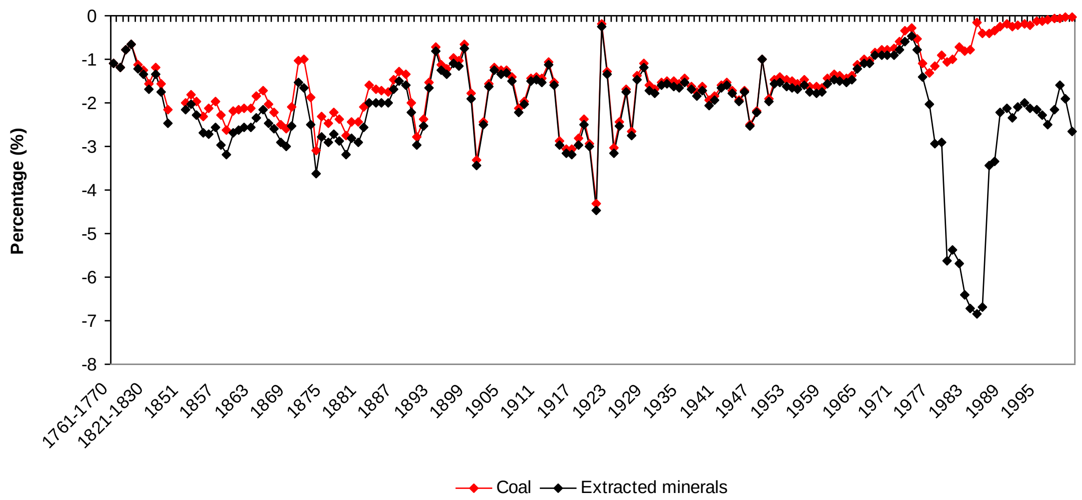
Table 7: Mean Genuine Savings rates (% GDP) and growth in real wages (% per annum), 1760-2000

	Net domestic	***Net overseas***	***Educ***	***Forestry***	***Extract***	***G S***	***Real wage s***
1760-1860	3.72	1.15	0.05	0.01	-1.36	3.57	0.46
1851-1860	4.84	3.06	0.10	0.00	-2.62	5.39	-0.18
1861-1870	6.31	3.79	0.12	-0.08	-2.45	7.69	2.16
1871-1880	5.61	4.09	0.22	0.06	-2.80	7.19	2.64
1881-1890	3.83	5.74	0.58	0.05	-2.05	8.14	1.25
1891-1900	4.83	3.15	1.07	0.17	-1.59	7.63	1.67
1901-1910	4.34	4.75	1.50	0.22	-1.68	9.14	-0.37
1911-1920	0.25	3.50	1.40	-0.02	-2.65	2.48	3.16
1921-1930	2.46	2.24	2.17	-0.06	-1.79	5.01	2.45
1931-1940	3.28	-2.10	2.44	-0.03	-1.72	1.87	0.04
1940-1950	1.29	-4.39	1.87	0.01	-1.81	-3.03	0.77
1951-1960	8.32	0.26	3.17	0.20	-1.64	10.32	1.67
1961-1970	10.79	0.03	4.55	0.19	-1.16	14.41	3.26
1971-1980	8.82	-0.12	5.32	0.23	-2.29	11.96	1.53
1981-1990	6.17	-0.61	4.82	0.19	-4.58	5.98	2.29
1991-2000	5.72	-0.83	4.64	0.09	-2.14	7.47	1.43

4.3 Extracting Natural Resource Rents, GS and Real Wages

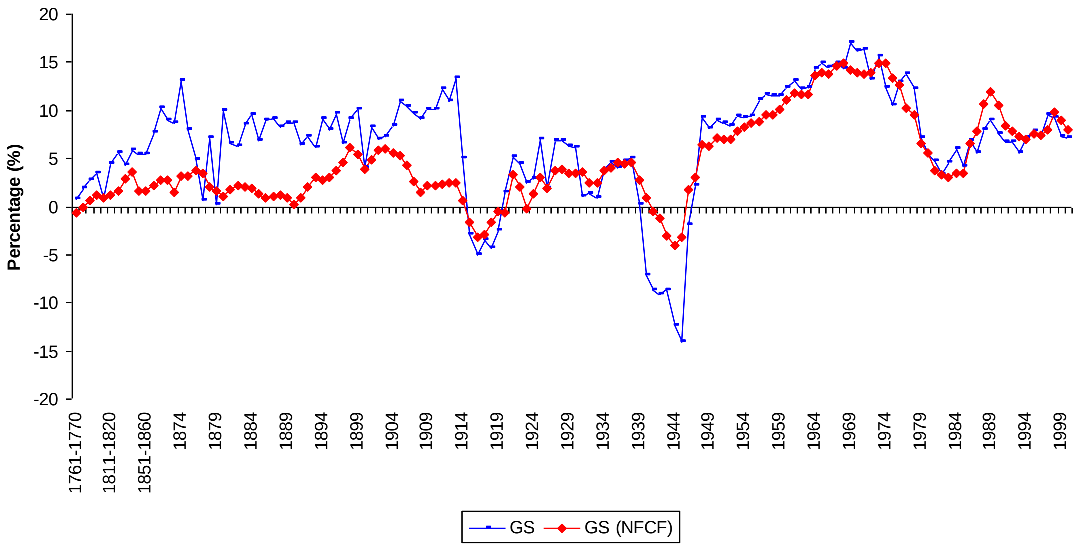
The British economy has persistently benefited from the extraction of natural resource rents since at least 1760. In the two centuries to 1960, see Figure 18, the value of extraction averaged around 2% of GDP, chiefly from coal mining. Thereafter coal rents became less important, but the extraction of North Sea oil pushed overall mineral rents to a peak of around 7% of GDP in the 1980s, with the ratio falling to its long term average in the 1990s.

Figure 18: Depletion of all minerals and coal as %GDP



Within a GS framework the value of mineral rents are treated as disinvestment which, unless offset by other forms of investment, equates to unsustainable development. Our findings (Tables 2-7) and Figure 19 below, show resource depletion was offset and that GS has generally been positive. Inspection of Figure 19, which shows trends in GS using the different measurments of produced capital, show GS rose from near zero in 1760 to above 10% of GDP by 1914. Within the pre-1914 period the major interruption to rising GS was in the 1870s and the early 1880s and arose from declines in circulating capital in the 1870s and lower net domestic fixed capital formation in the 1880s. Heightened overseas investment (see Figure 20) in the later 1880s and again after 1900 propelled GS to its 1914 peak.

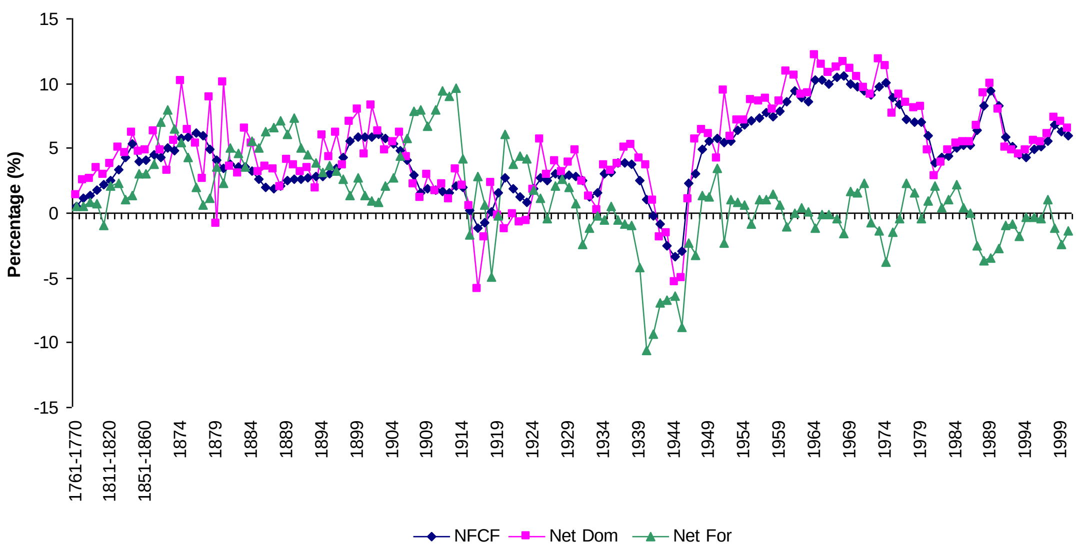
Figure 19: Genuine Savings as a percentage of GDP: 1760-2000



Note: GS =[Σ(**Net domestic investment + Net Foreign investment +** expenditure on education + Δ forest stock - Σ(extraction rents of non-renewables)]/GDP

GS (NFCF) = [Σ(**Net Fixed Capital Formation + +** expenditure on education + Δ forest stock - Σ(extraction rents of non-renewables)]/GDP

Figure 20: Investment rate as a percentage of GDP: 1760-2000



Notes: NFCF = Net Fixed Capital Formation; Net Dom = Net Fixed Capital Formation + Inventories; Net For = Net Foreign investment.

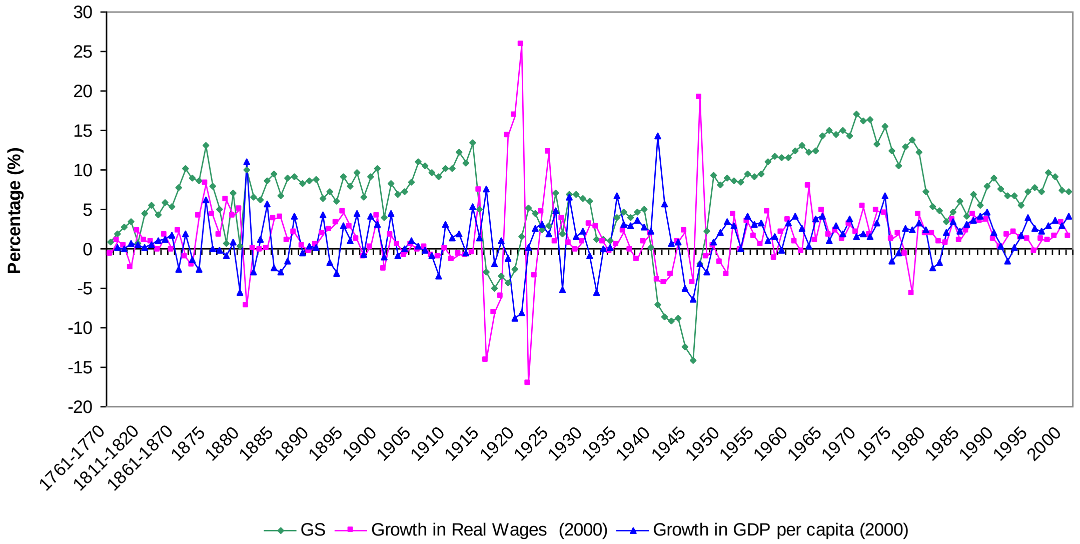
Turning attention to the post-1914 period, Figures 19 and 20 show historically low and often negative GS and produced investment 1914-45. The effects of the world wars and the downward shift in net overseas investment 1914-45 is striking. Domestic investment rose in the 1920s and 1930, but the ratio didn't regain the levels of the 1890s. Over the period 1915-45 the broader GS measure on average was negative, reflecting the low savings during the Great Depression of the early 1930s as well as the effects of the two world wars, which included lower education investment.

Equally dramatic was the rise of GS after 1945 to a late 1960s peak of around 15%. The increase in GS was due to heightened domeastic capital formation, which rose to above 10% of GDP and education investment which rose to above 5% of GDP, while the value of natural resource extraction was falling. GS fell from its 1960s peak to less than 5% of GDP during the early 1980s, see Figure 18, but recovered to above 7% of GDP in the 1990s as the rents from oil extraction fell.

Next we consider the implications of the GS results for well-being. At present the discussion is confined to average real wages as a simple indicator of changes in well-being over time, but eventually the research will consider a wider range of indicators. It should also be remembered that theory provides no guidance on the timeframe of the relationship between GS and well being. A number of prelimanary observations arise from the justaxposition of GS and real wages in Figure 21 (see also Tables 2-7). Real wage growth was low (averaging around 0.46% pa) during the Industrial Revolution period to 1860, despite the rise in GS over the same period. Real wage growth was higher 1860-1914, averaging 1.39% pa. On average the broader (domestic and overesaes investment) GS-GDP ratio was also twice the pre-

1860 level 1860-1914. However, there are shorter term disparaties, for example real wage stagnate 1900-14 while GS rises strongly in that period.

Figure 21. Genuine savings and growth in real wages per annum, 1761-2000



The period 1914-45 witnesses some dramatic fluctuations in wages and the cost of living and comcommitantly real wages, especially around the world wars. Real wage growth 1918-39 was high at 2.25% pa (see Table 6) and GS was low between the world wars and similar to the pre-1860 average. However real wage growth 1924-37 was 1.05% pa and gauging the relationship between real wages and GS 1914-1945 is made difficult by the sharp fluctuations in the values of both variables in this period.

Real wage growth has generally been positive since World War Two and averaged 1.74% pa 1946-2000. The GS-GDP was high 1951-80 (see Table 7) and averaged around 12%. However real wage growth was maintained 1981-2000 while the GS-GDP ratio fell by around 50%. The decade 1961-70 experienced the highest GS-GDP of 14.41% and also the fastest real wage growth at 3.26% pa (Table 7). The lack of simple symmetry between GS and real wages is highlighted though over the two following decades. The sharpest decadel fall in the GS ratio after World War 2 occurred in the 1980s, when the GS ratio fell to 5.98% 1981-90 compared to 12.03% 1971-80, but real wage growth rose by around 50% in the 1980s compared to the previous decade. Much of the fall in GS during the 1980s arose from the extraction of oil rents, which may in the short run have supported real wages.

The connection between the extraction of natural resource rents and well-being lies at the heart of the GS framework, even though timeframes of the relationship are not defined by theory. Thus it is possible that the oil extraction of 1980s supported consumption in that decade with adverse consequences for longer term well being. Over the two centuries before the oil boom, coal extraction rents dominated the depletion of Britain's natural resources. Indeed, on one measure (Table 2) GS was negative in the 1760s and 1770s as the extraction of coal rents exceeded fixed capital formation. Possibly the the key issues of sustainability in the case of Britain arose in the two centuries before 1760 given the earlier exploitation of coal and forest resouces, but, in the absence of produced capital estimates for earlier periods, this is only speculation.

Many interpretations of the Industrial Revolution highlight British leadership in coal use, where mineral resource abundance and use is seen as a boon rather than a curse. Yet the GS model equates coal extraction with the depletion of natural wealth, which over time is deleterious for well-being, unless the resource rents are wisely invested. Of course the latter might be what happened, to the extent that investment in metal and steam based industries offset coal depletion, and indeed made possible the exploitation of deeper coal seams. Thus the Industrial Revolution marked a watershed between an era of stagnant real wages and two subseqent centuries of real wage improvements, and possibly sustainabilty was underpinned by the prudent utilization of natural resource rents.

There are, however, alternative interpretations of the path to sustainable development, which possibly suggest natural resource depletion is of less importance than the GS framework implies. The estimates of Table 1 report 27 billion tons of coal has been extracted since 1760 whereas the best estimate of reserves, that of the Royal Commission on Coal Supplies, is 147 billion tons. On these figure less than 20% of Britain's coal has been extracted, which raises the question of why coal extraction equates to a diminishing of wealth when most British coal will never, on any plausible timeframe, be exploited. The other key issue arising from looking at GS and sustainable development over centuries is the role of technology. To an extent Britain's coal abundance was created by investment in mines (and mining engineers) but our GS estimates thus far exclude the measurement of technological progress, which for example meant improved steam engines could pump water from deeper mines. In due course we plan to include estimates of economy-wide TFP in the GS estimates to gauge the contribution of new technology to sustainable development.

4.4 Genuine Savings and Pollution

As we discussed in section 2.6 The World Bank expands the notion of a national "asset" to include its unpolluted air, and hence adjust its GS for the costs arising from stock pollutants. As a first approximation World Bank used the damage from a single stock major pollutant, Carbon Dioxide emissions using a constant damage of $20 per ton of Carbon, along with health damages associated with particulates. At the moment we are neither convinced that a constant damage for CO_2 can be used for the whole period under scrutiny nor that the damage cost suggested is suitable. In this section however we adjust our initial GS estimates assuming the World Bank's approach is valid and that it can be applied for the period since 1760.

Thus the GS estimates reported in Tables 8 and 9 are extensions of Tables 2 adjusted for the costs of carbon pollution. The carbon cost data are based upon the estimates of carbon dioxide output from Figure 7, using a constant and time variable price derived from the World Bank's damage cost of $20 per ton of carbon, deflated by retail prices. On the constant price basis the costs of pollution relative to GDP was highest in the 19th century. The GS ratios are reduced to low levels before 1914, but they generally remain positive. Using the time varying price variant the cost of pollution relative to GDP has been slightly higher since 1945.

Table 8: Mean Genuine Savings including Fixed Carbon Costs (% GDP) 1760-2000

	NFCF	***Education***	***Forestry***	***Extract***	***Carbon***	***GS***	*GS with carbon*
1760-1860	2.64	0.05	0.01	-1.36	-1.09	1.34	0.24
1860-1914	3.90	0.76	0.09	-2.10	-1.59	2.65	1.07
1918-1938	2.39	2.15	-0.06	-1.96	-1.06	2.53	1.46
1946-2000	7.06	4.31	0.17	-2.32	-0.50	9.22	8.71
1914-1918	0.07	1.30	-0.16	-2.95	-1.39	-1.74	-3.13
1939-1945	-0.91	1.58	-0.04	-1.82	-0.77	-1.19	-1.96
1946-1968	7.42	3.44	0.17	-1.54	-0.70	9.49	8.79

Table 8: Mean Genuine Savings including time varying Carbon Costs (% GDP) 1760-2000

	NFCF	***Education***	***Forestry***	***Extract***	***Carbon***	***GS***	*GS with carbon*
1760-1860	2.64	0.05	0.01	-1.36	-0.05	1.34	1.29
1860-1914	3.90	0.76	0.09	-2.10	-0.21	2.65	2.44
1918-1938	2.39	2.15	-0.06	-1.96	-0.30	2.53	2.23
1946-2000	7.06	4.31	0.17	-2.32	-0.31	9.22	8.90
1914-1918	0.07	1.30	-0.16	-2.95	-0.31	-1.74	-2.06
1939-1945	-0.91	1.58	-0.04	-1.82	-0.29	-1.19	-1.47
1946-1968	7.42	3.44	0.17	-1.54	-0.34	9.49	9.15

5. Conclusion

This paper reports one of the first attempts to measure Genuine Savings over the long run. We constructed time series on changes in different capital stocks for Britain over the period 1750-2000, and then used methods employed by the World Bank to derive estimates of Genuine Savings over the period. Overall, we find that GS was positive over these 250 years, which according to theory should be consistent with improvements in well-being, measured here using real wages. A (hypothetical) Treasury minister in 1800 in London who estimated GS as an indicator of the sustainability of development during the industrial revolution would have been correct in interpreting the positive value as a signal of rising well-being over the next 100 years. As the value of GS increased post 1850, real wage growth also rose. The most important adjustments to Britain's capital stock turn out to have been investments in produced capital and, before 1914, in overseas assets, which more than offset the value of the depletion of non-renewable capital stocks (coal and iron ore). Depletion of natural assets never accounted for more than 5% of GDP in the pre-oil era. Pollution damages turn out to contribute rather small adjustments using the accounting methods employed here.

Clearly, there are many improvements which could be made to the data. We are currently working on alternative measures of the human capital stock, and how pollution impacts on the value of this stock. Technological progress has not been explicitly included in GS, although it was clearly a major driving force in increases in economic output over the period, and in the availability of resources such as coal. Well-being has only been measured here using average real wages, and there are a range of alternative well-being measures which will be explored. Finally, a more formal investigation of the GS-real wage relationship over time is required.

References

Andres, R. J., Fielding, D. J., Marland, G., Boden, T. A., Kumar, N. Kearney, A. T. 1999, 'Carbon dioxide emissions from fossil-fuel use, 1751-1950', *Tellus* 51B, 759–765.

Arrow, K. J. and Dasgupta, P. and Goulder, L. H. and Mumford, K. J. & Oleson, K., 2010 'Sustainability and the Measurement of Wealth',NBER Working Papers,16599.

Ashworth, W. 1986, *The History of the British Coal Industry, 1946 - 1982: The Nationalized Industry*, Vol. 5, Oxford: Clarendon Press.

Aström, S.-E. 1988, *From tar to timber: studies in Northeast European forest exploitation and foreign trade 1660-1860*, Societas Scientiarum Fennica, Helsinki.

Beacham, A. 1946, 'The coalfields of Great Britain', *The Economic Journal* 56(222), 319–325.

Boden, T. A., Marland, G. Andres, R. J. 1995, 'Estimates of global, regional, and national annual CO_2 emissions from fossil-fuel burning, hydraulic cement production, and gas flaring: 1950-1992', ORNL/CDIAC-90, NDP-030/R6. http://cdiac.ornl.gov/epubs/ndp/ndp030/ndp0301.htm

Bolt, K.; Matete, M. & Clemens, M. 2002, ’Manual for Calculating Adjusted Net Savings’, http://go.worldbank.org/3AWKN2ZOY0

B.P.P. 1871, ‘ Report of the commissioners appointed to inquire into the several matters relating to coal in the United Kingdom. Vol. I. General report and twenty-two sub-reports’ *H.C.,* 1871*, [C.435] [C.435-I] [C.435-II]*, XVIII.1, 199, 815.

B.P.P. 1881, ‘Select committee on railways’, *British Parliamentary Papers* XIII. and XIV(374).

B.P.P. 1905, ‘Royal commission on coal supplies’, *H.C.* [Cd. 2353].

B.P.P. 1909, ‘Preliminary tables summarising the results of the returns received under the census of production act, 1906. part i.’, *H.C.* [Cd. 4896], cii, 655.

B.P.P. 1910, ‘Preliminary tables summarising the results of the returns received under the census of production act, 1906. part iv’, *H.C.* [Cd. 5254], cix, 249.

B.P.P. 1942-43, ‘Post-War Forst Policy: Report by H.M Forestry Commissioners’, *H.C.* iv, Cmd. 6447.

Brimblecombe, P. 1977, ‘London air pollution, 1500-1900’, *Atmospheric Environment* 11, 1157–1162.

Broadberry, S. van Leeuwen, B. 2008, ‘British economic growth and the business cycle, 1700-1850: annual estimates annual estimates’, Working paper online. http://www2.warwick.ac.uk/fac/soc/economics/staff/academic/broadberry/wp/pre1700v3.pdf

Boardberry, S., Campbell B., Alexander, K., Overton, M. and van Leeuwen, B. 2011, ‘British Economic Growth, 1270-1870: an output-based approach’, University of Kent School of Economics Discussion Papers, KDPE 1203, ftp://ftp.ukc.ac.uk/pub/ejr/RePEc/ukc/ukcedp/1203.pdf

Bulfin, M. 1974/75, ‘Timber and timber products trade, 1966-1973’, *Irish Journal of Agricultural Economics and Rural Sociology* 5, 239–251.

Burn, D. L. 1940, *The economic history of steelmaking, 1867-1939: a study in competition*, Cambridge University Press.

Burnham, T. H. and Hoskins, G. O. 1943, *Iron and Steel in Britain 1870-1930*, George Allen and Unwin.

Burt, R. 1984, *The British lead mining industry*, Dyllansow Truran.

Carpentier, V. 2001, *Systeme éducatif et performances économiques au Royaume-Uni: 19eme et 20eme siecle*, L'Harmattan, Paris.

Carpentier, V. 2003, 'Public expenditure on education and economic growth in the UK, 1833-2000', *History of Education, 32*, 1-15

Carpentier, V. 2008, 'Quantitative sources for the history of education', *History of Education, 37*, 701-720

Church, R. 1986, *The History of the British Coal Industry 1830-1913: Victorian Pre-Eminence*, Vol. 3, Oxford University Press, Clarendon Press.

Clark, G. Jacks, D. 2007, 'Coal and the industrial revolution', *European Review of Economic History* 11, 39–72.

Crafts, N. 1985, *British Economic growth during the Industrial Revolution,* OUP.

Crafts, N. 1995, Exogenous or Exogenous Growth- The Industrial Revolution Reconsidered, *Journal of Economic History*, 55, 745-72.

d'Autume, A. & Schubert, K., 2008. 'Hartwick's rule and maximum paths when the exhaustible resource has an amenity value', *Journal of Environmental Economics and Management*, v56(3), pages 260-274.

Deane, P and W. Cole, 1969 *British Economic Growth 1688-1959*, 2nd ed, CUP.

Deaton, A. 2007, 'Height, health, and development' *PNAS*, 104 (33), 13232-13237.

DUKES 1975, *Digest of UK Energy statistics*, Department of Trade and Industry.

Dietz, S., Neumayer, E., & De Soysa, Indra. 2007. 'Corruption, the resource curse and genuine saving' *Environment and Development Economics*, 12, 33-53.

Escosura, L. and Roses J. (2010) "Human capital and economic growth in Spain, 1850-2000" *Explorations in Economic History,* 47 (4), 520-532.

Feinstein, C. H. 1972, *National Income, Expenditure and output of the United Kingdom, 1855-1965*, Cambridge University Press.

Feinstein, C. H. Pollard, S., eds 1988, *Studies in Capital Formation in the United Kingdom, 1750-1920*, Oxford University Press.

Ferreira, S. & Vincent, J. R., 2005, 'Genuine Savings: Leading Indicator of Sustainable Development?', *Economic Development and Cultural Change, 53*, 737-754.

Ferreira, S., Hamilton, K. & Vincent, J. R., 2008, 'Comprehensive wealth and future consumption: accounting for population growth', *The World Bank Economic Review, 22*, 233-248.

Flinn, M. W. 1984, *The History of the British Coal Industry 1700-1830: the Industrial Revolution*, Vol. 2, Oxford University Press.

Forestry Commission. 2002. UK indicators of sustainable forestry. http://www.forestry.gov.uk/pdf/fullsfi.PDF/$FILE/fullsfi.PDF

Hamilton, K., and M. Clemens, 1999, 'Genuine Savings Rates in Developing Countries', *World Bank Economic Review* 13:2, 33-56.

Hamilton, K., and Withagen, Cees, 2007, 'Savings and the Path of Utility', *Canadian Journal of Economics* , 40, pp 703-713.

Hanley, N., Shogren, J. F., White, B.. 2006, *Environmental Economics in theory and practice* . Palgrave Macmillan.

Hartwick, J. M, 1977, 'Intergenerational Equity and the investing of rents from Exhaustible Resources', American Economic Review, 67(5), pages 972-74.

Hatch, F. H. 1920, 'The iron ore supplies of the world', *Geological Magazine* 57, 504–517.

Heske, F. 1938, *German Forestry*, Yale University Press.

Hiley, W. H. 1930, *The economics of forestry*, Oxford, Clarendon Press.

Hyde, C. K. 1977, *Technological change in the British Iron Industry, 1700-1870*, Princeton University Press.

Howard, J. L. 1997, 'U.S. timber production, trade, consumption, and price statistics, 1963-1994'. http://www.treesearch.fs.fed.us/pubs/viewpub.jsp? index=9681.

Iriarte-Goni, I. and Bosque, M. I. A. 2010, 'Not only subterranean forests: wood consumption and economic development in britain (1850-1938)',Online. http://www.unizar.es/

Jevons, H. S. 1915, *The British Coal Trade*, Kegan Paul and Trench and Trubner & Co Ltd, London.

Jevons, W. S. 1866, *The coal question: an inquiry concerning the progress of the nation and the probable exhaustion of our coal-mines*, Macmillan and co.

Kelly, T. D., Matos, G. R., Buckingham, D. A., Di Francesco, C. A., Porter, K. E. miner commodity specialists, U. 2010, 'Historical statistics for mineral and material commodities in the united states'. http://minerals.usgs.gov/ds/2005/140/

King, P. 2011, 'The choice of fuel in the eighteenth-century iron industry: the Coalbrookdale accounts reconsidered', *The Economic History Review* 64, 132–156.

Kunnas, J. Myllyntaus, T. 2007, 'The environmental Kuznets curve hypothesis and air pollution in Finland', *Scandinavian Economic History Review* 55, 101–127.

Le, T., Gibson, J. & Oxley, L., 2006, 'A forward-looking measure of the stock of human capital in New Zealand', *The Manchester School, 74*, 593-609

Lefohn, A. S., Husar, J. D. Husar, R. B. 1999, 'Estimating historical anthropogenic global sulfur emission patterns for the period 1850-1990', *Atmospheric Environment* 33(21), 3435–3444.

Louis, H. 1910, *The iron ore resources of the world: An inquiry made upon the initiative of the executive committee of the XI international geological congress, Stockholm*, Generalstabens Litografiska Anstalt.

MacGregor, J. J. 1946, 'Labour costs in english forestry since 1824', *Forestry* 20, 30–43.

MacGregor, J. J. 1950*a*, 'The price trends of some categories of home-grown timber, 1914-1949', *Journal of the Land Agent's Society* pp. 173–175.

MacGregor, J. J. 1950*b*, 'The trend of prices and volume of imported timber', *Journal of the land agents' society* pp. 241–6.

MacGregor, J. J. 1953, 'The sources and natures of statistical information in special fields of statistics: timber statistics', *Journal of the Royal Statistical Society. Series A (General)* 116(3), 298–322.

MacGregor, J. J. 1959, 'The preparation of price index numbers for forestry products', *Forestry* 32, 39–51.

McInnes, W., Dowling, D. B. Leach, W. W., eds 1913, *The Coal Resources of the World: An inquiry made upon the initiative of the executive committee of the XII international geological congress, Canada 1913*, Morang and Co Limited.

Mitchell, B. R. 1984, *Economic Development of the British Coal Industry, 1800-1914*, Cambridge University Press.

Mitchell, B. R. 1988, *British historical statistics*, Cambridge University Press.

Neumayer E. (2010) *Weak Versus Strong Sustainability: exploring the limits of two paradigms.* Cheltenham: Edward Elgar.

Officer, L. H., Williamson, S. H. 2010, 'Measures of worth'. www.measuringworth.com/worthmeasures.php

ONS 2006, *Economic Trends*.

Pearce, D.W. and G. Atkinson,1993. Capital theory and the measurement of sustainable development: an indicator of weak sustainability. *Ecological Economics* 8: 103-108.

PEP, ed. 1947, *The British Fuel and Power Industries: A report by Political and Economic Planning*, Political and Economic Planning.

Pezzey, J. 2004, 'One-sided sustainability tests with amenities, and changes in technology, trade and population', *Journal of Environmental Economics and Management*, 48, pp 613-631.

Pezzey, J. C., Hanley, N., Turner, K. & Tinch, D., 2006, 'Comparing augmented sustainability measures for Scotland: Is there a mismatch?', *Ecological Economics, 57*, 70-74

Pollard, S. 1980, 'A new estimate of British coal production, 1750-1850', *The Economic History Review* 33, 212–235.

Riden, P. 1977, 'The output of the British iron industry before 1870', *The Economic History Review* 30, 442–459.

Rostow, W. W., 1960, *The Stages of Economic Growth*, CUP.

Schlich, W. 1904, *Forestry in the United Kingdom*, Bradbury, Agnew, & Co, London.

Schumpeter, E. B. 1960, *English overseas trade statistics 1697-1808*, Oxford at the Clarendon Press.

Smith, S. J., Pitcher, H. Wigley, T. 2001, 'Global and regional anthropogenic sulfur dioxide emissions', *Global and Planetary Change* 29, 99–119.

Smith, S. J., van Aardenne, J., Klimont, Z., Andres, R. J., Volke, A. Arias, S. D. 2011, 'Anthropogenic sulf diox emissions: 1850-2005', *Atmospheric Chemistry and Physics* 11, 1101–1116.

Stamp, L. D. Beaver, S. H. 1954, *The British Isles: a geographic and economic survey*, 4th edition edn, Longmans, Green and Co.

Supple, B. 1987, *The History of the Britsh Coal Industry, 1913-1946: The Political Economy of decline*, Vol. 4, Oxford: Clarendon Press.

Taylor, A. J. 1961, 'Labour productivity and technological innovation in the British coal industry, 1850-1914', *The Economic History Review* 14, 48–70.

Trueman, S. A., ed. 1954, *The Coalfields of Great Britain*, Edward Arnold, London.

Warde, P. 2007, *Energy consumption in England and Wales, 1560-2000*, Consiglio Nazionale delle Ricerche: Instituto di Studi sulle Societa del Mediterraneo.

World Bank (Hamilton, K.; Ruta, G.; Bolt, K.; Markandya, A.; Pedroso-Galinato, S.; Silva, P.; Ordoubadi, M. S.; Lange, G.-M. & Tajibaeva., L.). 2006. *Where is the wealth of nations? Measuring Capital for the 21st century* (Washington D.C.).

World Bank (Lange, G.-M.; Hamilton, K.; Ruta, G.; Chakraborti, L.; Desai, D.; Edens, B.; Ferreira, S.; Fraumeni, B.; Jarvis, M.; Kingsmill, W. & Li., H.). 2011. *The Changing Wealth of Nations Measuring Sustainable Development in the New Millennium* (Washington D.C.).

WEC (World Energy Council 2010), 2010, 'Survey of energy resources 2010', http://www.worldenergy.org/publications/3040.asp