UNIVERSITY OF STIRLING

Stirling Management School

Genuine savings and future well-being in Germany, 1850-2000

Matthias Blum, Eoin McLaughlin and Nick Hanley

Stirling Economics Discussion Paper 2013-13

December 2013

Online at

http://www.stir.ac.uk/management/research/economics/working-papers/

Genuine savings and future well-being in Germany, 1850-2000

Matthias Blum[1] Eoin McLaughlin[2] and Nick Hanley[3]

Abstract:

Genuine Savings (GS), also known as 'net adjusted savings', is a composite indicator of the sustainability of economic development. Genuine Savings reflects year-on-year changes in the total wealth or capital of a country, including net investment in produced capita, investment in human capital, depletion of natural resources, and damage caused by pollution. A negative Genuine Savings rate suggests that the stock of national wealth is declining and that future utility must be less than current utility, indicating that economic development is non-sustainable (Hamilton and Clemens, 1999). We make use of data over a 150 year period to examine the relationship between Genuine Savings and a number of indicators of well-being over time, and compare the relative changes in human, produced, and components of natural capital over the period. Overall, we find that the magnitude of genuine savings is positively related to changes in future consumption, with some evidence of a cointegrating relationship. However, the relationships between genuine savings and infant mortality or average heights are less clear.

Keywords: Sustainability, economic development, Net adjusted savings, Genuine Savings, well-being

JEL codes: E01, E21, N11, O11, 044, Q01

Acknowledgements: This paper has benefitted by comments and suggestions from Jean-Pascal Bassino, David Greasley, Jan Kunnas, Les Oxley, Paul Warde, the participants of the Economic History Society 2013 annual conference and the 2013 FRESH meeting in Edinburgh.

[1] Chair Group Agricultural and Food Economics, Technische Universität München, Weihenstephaner Steig 22, 85354 Freising, Germany. E-Mail: matthias.blum@tum.de

[2] School of History, Classics and Archaeology, University of Edinburgh: eoin.mclaughlin@ed.ac.uk

[3] Economics Division, University of Stirling, Stirling FK9 4LA, UK: n.d.hanley@stir.ac.uk.

Introduction

Economists' definitions of sustainable development can be categorised into those based on outcomes, and those based on capabilities (Hanley et al., 2006). Outcome-based definitions focus on non-declining utility, well-being or consumption per capita over time, or that utility in any time period does not exceed a maximum, sustainable level which is determined by technology and resource endowments (Arrow et al., 2012; Hamilton and Withagen, 2007; Pezzey, 2004). Capabilities-based definitions involve some idea of non-declining capital over time. For instance, Neumayer (2010) defines sustainable development as "*a pattern over time where… the value of an economy's total stock of capital is maintained*'. By total capital stock, we mean all assets which are important for generating flows of well-being over time, namely produced capital (e.g. roads, machines), natural capital (e.g. coal reserves, forests), human capital (skills, capabilities) and social capital. This capital-based definition typically presumes an idea of "weak sustainability" whereby a sufficient degree of substitutability is assumed between these different elements of a nation's total assets, so that no constraint needs to be placed on the time path of any particular element of this overall capital stock. An implication is that a country can deplete its natural capital whilst remaining on a sustainable path 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).[4]

Given the assumption of weak sustainability, a macro level test of sustainable development would be to examine whether, year-on-year, an economy's total capital stock is falling,

[4] The Hartwick Rule shows conditions under which constant consumption is possible over time for a resource-dependent economy with Cobb-Douglas technology.

rising, or remaining constant in value terms. Such "comprehensive wealth accounts" are increasingly prominent in inter-governmental initiatives over sustainable development (UNEP, 2012). Beginning with Pearce and Atkinson (1993), the Genuine Savings[5] indictor has emerged as one measure of changes in a nation's overall capital stock. 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 in terms of its contribution to welfare, which in turn is defined as the present value of aggregated utility over infinite time. Changes in the stock of certain pollutants (such as CO_2) can also be added (World Bank (2006)) to the index, valued using marginal damage costs. Changes in human capital can be approximated using expenditures on education. Changes in social capital are typically measured as a residual (World Bank (2011)). The effects of technological change, resource price appreciation (capital gains/losses) for resource exporters and importers, and population change can also be incorporated (Pezzey, 2004; Pezzey et al., 2006).

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 total capital stocks would not be declining in value. Concomitantly, countries with negative GS values would be experiencing un-sustainable development. A formal proof of a theoretical link between GS and future well-being is provided by Hamilton and Withagen (2007), who showed that, under certain conditions[6], a country with a positive GS would experience increasing consumption into the future. Pezzey (2004) argues that GS is only a one-sided

[5] Also referred to as Adjusted Net Savings or Comprehensive Investment.
[6] A present-value maximising economy with no externalities, and where GS is growing over time at a rate less than the real interest rate.

indicator which can only prove un-sustainability, due to the failure to use what have been termed "sustainability prices" which include sustainability constraints to value changes in capital stocks. Moreover, he argues that there is no theory linking negative GS with un-sustainability away from an optima (PV-maximising) path. A somewhat different perspective was offered by Dasgupta and Maler (2000), who showed that a measure of change in wealth stocks year-on-year can be used as an indicator of sustainable increases in well-being in non-optimising economies or imperfectly competitive economies. However, the indicator they derive for a non-declining path of welfare, referred to as comprehensive investment in Arrow et al. (2012), is conceptually very similar to GS.

This paper investigates the relationship between German GS and German well-being over the long-run. Previous empirical tests of the relationship between GS and future well-being have mainly focussed on rather short historical periods, for example from 1970 to 2000 (Ferreira et al., (2013); although see Greasley et al. (2013) for an exception)). By adopting a longer term historical framework, we test for long-run influences of sustainability, a concept that cannot be implemented in more contemporary analyses due to the limited time span available. Since the theory linking GS and future well-being revolves around a long run equilibrium relationship, extending the period for data analysis seems advisable.

Our paper thus focuses on the period 1850 through 2000, and analyses trends in German Genuine Savings. Using German economic development as a case study offers several advantages. During its rapid phase of industrial industrialisation in the 20th century, Germany was more a follower than a leader in terms of economic progress. Its success was partly based on its role as a latecomer and imitator of previous development successes (such as the UK) and also a pioneer in the "second industrial revolution" in the field of chemistry and electricity, but its success was also based on exploitation of national resources and the emission of pollutants in the atmosphere. This similarity to modern-day emerging economies makes Germany a unique case study that can provide valuable insight into the impact of (un)sustainability of economic development. Moreover, Germany's experiences during and after the First and Second World Wars can be considered massive natural experiments. This historical scenario may serve as a basis to test whether the theoretical model can cope with economic shocks, such as the war-related destruction of physical capital and dismantlement, or whether its implications only hold for conventional economic scenarios.

This paper develops as follows: First we outline the framework for our empirical strategy, then we proceed to discuss the data constructed in this paper. We then discuss empirical findings using conventional measures of well-being as well as alternative measures. Finally we conclude with some discussion and suggestions for future research.

2. A framework for empirical tests of the relationship between genuine savings and future well-being

This paper follows the empirical strategy of Ferreira et al. (2008), and Greasley et al. (2013; 2012; 2014), who look at the relationship between the present value of future changes in consumption and a set of comprehensive sustainability indicators. Ferreira and Vincent (2005) test this relationship empirically and conclude that not "even the broadest of the World Bank's net investment measures coincides with the difference between current and average future consumption". Their results are robust to changes in the discount rate and the choice of time horizon. Ferreira et al. (2008) use panel data for 64 developing countries during the period 1970 through 1982 to test the relationship between GS and the present value of changes in future consumption. They base this on their representation of the long-run equilibrium relationship between GS and future well-being:

$$PVC_t = \beta_0 + \beta_1 GS_t + \varepsilon \qquad (1)$$

where PVC_t is the present value of changes in future consumption over some defined time period as evaluated at period *t*. The strongest test of the theory is:

H1: $\beta_0 = 0$ and $\beta_1 = 1$;

Hypothesis 1 implies that all that matters for changes in future well-being is the size of the net investment term GS. A weaker hypothesis is that:

H2: $\beta_1 = 1$,

Hypothesis 2 implies that each $ increase in GS brings about a $ increases in the present value of future consumption flows.

The key results that emerge from Ferreira et al. (2008) are that their strong hypothesis is rejected for all models. For their weaker hypothesis, they report significant correlation between a measure of net investment and the present value of future changes in consumption only when GS or population-adjusted GS is used as the measure of net investment. In fact, the crucial adjustment seems to be that made for natural resource depletion; additionally allowing for population growth has very small effects on the size of β_1. In most models, the size of β_1 for GS is around 0.4-0.5, depending on the precise econometric specification and therefore represents support for the weaker hypothesis that $\beta_1 > 0$.

Greasley et al. (2013; 2012; 2014) investigate the long-run relationship between real wages and comprehensive investment in Britain and the U.S, using the same hypothesis testing as Ferreira et al. (2008). For the UK, data is analysed over the period 1760-2000, and for the USA from 1869-2000. They found that the choice of time horizon and discount rate respectively, had the greatest effect on the estimated parameters than the alternative indicators used. Overall, they found that the inclusion of measures of technology, which they proxied using the present value of TFP, substantially improved the power of prediction of the estimated parameters giving β_1 coefficients close to 1. Once technological progress was included within the measure of GS, then a cointegrating relationship was detected between GS and consumption growth.

3. Data

We have largely followed the World Bank (2006, 2011) methodology for calculating Genuine Savings to produce a range of increasingly-comprehensive measures of year-on-year changes in total capital for Germany over time. We use the following indicators:

- Net investment = net fixed produced capital formation and overseas investment
- Green investment = net investment – natural resource extraction
- Genuine Savings (GS) = Green investment + education expenditure
- GS carbon = GS + carbon emissions
- GreenTFP = Green investment + the present value of TFP growth
- GSTFP = GS + the present value of TFP growth

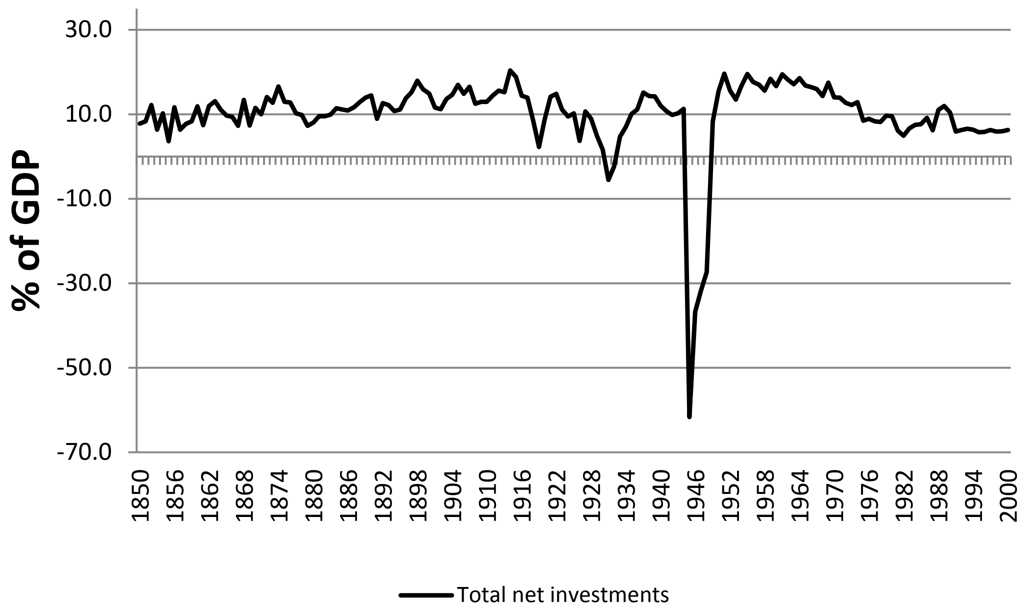
The following section outlines the historical trends in these data and a more comprehensive description of data and sources is provided in the appendix.

3.1 Changes in produced and net overseas capital

The net investment series we use comprises of domestic net investment in produced capital (e.g. factories, machine tools, and transport links) and changes in foreign net capital stock.[7] The latter contributes only little to overall investment, whereas domestic investment is the major component of overall investment. Overall net investment varied around a 10 per cent of GDP during the mid-19th century. During the heyday of the German economy in the late 19th and early 20th century, net investment increased to approximately 15 per cent. Massive shocks occurred during the First World War, the inter-war years, and especially towards the end of the Second World War and the immediate post-war years when war destruction and dismantlement resulted in highly negative net saving rates. German net investment was generally positive during the Nazi era, resulting in capital accumulation, especially in the heavy industries (Kirner, 1968; Vonyó, 2012). During the years of the "economic miracle", net savings rate were on an all-time high, ranging between 15 per cent and 20 per cent. Until the mid-1970s net savings rates subsequently declined to a level under 10 per cent and remained there for most of the period between 1975 and 2000 (Figure 1).

[7] Information on net investment are taken from Hoffmann et al. (1965), which still serves as the main source for German historical national account series. See for example Metz (2005), who uses Hoffmann et al.'s (1965) series for estimating German capital stocks between 1850 and 2000. A wide array of German historical national account statistics using Hoffmann et al.'s figures can be downloaded under www.gesis.org/histat.

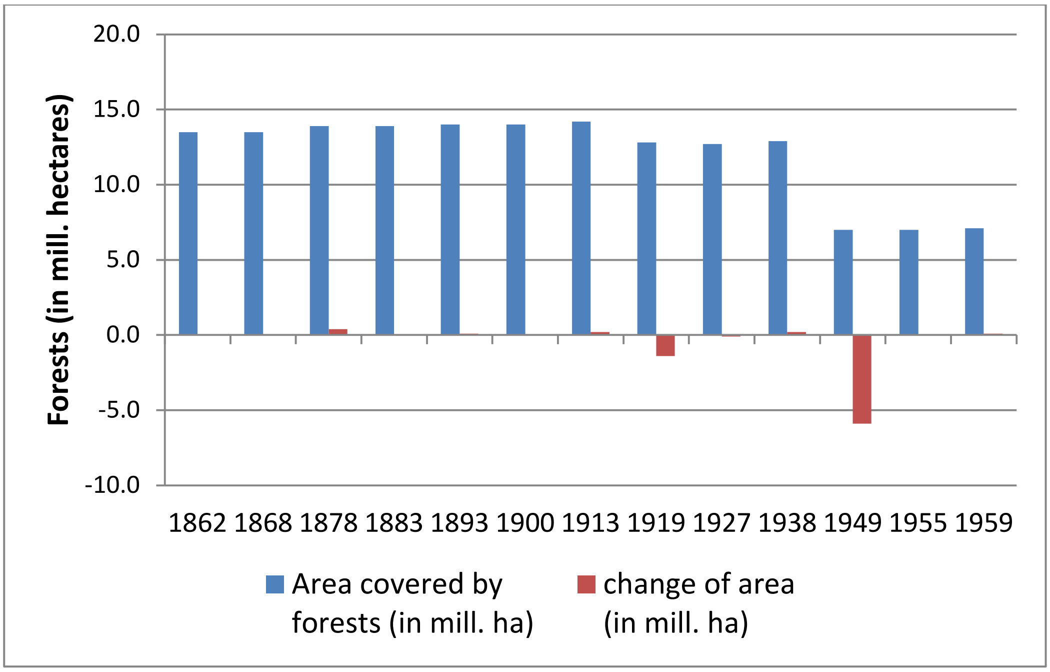
Figure 1: German total net investment, net domestic investment, and changes in overseas capital stock 1850-2000



3.2 Natural capital

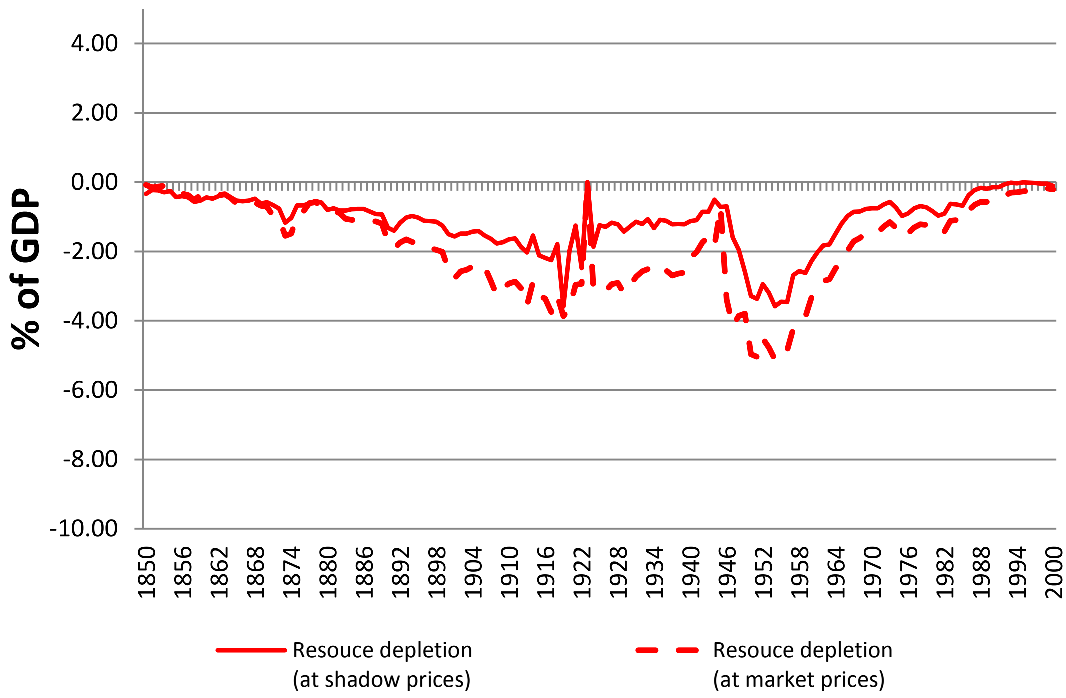
Natural capital consists of all "gifts of nature", including renewable and non-renewable resources, agricultural land, ecosystems and biodiversity (Barbier, 2011). Changes in the natural capital stock are calculated from data on physical changes in stocks (e.g. due to depletion) and the per-unit rental values of these changes. Renewable sources include forestry and coastal fisheries. In terms of forestry, the only noteworthy changes to the German forest stock seem to occur due to changes in territory: increase after 1871 due to annexation of Alsace-Lorraine, losses of territory after WWI and WWII, and the reintegration of Saarland and West Berlin into the German economy in the 1950s. Furthermore, during the early twentieth century Germany was seen as a leader in the field of silviculture (Heske, 1938). The nature of these changes does not correspond well with the World Bank's condition that Genuine Savings adjustments are supposed to reflect depreciation of forest stocks due to forest clearance, or the planting of new forests, or forest growth. Besides the aforementioned events, changes in forestry stock were negligible. For example, between 1900 and 1913 an annual increase in forest stocks occurred in the order of 0.015 per cent (see figure 2). Given the nature and size of these changes, we have not included changes in forestry stock. No historical data was available on changes in coastal fish stocks.

Figure 2: German stocks and changes in forest stocks, 1862-1959



In the non-renewable sector, the most important commodities for Germany are brown and hard coal. Data on natural gas and crude oil depletion, iron ore, copper ore, zinc ore, lead ore, silver ore, tin ore, and nickel ore extraction are also included, but contribute only small shares to the overall figure on resource depletion. Costs of production have been subtracted from gross revenues using wages and employment figures in order to estimate the economic rent per unit of resource extracted. In Figure 3 the net-contribution (gross revenues minus average extraction costs) of non-renewable resource depletion is shown. In 1850, these figures are very small, ranging under 1 per cent of GDP for most of the years until the early 1880s. The value of resource depletion increases constantly until the First World War, mainly due to increases in production quantities. Shocks occur during 1914-1919 and in 1923 when resource extraction skyrocketed and plummeted during WWI and the German hyperinflation, respectively. In the inter-war years and the Second World War non-renewable resource extraction was somewhat lower, ranging between 0.5 per cent and 1.5 per cent of GDP. Between the late 1940s until the 1960s, Germany's mining sector experienced a heyday, mainly due to increases in value, resulting with extracted quantities contributing up to 3.6 per cent to the overall genuine saving rate.

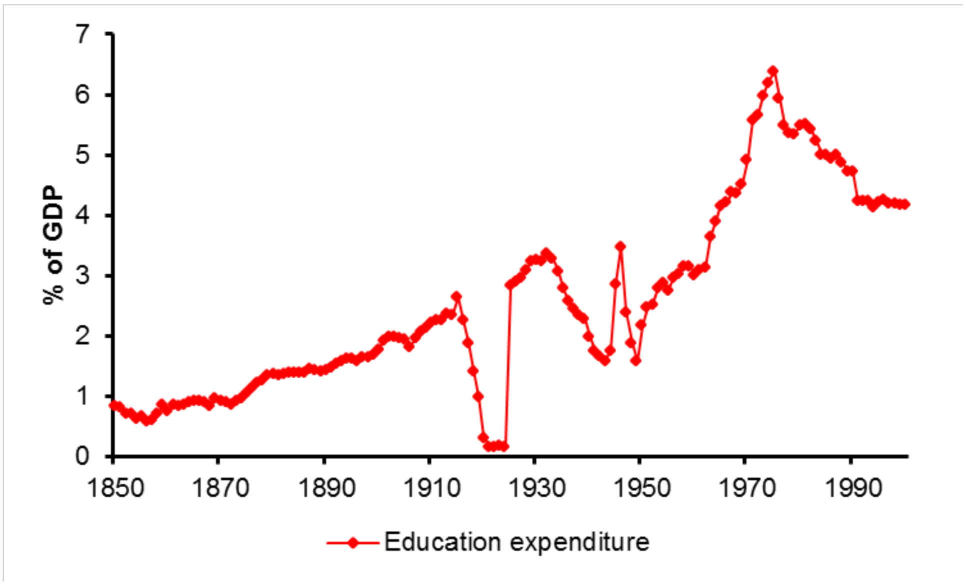
Figure 3: Resource depletion at market prices and shadow prices (red line)



3.3 Genuine savings

Hamilton and Clemens (1999, p.334, 336) argue that investment in human capital is equivalent to endogenous technological change and include education spending in their measure of genuine savings. The motivation for including human capital is also outlined by the World Bank's Genuine Savings manual for calculating adjusted net savings (Bolt et al., 2002): "The world's nations augment the stock of human capital in large part through their educational systems, into which they collectively pour trillions of dollars each year." We follow this approach and use education expenditure as a metric for investment in human capital. This approach has limitations as it assumes that schooling equates to human capital development but this framework is an underestimate as it excludes on the job training, apprenticeships and other informal forms of human capital development. Figure 4 indicates that schooling expenditure in Germany, including investment in primary, secondary, and tertiary education, generally increased from under 1 per cent in the mid-19th century to 6.2 per cent in 1974. In the nineteenth century Prussia was in fact a leader in the provision of publicly funded education (Lindert, 2004). Significant slumps occurred during the 1920s, the Second World War and the post-war years. Slumps during the 1920s and the war years are the result of disproportionate inflation of GDP relative to absolute education expenditure and disproportionate economic upswing, respectively. Low human capital investment rate in the late 1940s are the result of generally low education expenditure combined with economic recovery. In terms of capturing information on public expenditure on schooling, we believe that our data series reflects this better that data provided by the World Bank as they assume expenditure to be at a constant 4.3 per cent of GDP, whereas we utilise more accurate estimates provided by Diebolt (1997, 2000).

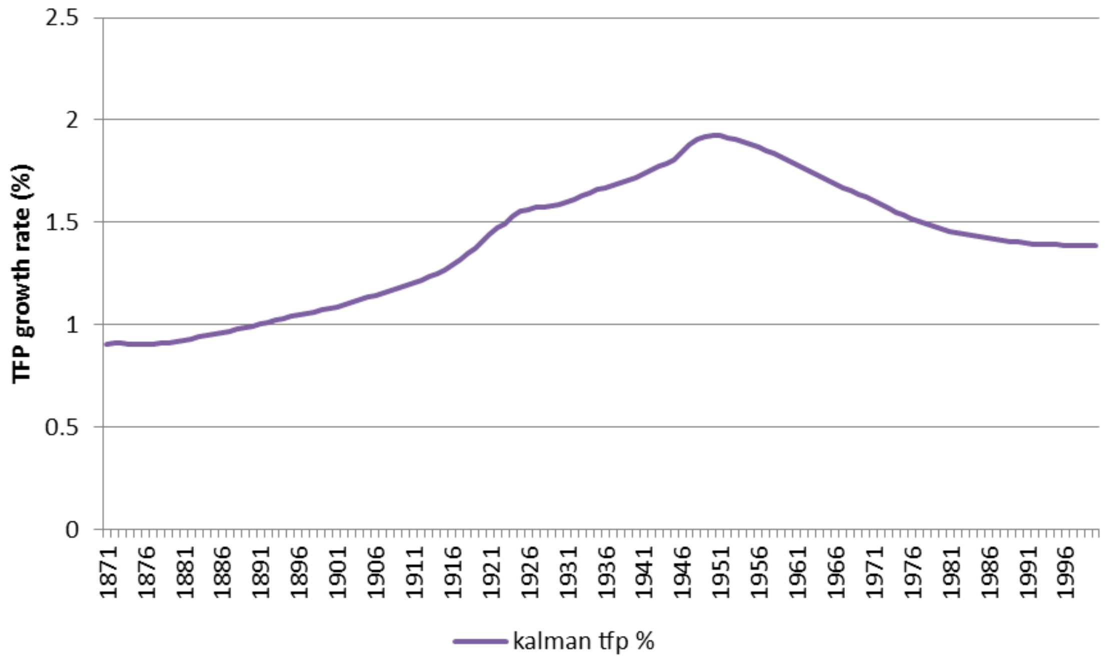
Figure 4: Education expenditure in Germany, 1850-2000



3.5 Changes in the value of exogenous technological progress (TFP)

We have incorporated the effects of exogenous technological progress in our measure of Genuine Savings by including the present value of TFP growth. Weitzman (1997) suggested that such a technological change premium could be as high as 40 per cent of Net National Product. We have estimated trend TFP growth using sources outlined in the appendix, shown in figure 5, and this is in line with the literature which indicates rising TFP growth from the 1870s and a subsequent decrease from the 1970s (Carreras and Josephson, 2010; Crafts and Toniolo, 2010; Roses and Wolf, 2010).

Figure 5: German trend TFP growth, 1871-2000

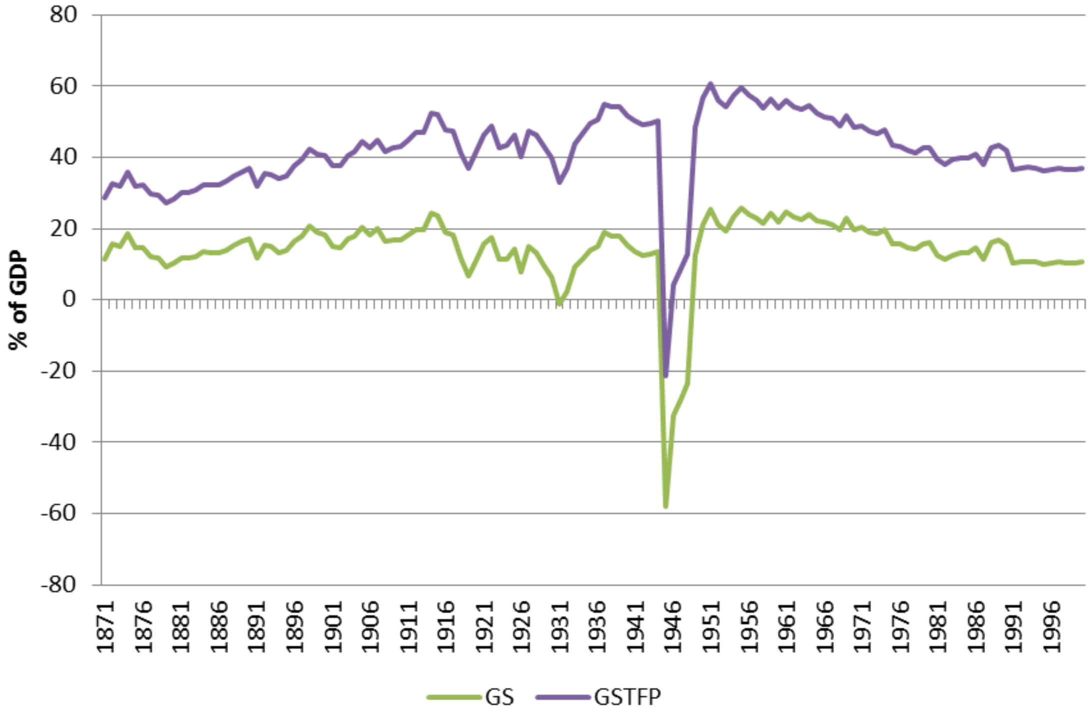


Our approach, derived from Pezzey et al. (2006), estimates exogenous technology's contribution to the future values of GDP by using trend TFP growth for 1870-2021 where TFP per cent is trend TFP:

$$GDP_{t+20} = GDP_t * (1 + \sum TFP\%_{t \ldots t+20}) \quad (3)$$

Following Pezzey et al. (2006) the current value of GDP is deducted from the future value of GDP, and the present value of this differential, over a 20 year time horizon with a 1.5 per cent discount, represents the value of technological progress to the economy [PV (GDP_{t+20} - $GDP_{t)}$]. The present value of TFP contribution to GDP was estimated similar to Greasley et al. (2012, 2013, 2014). In line with Weitzman (1997), we find that the present value of TFP averages 36.78 percent of GDP over the period 1871-2000 and considerably boosts our indicators of sustainability (figure 6).

Figure 6: GS incorporating the present value of TFP 1871-2000 (discounted 1.95% over 20 years)



3.6 Consumption as a welfare indicator

The share of GDP used for private consumption is used to capture changes in future well-being.[8] It reflects average material well-being, expressed in monetary units. To implement the hypotheses tests set out earlier derived from Ferreira et al. (2008), the present value of the change in future consumption was calculated over four time horizons, 20, 30, 50, 100 years using a 1.95 per cent discount rate (the average real interest rate in Germany from 1850-2010) and also using a 3.0 per cent discount rate (the average rate of real GDP growth over the time period). In figures 7 and 8 the development of private consumption and present value change in consumption per capita over four different time horizons are

[8] This ignores the value of changes in the value of leisure time over the period, and other elements of full consumption.

presented. These serve as target variables in the empirical analysis testing for the relationship between net investment and future consumption.

Figure 7: Private consumption 1850-2009

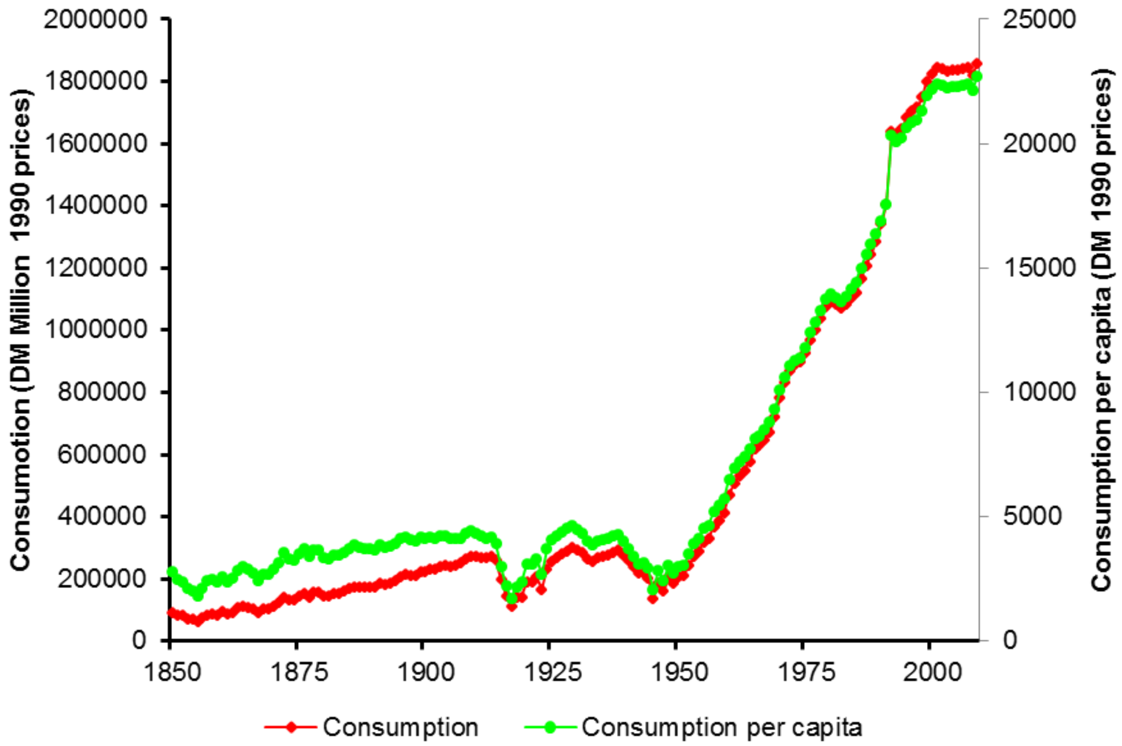
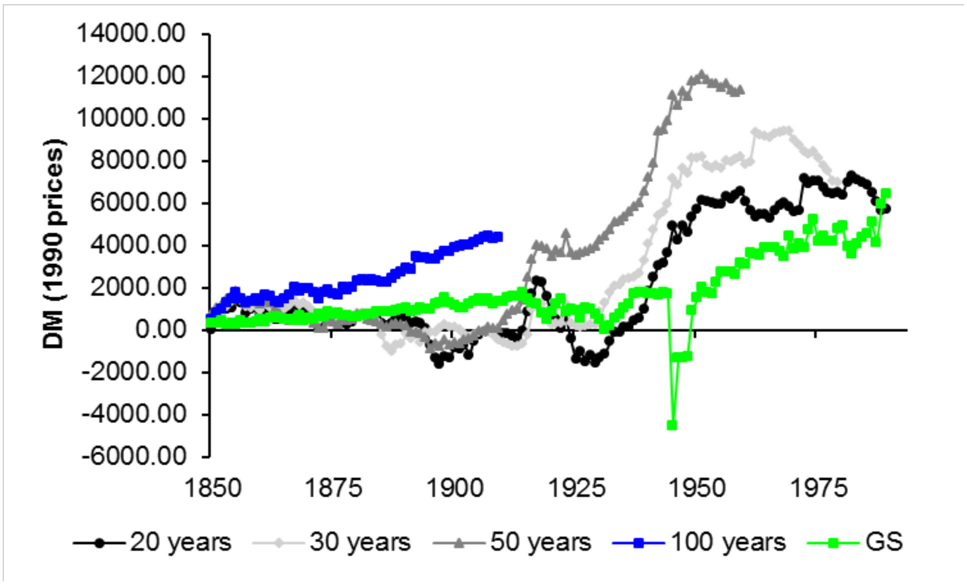


Figure 8: Present value future changes in consumption per capita, (1990 DM, 1.95% discount rate)



4 Empirical tests of the relationship between Genuine Savings and future well-being

Figures 9a and 9b show the results of our calculations of year-on-year changes in comprehensive wealth. Following and Ferreira et al. (2008), we have tested the relationship between increasingly comprehensive indicators of sustainability and measures of well-being over different time horizons:

$$PV\Delta C_t = \beta_0 + \beta_1 g_t + \varepsilon_t$$

Where $PV\Delta C_t$ is the present value of future changes in consumption per capitas and g_t is genuine savings per capita. Based on this equation, Ferreira et al. (2008) outline four hypotheses:

1. $\beta_0 = 0$; $\beta_1 = 1$

2. $\beta_1 > 0$ and → 1 as *g* includes more types of capital.

In theory, Genuine Savings indicator is supposed to include all changes in wealth. Therefore, ideally empirical results reflect a one-to-one relation between genuine savings and consumption changes ($\beta_1 = 1$). In this case, the intercept is zero ($\beta_0 = 0$) since in the absence of positive net investment the future change in utility is expected to be zero.

3. $\beta_1 > 0$

As empirical data may not reflect theoretical assumptions perfectly, a weaker hypothesis may be tested where genuine savings and changes in consumption are positively correlated ($\beta_1 > 0$).

Figure 9a: Net, Green and GS per capita in Germany (1990 prices), 1850-2000

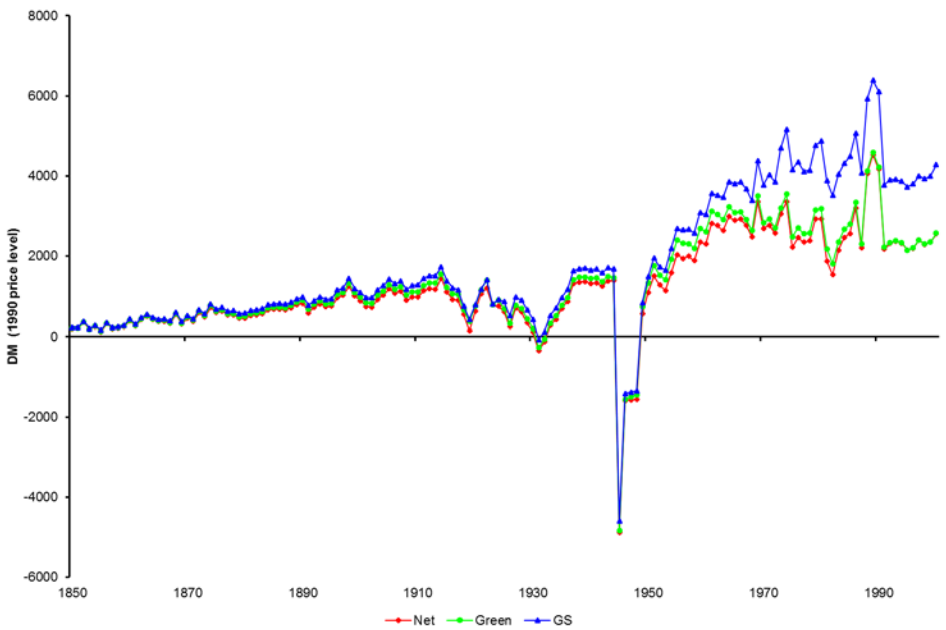
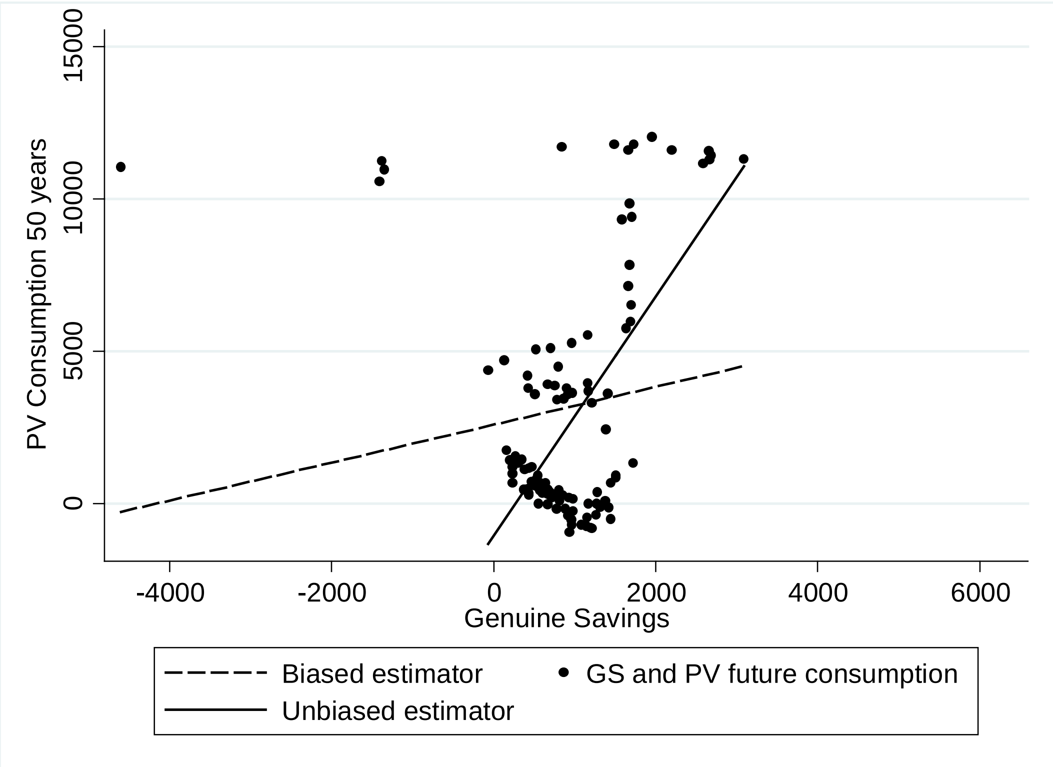


Figure 9b: Genuine Savings per capita with and without the present value of changes in TFP 1871-2000 (discounted 1.95% over 20 years)

Before testing these hypotheses empirically, an issue specific to the case of Germany needs to be addressed. The theoretical model described above does not specifically take into account shock, such as war-related destruction and dismantlement in Germany during and after WWII. Therefore, the underlying theoretical framework of this study is rather based on the assumption that a long-run equilibrium relationship exists between genuine savings and future well-being. Figure 10 illustrates the relationship between Genuine Savings and present value of future changes in private consumption over a 50 year time horizon. A series of extreme values, referring to the years between 1944 through 1948 located in the upper left of the scatterplot illustrate this effect. Highly negative net investment rates go along with fairly high discounted differences in future consumption. Negative investment rates can be explained by destroyed and damaged capital stock, while positive differences in future consumption are mainly driven by catch-up growth and consumption in the post-war era. If the Ferreira et al.'s (2008) empirical strategy was applied to total the total dataset, the resulting estimated relationship is indicated by the dashed line. In this case, the existence of a small number of outliers downward bias the coefficient, systematically underestimating the empirical relationship between investment and discounted future consumption growth. If the war and post-war period is excluded, empirical tests reflect the relationship between genuine savings and utility more accurately (solid line).

Figure 10: Investment and future consumption over 50 years



4.1 Results

Corresponding numerical results over four different time horizons are shown in table 1. Here β_0, β_1, the results of a series of Augmented Dickey-Fuller (ADF) tests, and several F-tests are shown. ADF tests aim at testing for unit root in the residual of a regression of the consumption variable and the investment variable. We use this test to investigate whether the consumption and comprehensive investment series are cointegrated in order to assess a potential long-term relationship of these indicators. F-tests are applied to test the hypotheses that $\beta_1 = 1$ and $\beta_0 = 0$ & $\beta_1 = 1$. Our preferred discount rate is 1.95 per cent, which is based on real returns to German government bonds.

The results for 20, 30, and 50 year time horizons indicate that $\beta_1 > 1$ but do not indicate that $\beta_1 = 1$ & $\beta_0 = 0$. However, the intuition gained from figure 9 above suggests that three of four results are biased. Information about future consumption for the period 1944-1948 is available for time horizons up to 50 years, but it is not available for periods exceeding this threshold. If we included observations based on war years we would have to pertain to this bias in estimations on 50 years and below, whereas any empirical test investigating a relationship over longer periods would not suffer from this bias. On account of these reasons we do not consider observations referring to the periods 1914-19 and 1944-48 in the main empirical tests carried out below. In table 1 biased results, which correspond to the scatterplot presented in figure 10, are shown.

Conversely, in our benchmark results (table 2) we exclude the periods 1914-19 and 1944-48, but preserve other properties of the analysis. We apply five investment metrics over 20, 30, 50, and 100 time horizons for the present value of future changes in consumption and the 1.95 per cent discount rate we use is based on real returns to German government bonds. In general, unbiased empirical results indicate the existence of a positive relationship between current investment and future utility ($\beta_1 > 0$), measured as private consumption. However, depending on time horizon and investment indicator, the coefficient indicating the magnitude of this relationship varies considerably. Generally, the majority of tests indicate that $\beta_1 > 1$ and these coefficients tend to be larger for longer time spans. We also test the hypothesis that $\beta_1 > 0$ and $\rightarrow 1$ as the investment metric includes more types of capital. We find that this is the case for all four time horizon when we consider resource extraction, education expenditure, and costs of pollution. When technology (TFP) is incorporated β_1 drops for all time horizons. In this case we also find that $\beta_1>0$ for 20-year time horizons and $\beta_1>1$ for time horizons exceeding 20 years, and that this coefficient is closer to the size predicted by economic theory ($\beta_1 = 1$). The hypothesis that $\beta_1 = 1$ & $\beta_0 = 0$ has to be rejected on the basis of this set of tests.

Additionally, we apply a set of cointegration tests to assess a long-term relationship between aforementioned investment indicators and present value of future consumption at any given point in time. This measure helps us assessing this relationship from a different angle. We find that if we focus on 100 year time spans, all investment series are equally cointegrated with the present value of future consumption, indicating that there is no particular advantage of adjusted net saving indicators in this regard. Interestingly, in our preferred testing scenario we find that Green and Genuine investment indicators are cointegrated with the present value of future consumption over 50 years if technological change (TFP) is taken into account, while this does not seem to be the case for conventional investment. Conversely, our results do not suggest that investment indicators and present value of future consumption are cointegrated over 20 and 30 years.

Table 1: Estimated parameter values for alternative measures of investment when future wellbeing is measured by the PV of consumption per capita over 20-100 years horizons, 1.95 per cent / year discount rate

Dependent variable	Independent variable	β_1	Standard error	β_0	Standard error	N	β_1=1	β_0=0; & β_1=1	ADF	R^2	Sample
PV Cons. 20	Net	1.408***	0.173	621.0**	276	140	5.54**	17.42***	-2.235	0.324	1850-1989
PV Cons. 30		1.636***	0.253	1,128***	366.1	130	6.3**	24.45***	-1.674	0.246	1850-1979
PV Cons. 50		0.063	0.479	3,099***	500.4	110	3.82*	22.48***	0.270	0	1850-1959
PV Cons. 100		3.356***	0.233	355.0**	154.9	60	101.97***	420.48***	-3.189**	0.781	1850-1909
PV Cons. 20	Green	1.412***	0.162	453.1	276.7	140	6.5**	15.5***	-2.318	0.356	1850-1989
PV Cons. 30		1.647***	0.236	935.1**	368.2	130	7.53***	23.26***	-1.766	0.276	1850-1979
PV Cons. 50		0.361	0.454	2,868***	516	110	1.99	20.16***	-0.234	0.006	1850-1959
PV Cons. 100		3.096***	0.193	360.8**	139	60	118.02***	475.26***	-3.399**	0.816	1850-1909
PV Cons. 20	GS	1.207***	0.109	260	246.5	140	3.63*	7.48***	-2.261	0.471	1850-1989
PV Cons. 30		1.504***	0.177	695.4**	344.3	130	8.13***	19.64***	-1.823	0.361	1850-1979
PV Cons. 50		0.622	0.432	2,594***	539.4	110	0.76	17.86***	-0.484	0.019	1850-1959

PV Cons. 100		2.805***	0.158	350.7***	126.9	60	129.94***	515.86***	-3.455**	0.844	1850-1909
PV Cons. 20	GScarbon	1.194***	0.106	252.3	244.8	140	3.32*	6.92***	-2.258	0.477	1850-1989
PV Cons. 30		1.495***	0.173	680.6**	342.4	130	8.14***	19.38***	-1.827	0.367	1850-1979
PV Cons. 50		0.659	0.429	2,556***	539.8	110	0.63	17.69***	-0.515	0.021	1850-1959
PV Cons. 100		2.790***	0.157	354.1***	126	60	130.64***	519.12***	-3.468**	0.846	1850-1909
PV Cons. 20	GreenTFP	0.669***	0.0514	-705.0**	299	119	41.48***	101.11***	-1.906	0.591	1871-1989
PV Cons. 30		0.986***	0.0888	-885.0**	432.7	109	0.03	7.39***	-1.843	0.535	1871-1979
PV Cons. 50		1.389***	0.255	-396	843.2	89	2.32	2.86*	-1.679	0.254	1871-1959
PV Cons. 100		1.612***	0.0892	-416.3**	190	39	47.12***	174.49***	-2.914*	0.898	1871-1909
PV Cons. 20	GSTFP	0.584***	0.0446	-559.5*	288.4	119	86.81***	158.05***	-1.740	0.594	1871-1989
PV Cons. 30		0.873***	0.0787	-702.4*	419.6	109	2.61	14.27***	-1.632	0.535	1871-1979
PV Cons. 50		1.383***	0.244	-577.8	843.8	89	2.46	2.35	-1.718	0.269	1871-1959
PV Cons. 100		1.530***	0.0824	-391.6**	183.7	39	41.38***	145.64***	-2.910*	0.903	1871-1909

Note: In the column labelled ADF results of a set of Augmented Dickey Fuller statistic which was used to perform the Engle-Granger (1987) two-step method to test for cointegration. The degree of augmentation is determined by the Hannan-Quinn Information Criteria. ***, **, and * indicate rejection of the null of non-stationary residuals at the 1%, 5%, and 10% level, respectively.

Table 2: Estimated parameter values for alternative measures of investment when future wellbeing is measured by the PV of consumption per capita over 20-100 years horizons, 1.95 per cent / year discount rate <u>(excluding periods 1914-19 and 1944-48)</u>

Dependent variable	Independent variable	β_1	Standard error	β_0	Standard error	N	β_1=1	β_0=0; & β_1=1	ADF	R^2	Sample
PV Cons. 20	Net	2.400***	0.157	-840.2	246	130	79.45***	56.44***	-2.530	0.646	1850-1989
PV Cons. 30		3.331***	0.215	-1,031***	301.3	120	117.30***	93.06***	-2.119	0.67	1850-1979
PV Cons. 50		4.339***	0.672	-622.7	614.1	100	24.67***	30.81***	-1.807	0.298	1850-1959
PV Cons. 100		3.356***	0.233	355.0**	154.9	60	101.97***	420.48***	-3.189**	0.781	1850-1909
PV Cons. 20	Green	2.307***	0.141	-994.1***	239.9	130	85.43****	56.45***	-2.594*	0.675	1850-1989
PV Cons. 30		3.134***	0.193	-1,161***	294.5	120	112.80***	93.14***	-2.050	0.692	1850-1979
PV Cons. 50		4.112***	0.563	-822.8	579.3	100	30.54***	33.47***	-1.784	0.352	1850-1959
PV Cons. 100		3.096***	0.193	360.8**	139	60	118.02***	475.26***	-3.399**	0.816	1850-1909
PV Cons. 20	GS	1.626***	0.092	-703.1***	210.8	130	46.32***	26.95***	-2.204	0.709	1850-1989
PV Cons. 30		2.296***	0.143	-771.4***	278.5	120	82.63***	61.77***	-1.634	0.687	1850-1979
PV Cons. 50		3.886***	0.486	-1,095*	566.3	100	35.32***	34.73***	-1.898	0.395	1850-1959
PV Cons. 100		2.805***	0.158	350.7***	126.9	60	129.94***	515.86***	-3.455**	0.844	1850-1909
PV Cons. 20	GScarbon	1.594***	0.0898	-689.2***	209.3	130	43.84***	25.24***	-2.189	0.711	1850-1989
PV Cons. 30		2.256***	0.139	-755.4***	276.6	120	81.15***	60.49***	-2.021	0.689	1850-1979

PV Cons. 50		3.865***	0.475	-1,110*	560.4	100	36.34***	35.27***	-1.903	0.403	1850-1959
PV Cons. 100		2.790***	0.157	354.1***	126	60	130.64***	519.12***	-3.468**	0.846	1850-1909
PV Cons. 20	GreenTFP	0.765***	0.046	-1,417***	276.7	109	26.04***	145.14***	-1.705	0.721	1871-1989
PV Cons. 30		1.179***	0.0725	-1,999***	365.1	99	6.13**	22.62***	-1.962	0.732	1871-1979
PV Cons. 50		2.341***	0.198	-3,920***	668	79	45.65***	22.99***	-2.641*	0.644	1871-1959
PV Cons. 100		1.612***	0.0892	-416.3**	190	39	47.12***	174.49***	-3.603**	0.898	1871-1909
PV Cons. 20	GSTFP	0.658***	0.0405	-1,184***	271.5	109	71.32***	211.91***	-1.713	0.711	1871-1989
PV Cons. 30		1.020***	0.0662	-1,656***	365.6	99	0.09	28.83***	-1.763	0.71	1871-1979
PV Cons. 50		2.249***	0.188	-3,965***	663.4	79	44.04***	22.02***	-2.708*	0.65	1871-1959
PV Cons. 100		1.530***	0.0824	-391.6**	183.7	39	41.38***	145.64***	-2.910*	0.903	1871-1909

Note: see table 1

Table 3: Estimated parameter values for alternative measures of investment when future wellbeing is measured by the PV of consumption per capita over 20-100 years horizons, 3 per cent /year discount rate (excluding periods 1914-19 and 1944-48)

Dependent variable	Independent variable	β_1	Standard error	β_0	Standard error	N	$\beta_1=1$	$\beta_0=0$; & $\beta_1=1$	ADF	R^2	Sample
PV Cons. 20	Net	2.186***	(0.142)	-785.4***	(222.0)	130	70.09***	47.03***	-2.573	0.650	1850-1989
PV Cons. 30		2.897***	(0.186)	-942.9***	(260.4)	120	804.04***	77.71***	-2.170	0.673	1850-1979
PV Cons. 50		3.481***	(0.528)	-622.0	(482.4)	100	22.08***	24.17***	-1.861	0.307	1850-1959
PV Cons. 100		0.839***	(0.124)	705.3***	(82.48)	60	1.67	154.27***	-2.970**	0.440	1850-1909
PV Cons. 20	Green	2.100***	(0.128)	-923.3***	(216.6)	130	74.20***	46.03***	-2.630*	0.679	1850-1989
PV Cons. 30		2.726***	(0.166)	-1,055***	(254.5)	120	107.59***	76.28***	-2.097	0.695	1850-1979
PV Cons. 50		3.296***	(0.442)	-779.7*	(454.4)	100	27.01***	25.83***	-1.852	0.362	1850-1959
PV Cons. 100		0.783***	(0.109)	701.0***	(78.58)	60	3.95	139.38***	-3.043**	0.471	1850-1909
PV Cons. 20	GS	1.481***	(0.0829)	-659.8***	(189.9)	130	33.66***	17.79***	-2.273	0.714	1850-1989
PV Cons. 30		1.998***	(0.123)	-718.2***	(240.3)	120	65.80***	44.96***	-2.103	0.691	1850-1979
PV Cons. 50		3.092***	(0.382)	-975.4**	(445.7)	100	29.96***	25.62***	-1.971	0.400	1850-1959
PV Cons. 100		0.713***	(0.0953)	696.4***	(76.36)	60	9.09***	113.37***	-3.096**	0.491	1850-1909
PV Cons. 20	GScarbon	1.452***	(0.0809)	-647.2***	(188.5)	130	31.25***	16.33***	-2.259	0.716	1850-1989
PV Cons. 30		1.963***	(0.120)	-704.4***	(238.7)	120	64.10***	43.59***	-2.084	0.693	1850-1979

PV Cons. 50		3.075***	(0.374)	-986.9**	(441.1)	100	30.77***	25.98***	-1.977	0.408	1850-1959
PV Cons. 100		0.709***	(0.0945)	696.8***	(76.07)	60	9.46***	112.67***	-3.103**	0.492	1850-1909
PV Cons. 20	GreenTFP	0.747***	(0.0439)	-1,332***	(247.6)	109	33.25***	173.20***	-1.786	0.730	1871-1989
PV Cons. 30		1.093***	(0.0666)	-1,801***	(315.3)	99	1.93	35.97***	-2.016	0.735	1871-1979
PV Cons. 50		1.960***	(0.172)	-3,210***	(544.0)	79	31.11***	17.56***	-2.652*	0.627	1871-1959
PV Cons. 100		0.628***	(0.0513)	80.99	(103.2)	39	52.67***	324.04***	-3.265**	0.802	1871-1909
PV Cons. 20	GSTFP	0.636***	(0.0384)	-1,107***	(242.8)	109	89.86***	254.81***	-1.794	0.719	1871-1989
PV Cons. 30		0.937***	(0.0605)	-1,490***	(315.4)	99	1.07	49.10***	-1.815	0.712	1871-1979
PV Cons. 50		1.878***	(0.163)	-3,247***	(540.5)	79	29.07***	18.06***	-2.735*	0.633	1871-1959
PV Cons. 100		0.594***	(0.0478)	89.98	(100.9)	39	72.09***	437.85***	-3.304**	0.807	1871-1909

Note: Discount rate of 3 per cent per anno was chosen on the basis of average real growth rate of the German economy during the period under observation. Also see table 1 for notes.

5 Robustness tests: accounting for an alternative discount factor and territorial changes

We use an alternative discount rate of 3 per cent, which is based on real GDP growth of the German economy during the period under observation. For the scenario based on a 3 per cent discount rate, we also find a positive relationship ($\beta_1 > 0$) throughout all investments measures and time horizons. Here, empirical results are similar to the ones obtained in the main analysis and also indicate the existence of a positive relationship between current investment and future utility ($\beta_1 > 0$). Conversely, here we find that $\beta_1 > 0$ and → 1 when additional forms of investment are considered over 20, 30, and 50 years. The opposite is true over 100: β_1 of conventional net investment is fairly close to the predicted value of 1; incorporating additional forms of investment leads to a divergence of this coefficient from the value 1. Adding technological change confirms $\beta_1 > 0$, but not $\beta_1 > 0$ and → 1. In the 3 per cent scenario we also reject the hypothesis that $\beta_1 = 1$ & $\beta_0 = 0$., For cointegration tests, we also find all investment series are equally cointegrated with the present value of future consumption over 100 years, indicating that there is no particular advantage of adjusted net saving indicators in this regard. For other time horizons this set of tests do not indicate cointegration.

We run another robustness test, simulating the continuous existence over the period under observation of the former Western part of Germany as it existed between 1945 and 1989 in order to address multiple territorial changes in the 20th century: Most important territorial changes include the temporary annexation of Alsace-Lorraine (1871-1918), as well as territorial losses after 1918/19 and 1945. Moreover, the figures used in this compilation for the post-1945 period do not include the East German economy. Accordingly, most statistics fall short of covering an “unchanged” German territory, potentially biasing the results of our empirical tests. Speaking in terms of fractional arithmetic's, some original series (used in the nominator and the denominator of the GS calculation) undergo a subsequent selection: between 1871 and 1918 Alsace-Lorraine is a part of the German Empire, after 1918/19 and 1945 predominantly regions with low population density and low levels of industrialization "leave" German statistics (Maddison, 1995). The overwhelming part of population and GDP remained in Germany, with approximately 72 per cent of remaining economic activity being located in West Germany. We are able to adjust for Alsace-Lorrain's temporary entry entirely since it is not included or can be excluded from official figures, but we have to correct for other of the aforementioned changes arithmetically. To find appropriate metrics to weight Germany's territories, we use Maddison (1995) who reports the economic power for the territories that formed former Germany. For example, in 1936, the territory which later forms 'West Germany' accounts for 64 per cent of total economic power at the time. The territory that becomes 'East Germany' accounts for approximately 25 per cent; the territories east to the Oder-Neisse line account for the remaining 11 per cent. In 1990, the Western part of the re-united Germany accounts for approximately 90 per cent of the total figure. These weights are used to construct fictive GDP, net investment, private consumption and pollution series for West Germany. We use Maddison's (1995) per-capital figures and census population figures provided by the Statistical Office of the German Empire (KaiserlichesStatistischesAmt, 1915) to estimate the economic weight of the territories lost after WWI.

For resource extraction, detailed figures are available allowing detailed adjustments even for smaller territorial units. Most significantly, territories east to the Oder-Neisse line accounted for approximately half of the hard coal extraction before WWI, and East Germany accounted for approximately 70 per cent of overall German brown coal production, but only 3 per cent of hard coal production. Other minerals and energy sources account for very little compared to hard and brown coal production. Accordingly, we subtract 70 per cent of brown coal production for the pre-1945 period, 3 per cent and 50 per cent of hard coal production for pre-1945 and pre-1918 period, respectively, to obtain a continuous West Germany series.

For education expenditure, given the similar institutional standards we assume that per-capita expenditure was fairly similar throughout Germany. Therefore, we use shares of population in respective territories to identify education expenditures in West Germany. Territories ceded to Poland after WWI – other territories constitute a negligible share – account for approximately 4.4 per cent of Germany's population. East Germany and the territories annexed by Poland and the Soviet Union after WWII accounted for approximately 37 per cent of pre-war population (Maddison 1995, German census 1910). We adjust education expenditure using these population shares to obtain hypothetical West German data series.

The result of this exercise confirms earlier results. Results are almost identical, irrespective whether the analysis is based on actual German figures or hypothetical West German ones. β_1 coefficients for the 1.95 per cent scenario is shown in table 5.

Table 4: Estimated parameter values for alternative measures of investment when future wellbeing is measured by the PV of consumption per capita over 20-100 years horizons, 1.95 per cent /year discount rate <u>(West-Germany only; excluding periods 1914-19 and 1944-48)</u>

Dependent variable	Independent variable	β1	Standard error	β0	Standard error	N	β1=1	β0=0; & β1=1	ADF	R^2	Sample
PV Cons. 20	Net	2.353***	0.188	-559.4*	295.6	130	52.08***	45.71***	-1.997	0.552	1850-1989
PV Cons. 30		3.323***	0.282	-642.4	397.8	120	67.97***	67.42***	-1.859	0.541	1850-1979
PV Cons. 50		4.585***	0.812	-203.6	759.5	100	19.47***	32.98***	-1.382	0.245	1850-1959
PV Cons. 100		3.925***	0.254	530.8***	177.8	60	132.84***	575.42***	-3.537**	0.805	1850-1909
PV Cons. 20	Green	2.341***	0.197	-659.3**	315.7	130	46.49***	40.24***	-2.042	0.525	1850-1989
PV Cons. 30		3.318***	0.293	-813.5*	423.4	120	62.67***	61.67***	-1.983	0.521	1850-1979
PV Cons. 50		4.449***	0.795	-379.6	792.2	100	18.80***	31.45***	-1.498	0.242	1850-1959
PV Cons. 100		3.679***	0.217	524.8***	163.1	60	152.20***	645.41***	-3.748***	0.832	1850-1909
PV Cons. 20	GS	1.580***	0.131	-298.3	288.7	130	19.58***	16.70***	-1.605	0.532	1850-1989
PV Cons. 30		2.363***	0.211	-366.6	396.2	120	41.60***	42.44***	-1.518	0.514	1850-1979
PV Cons. 50		4.370***	0.677	-906.6	776	100	24.77***	33.78***	-1.674	0.298	1850-1959
PV Cons. 100		3.289***	0.17	511.4***	144.3	60	180.31***	749.78***	-3.943	0.865	1850-1909
PV Cons. 20	GScarbon	1.549***	0.128	-285.1	286.7	130	18.42***	15.64***	-1.591	0.534	1850-1989

PV Cons. 30		2.323***	0.206	-352.5	393.3	120	41.07***	41.80***	-1.497	0.518	1850-1979
PV Cons. 50		4.369***	0.662	-946.4	767.4	100	25.87***	34.45***	-1.683	0.307	1850-1959
PV Cons. 100		3.270***	0.168	515.9***	143	60	181.63***	755.75***	-3.961***	0.867	1850-1909
PV Cons. 20	GreenTFP	0.728***	0.0631	-904.7**	373.8	109	18.55***	66.43***	-1.389	0.555	1871-1989
PV Cons. 30		1.221***	0.102	-1,631***	507	99	4.68**	5.78***	-1.520	0.595	1871-1979
PV Cons. 50		2.852***	0.259	-4,695***	868.1	79	51.35***	30.18***	-2.523	0.613	1871-1959
PV Cons. 100		1.755***	0.0939	-84.92	209.9	39	64.74***	453.48***	-3.161**	0.904	1871-1909
PV Cons. 20	GSTFP	0.617***	0.0556	-647.4*	367.4	109	47.46***	103.78***	-1.376	0.535	1871-1989
PV Cons. 30		1.042***	0.0924	-1,228**	503.6	99	0.20	7.21***	-1.334	0.567	1871-1979
PV Cons. 50		2.740***	0.244	-4,798***	863.8	79	50.68***	28.58***	-2.566	0.62	1871-1959
PV Cons. 100		1.655***	0.0853	-53.31	200.7	39	58.95***	416.93***	-3.186**	0.911	1871-1909

Note: Discount rate of 1.95 per cent per annum was chosen on the basis of average net returns of German government bonds during the period under observation. Also see table 1 for notes.

Table 5: Results of Germany and West Germany scenario (both scenarios: 1.95 per cent / year discount rate, excluding periods 1914-19 and 1944-48)

		Germany	West Germany
PV Cons. 20	Net	2.400***	2.353***
PV Cons. 30		3.331***	3.323***
PV Cons. 50		4.339***	4.585***
PV Cons. 100		3.356***	3.925***
PV Cons. 20	Green	2.307***	2.341***
PV Cons. 30		3.134***	3.318***
PV Cons. 50		4.112***	4.449***
PV Cons. 100		3.096***	3.679***
PV Cons. 20	GS	1.626***	1.580***
PV Cons. 30		2.296***	2.363***
PV Cons. 50		3.886***	4.370***
PV Cons. 100		2.805***	3.289***
PV Cons. 20	GScarbon	1.594***	1.549***
PV Cons. 30		2.256***	2.323***
PV Cons. 50		3.865***	4.369***
PV Cons. 100		2.790***	3.270***
PV Cons. 20	GreenTFP	0.765***	0.728***
PV Cons. 30		1.179***	1.221***
PV Cons. 50		2.341***	2.852***
PV Cons. 100		1.612***	1.755***
PV Cons. 20	GSTFP	0.658***	0.617***
PV Cons. 30		1.020***	1.042***
PV Cons. 50		2.249***	2.740***
PV Cons. 100		1.530***	1.655***

6 Carbon costs caused by pollution

In a further step, environmental costs due to pollution are considered, based on the idea that emissions of greenhouse gases deplete the global assimilative capacity for such emissions, and thus constitute a negative investment flow which should be priced according to estimates of marginal damage costs per tonne of emission (Pezzey and Burke, 2013). In the following table total CO2 emissions in Germany and a set of corresponding estimations of damage costs are presented. Over most of the period between 1850 and 2000, trends in German CO2 emissions correspond with overall economic activity: Increases before the end of the Second World War, with brief interruptions in the 1920s and 1930s; a deep slump in the mid- and late-1940s, followed by a steep increase until the mid-1970s when absolute CO^2 emissions started to decline.

There are four different pricing options available, the first price follows the World Bank methodology as outlined by Bolt et al. (2002): 'The global marginal social cost of a metric ton of carbon emitted is assumed to be $20 in 1995 (Fankhauser, 1994). This is deflated for other years using the U.S.A. GDP deflator.' We followed this methodology by using DM 35 as the value of the social cost of carbon in 2000 and deflate using a price index. The second pricing methodology is from Lindmark and Acar (2012) who state that: 'Expressed in current prices, the pollutant social cost is given by: (Pollution Quantity * Unit Social Cost of the pollutant in year 2009) * wage index (2009 = 1).' Lindmark and Acar use the 2000 price of 0.3 SEK/ kg $CO_{2,}$ equating to 1101 SEK/Tonne Carbon. Our value for 2000 is DM 211.5. Lindmark and Acar (2012) then discount the 2000 price by 2 per cent per annum because the 'social cost of carbon is time dependent (the damage is not immediate but occurs in the future), we adjust the historical price by calculating the historical discounted unit cost based on a 2-percent interest rate.' We have followed this approach and discounted the 2000 value (DM 202) by 2 per cent per annum and subsequently deflate using our price deflator.

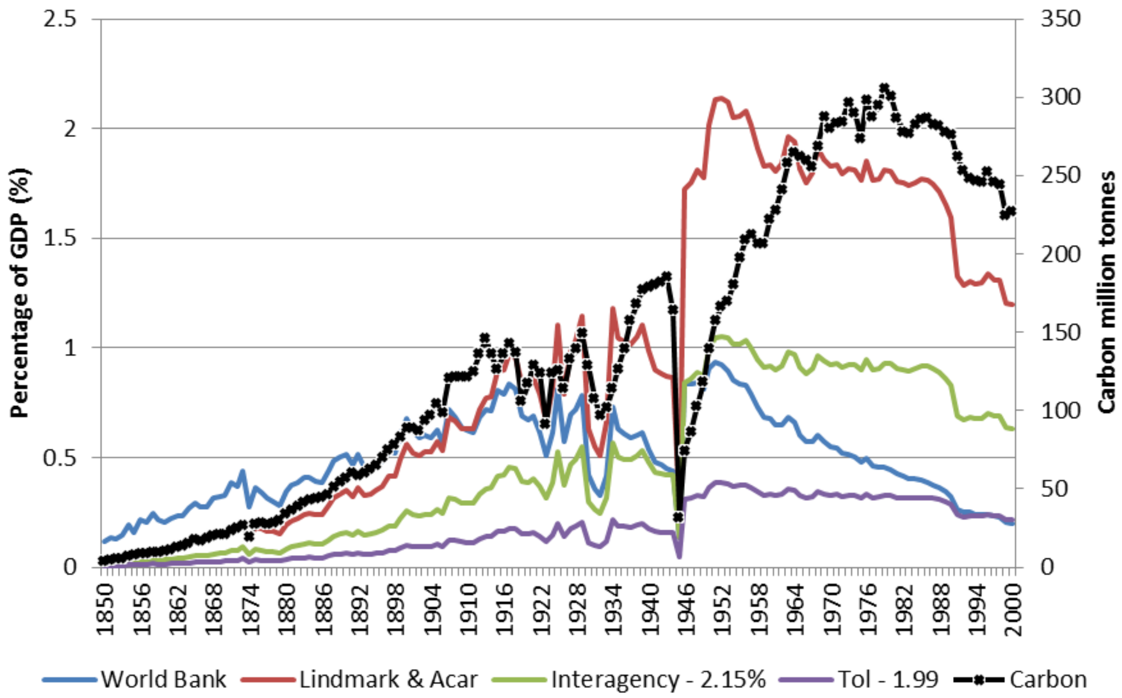
Another method, which is in principle similar to Lindmark and Acar (2012), is to argue that the real price decreases over time as the stock of pollutants in the atmosphere diminishes. Using prices from Tol (2012) and US (2010), we argue that the 2000 price, DM

37.96 in Tol (2012) and DM 111.64 from US (2010), decrease by 1.99 per cent per annum and 2.15 per cent per annum respectively as these are the growth rates of future prices.[9]

Expressed in per cent of GDP, all estimations follow the aforementioned patterns. Tol's (2012) estimation is the most modest one, ranging under 0.4 per cent throughout the period under observation. Maximum values are estimated on the basis of the World Bank methodology for the 19th century and on the basis of Lindmark and Acar (2013) for the 20th century. Taken together, disinvestment due to CO^2 emissions are relatively modest, ranging below 0.5 per cent before 1890, and between 0.5 per cent and approximately 1 per cent between then and 1945. Variation between different estimates are more pronounced after 1945, with values between 1.2 per cent and 2.1 per cent (Lindmark and Acar, 2013) and 0.3 per cent and 0.4 per cent (Tol).

[9] The interagency price is discounted by 2.15 per cent from a 2010 price of $78.50 and the Tol price is discounted by 1.99 per cent from a 2015 price of $ 29. We have converted discounted $ prices to DM using US/Mark exchange rate of 1.7593 in 1998.

Figure 11: Carbon as a percentage of GDP and carbon output (million tonnes), 1850-2000



Given the low value of carbon emissions relative to GDP, as illustrated in figure 11, we do not anticipate that the inclusion of carbon in GS will affect our results dramatically. Using our benchmark model, 1.95 % discount rate and excluding the war years, table 6 illustrates the effect of the various carbon prices on our GS indicator. As expected, the choice of carbon price does not have a significant effect on the results relative to the benchmark GS. Of the prices used, those based on Lindmark & Acar have the largest effect on the GS coefficient increasing the 20 year coefficient by 0.213 and the 30 year by 0.278, but over 50 years this effect is reversed and it lowers the coefficient by 0.103. Over the 100 year time horizon the effect is greater using the World Bank constant price, but this is similar to the Lindmark & Acar price, the other prices have coefficients half the size which reflects their discounted prices. The interagency and Tol prices do not dramatically alter the baseline GS result over 100 years; in fact the Tol price has the least effect on the GS baseline result.

Table 6: β1 results of including different estimates of carbon prices 1.95 per cent /year discount rate (excluding periods 1914-19 and 1944-48)

	GS	GScarbon (World Bank)	GScarbon (Lindmark & Acar)	GS carbon (Interagency)	GS carbon (Tol)
PV Cons. 20	1.696	1.739	1.909	1.801	1.732
PV Cons. 30	2.468	2.536	2.746	2.604	2.515
PV Cons. 50	4.502	4.581	4.399	4.472	4.497
PV Cons. 100	3.279	3.394	3.385	3.327	3.298

6 Alternative indicators of well-being

In this section the possibility of using alternative metrics of well-being is discussed. It has been argued that conventional monetary-oriented welfare measures may be inaccurate when substantial shares of economic activity such as subsistence farming, shadow markets, and intra-family transfers are not included in official statistics. Alternative metrics may help to address this shortcoming and to assess the success of a country's long-term savings and investment strategy. Additionally, savings and investment can be considered forgone immediate consumption which is invested in order to increase future wellbeing instead. We use infant mortality rate (IMR) and average male height to gain a fresh view on the impact of investment on future well-being in the long run. These metrics are frequently used as output-oriented proxies for living standards, reflecting disease environment, nutritional standards and medical technology available (Baten and Blum, 2013; Gnegne, 2009). IMR reflects merely health standards, whereas average height can be interpreted as net-nutrition; this is gross nutritional intake less energy requirements to deal with diseases, physical labour, quality of housing, etc. (Baten and Blum, 2012; Baten and Blum, 2013; Floud et al., 2011; Fogel et al., 1982; Komlos and Baten, 2004; Steckel, 1995).

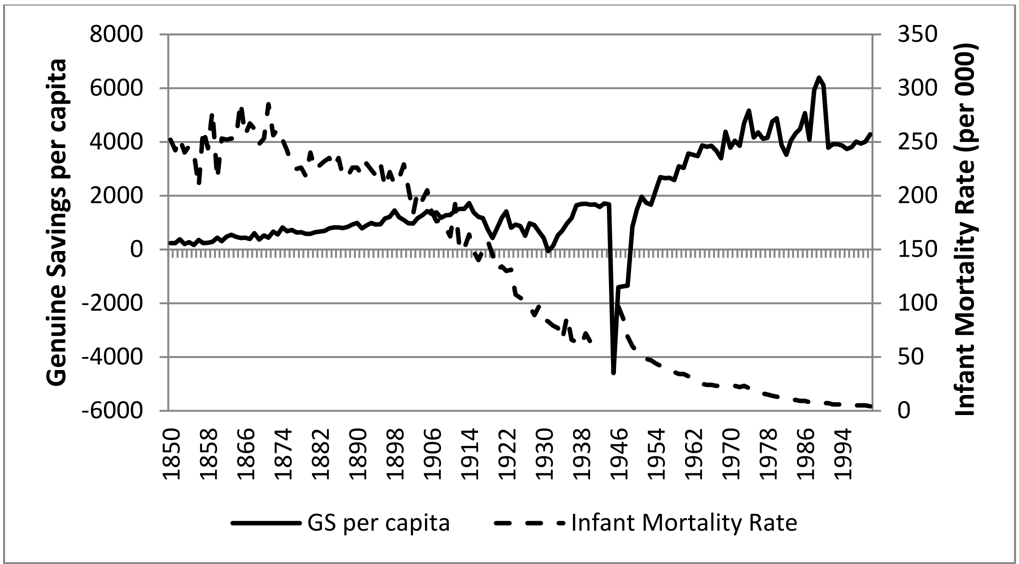
The following figures compare Genuine Savings per capita (GS henceforth) with corresponding values of IMR and average male height. Both metrics are ordered by time of birth. While this procedure is straightforward in the case of IMR, the rationale to do this for average height is that the crucial period for the determination of final average height is the first three years in life.

The following figures (12 & 13) allow an investigation of the relationship between GS and IMR and average height, respectively. GS increase constantly prior to the Second World

War, experiencing slumps during the First World War and economic crises in the 1920s and 1930s. After a substantial break with highly significant saving rates between 1944 and 1948 due to war-related effects, GS increased rapidly. Corresponding development in IMR and average height reflect this development only to some extent. IMR during the 19th century did not show a clear trend despite growing Genuine Savings. Beginning in the early 20th century IMR fell rapidly, with a modest increase during the Second World War. After 1948, GS increased substantially while the velocity of IMR declines slowed down. Similar development can be observed for average height: Average height does not follow a clear rend until the late 19th century. The series indicates rising average heights until 1914, when food shortages led to deteriorating living standards during First World War. During the interwar period economic turmoil and the Nazi government's autarchy policy put pressure on nutritional and health standards in Germany (Baten and Wagner, 2003; Blum, 2011). The Second World War did not lead to decreasing heights, but hindered further improvements. Between 1945 and the 1960s German heights experienced substantial increased due to improvements in food quantities and quality, as well as medical advances and reduced physical work burden. Interestingly, substantial increases in GS during the 1980s did not lead to increases in IMR and average height of the same magnitude.

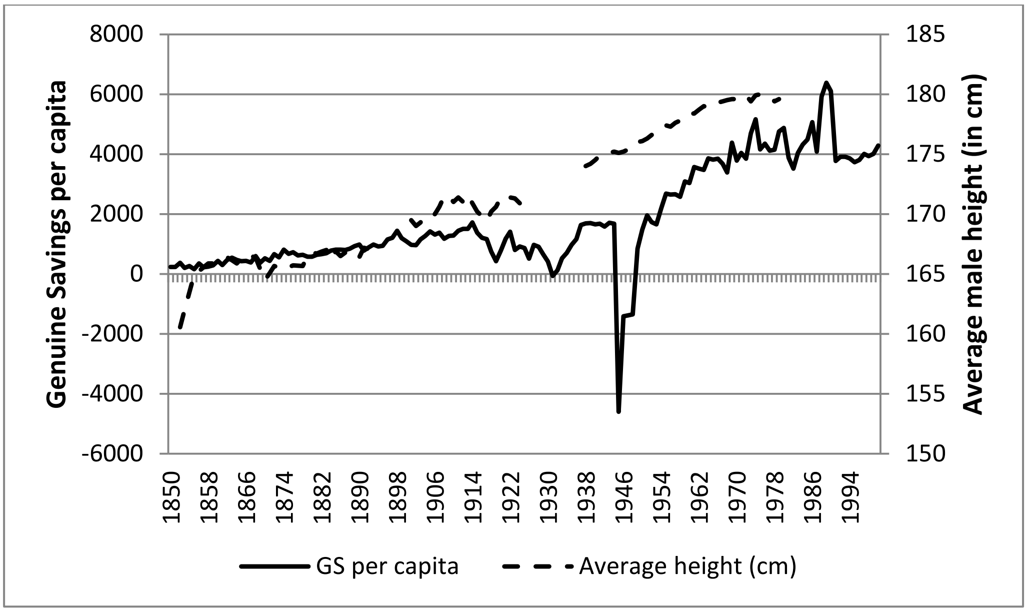
The reason for this apparent contradiction lies in the nature of the target variable which is supposed to reflect outcomes of previous investments. The space, in which both metrics – IMR and average height – range, has natural and biological limits. IMR cannot improve beyond zero, and average height is not likely to be outside a certain biological minimum and maximum. We do not have evidence on a German minimum height, but average height values reached towards the end of the height series indicate that a biological limitation is close. On the other hand, investment does not face similar boundaries as they can – at least in theory – grow almost infinitely since its value is determined not only by quantity but also but its price. Any analysis combining previous investments and future anthropometric outcomes needs to take this phenomenon into account.

Figure 12: Infant Mortality Rate and Genuine Savings in Germany, 1850-2000



As far as inputs (investment) to metrics of biological well-being are concerned, they also do not follow a clear one-to-one relationship, as proposed by Ferreira et al. (2008). On the contrary, at early stages of economic development, (future) returns to investment in terms of IMR or average height is naturally higher since marginal utility of consumers is high. During high stages of economic development, the opposite is the case since biological boundaries move closer and marginal utility is declining (Blum, 2013; Dalton, 1920). This relationship is best described in the form of a scatterplot where the correlations between GS and future changes over 30 years in average height and IMR, respectively, are shown.

Figure 13: Average height (in cm) in Germany and Genuine savings per capita, 1850-2000



Correspondingly, figure 14 indicates that if only observation from pre-1940 are taken into account the correlation between GS and IMR is highly negative since investment goes along with decreasing IMR rates. For the post-1940 period, the opposite seems to be the case. High GS values seem to be positively correlated with IMR, indicating deteriorating disease environment caused by previous investment. However, this is merely the case due to boundaries of the metric and decreasing returns to investment.

For the average height case, we do not find the same phenomenon. This does not necessary mean the aforementionel problem does not exist. In contrast to the IMR case, final average height data for the post-1980 period is not available yet, partly because these cohorts are just about to reach their final average height. For the existing data, we find a positive relationship between GS and future changes in average height when using a 30 and a 50 year time horizon (see Figure 15; latter not shown here).

Figure 14: GS per capita and future changes in infant mortality rate in Germany, 1850-2000

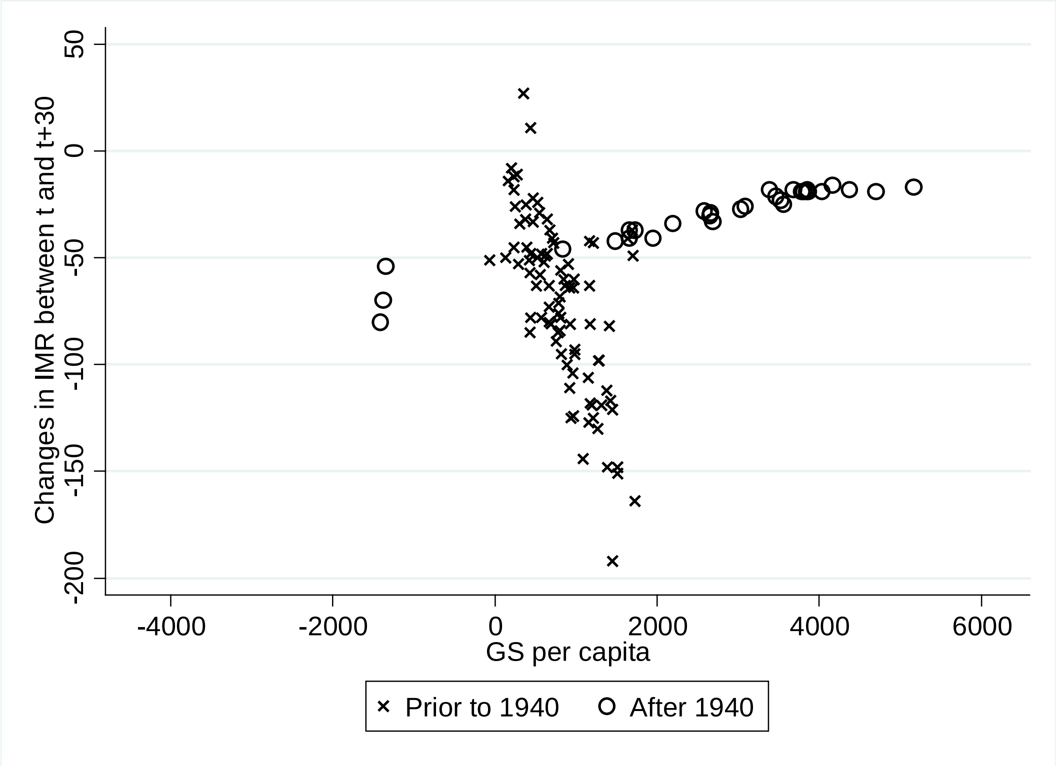
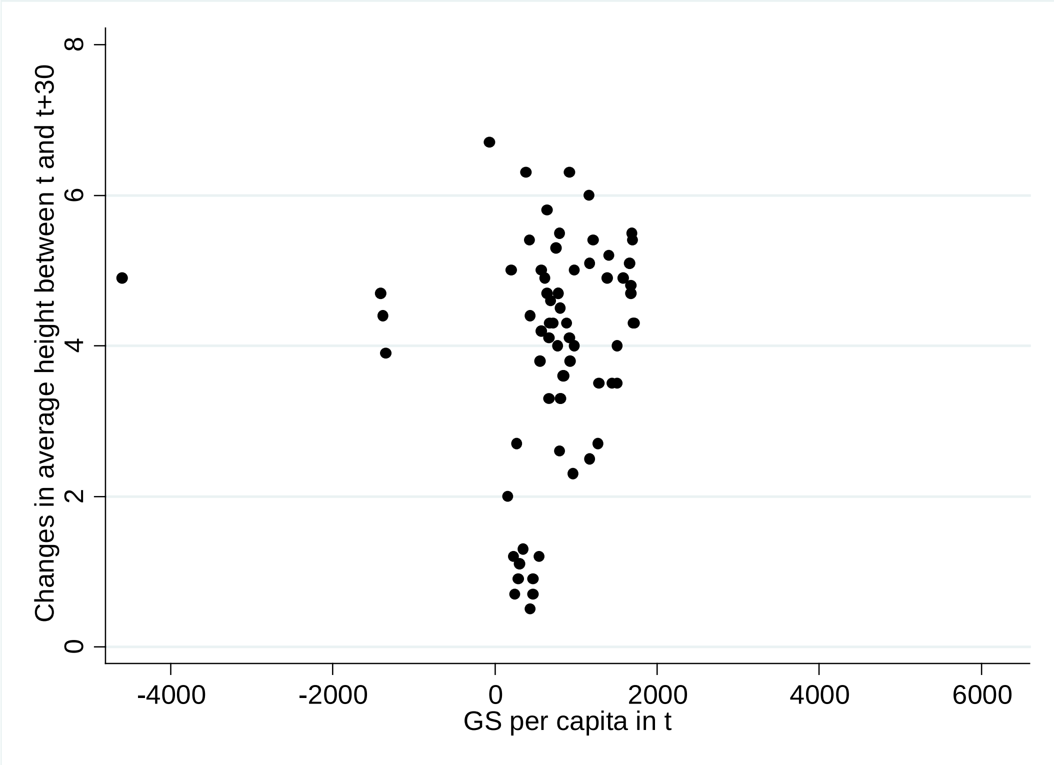


Figure 15: GS per capita and future changes in average height in Germany, 1850-2000



7 Discussion and conclusion

In this paper we have constructed long-run estimates of sustainability indicators for Germany over the period 1850 to 2000. We found that over this period German Genuine Savings were positive for the most part except for some episodes during the World Wars and Great Depression. We also tested the predictive power of Genuine Savings by constructing tests of the relationship between comprehensive wealth measures and the present value of future changes in consumption.

Our benchmark results (table 2) found that increasingly comprehensive indicators of sustainability were good predictors of future changes in well-being, the β1 coefficients of our GSTFP metric (Genuine Savings including benefits from technological progress) ranged from 0.5-1.47. Our results were sensitive to both time-horizon and discount rate, in line with the findings of Greasley et al (2012, 2013, 2014). In the German case, our results were severely sensitive to the effects of Wars as these had dramatic effects on both investment and consumption.

We also looked at the inclusion of CO_2 emissions in a GS framework. We found that the pricing of carbon effected our results. The higher the price of carbon the bigger the effect on our GS estimate. This confirms that how carbon is priced will affect estimates of future sustainability (Pezzey and Burke, 2013).

Another contribution of this paper was to analyse the relationship between GS and alternative measures of well-being, average heights and infant mortality, shows how the framework implied by Ferreira et al. (2008) of a one-for-one increase in GS and well-being does not automatically transfer as these variables have natural limits. The authors of this article believe that applying alternative metrics of well-being may be a fruitful exercise, but a careful investigation of the feasibility of these metrics is necessary before applying them as a target variable to test the outcomes of comprehensive investments. It is also difficult to translate intergenerational improvements in well-being in terms of height increases in a present value context.

Future directions for research would be to see how the German historical experience compares with Britain and the US. The three countries were part of an increasingly integrated global economy and all shocks outlined here for Germany, such as World Wars and the Great Depression, were felt in the Anglo-American sphere as well. Thus isolating the common shocks may help get a better trans-national understanding of sustainability that may be hidden by idiosyncratic country histories.

Alternative measures of human capital could also be incorporated into this framework to get a better understanding of the role of human capital development in long-run development. Education expenditure, the measure used here and in World Bank measures of Genuine Savings, is a partial measure and does not take account of depreciation or other determinants of human capital formation. A useful pathway for future research could be the application of alternative measures such as the discounted lifetime earnings to more fully account for human capital development.

Data appendix

Table 1a: Descriptive statistics (refer to results presented in table 2):

	N	Mean	St.Dev.	Min	Max
Net investment	130	1219.85	979.93	-340.13	4527.06
Green	130	1336.84	1039.71	-269.68	4597.29
Genuine Savings (GS)	130	1720.87	1511.51	-68.84	6386.12
GS carbon	130	1746.55	1543.61	-62.53	6498.62
GS TFP	109	5373.19	4003.70	1074.94	16355.84
Green TFP	109	4920.52	3465.58	1040.67	14567.01
PV consumption 20 years	130	2124.08	2903.61	-1620.85	7275.89
PV consumption 30 years	120	2654.79	3514.02	-1073.66	9360.81
PV consumption 50 years	100	2769.69	3846.11	-944.89	12046.91
PV consumption 100 years	60	2375.34	1070.67	421.86	4381.07

Note: All investment measures are corrected for population changes; consumption: present value of future private consumption.

GDP and GDP deflator: Pre-1975 data on German national product is available from Flora et al. (1983) and Hoffmann et al. (1965). GDP levels for later periods are taken from German Statistical Yearbooks (1999, 2008). Missing periods 1914-1924 and 1940-1949 were estimated using Ritschl and Spoerer's (1997) GNP series. A GDP deflator was constructed using data from Hoffmann et al. (1965), Mitchell (2007) and the United Nations Statistical Division (2013).

Net investment: Net investment from 1850-1959 is provided by Hoffmann et al. (1965). We estimated the gap during 1914-1924 using Kirner (1968) who reports investment in buildings, construction, and equipment by sector for the war and inter-war periods. The period 1939 to 1949 was estimated by using data on net capital stock provided by Krengel (1958).[10] To estimate investment during 1960 to 1975 we used Flora et al.'s (1983) data on net capital formation. For the period 1976 to 2000 we use official World Bank (2013) and United Nations UNSD (2013) investment statistics to complete the series. Data on the change in overseas capital stock and advances is provided by Hoffmann et al. (1965). Gaps

[10] Despite the existence of several estimates and approximations of the development of investment we stick to Krengel's (1958) data (Vonyó 2012, Scherner 2013).

during war and inter-war periods were estimated using information on the balance of payments provided by the German central bank (DeutscheBundesbank, 1998, 2005). Remaining missing values were estimated using trade balances as a proxy for capital flows (DeutscheBundesbank, 1976; Flora et al., 1983; Hardach, 1973).

Private Consumption is taken from Flora et al. (1983), German Statistical Office, downloadable under www.gesis.oreg/histat (Bundesamt, 2013), Ritschl (2005), Abelshauser (1998), and Harrison (1988).

Average height data are taken from the following sources: Germany (West und total): Jaeger et al. (2001), Komlos and Kriwy (2003); Germany (East): Jaeger et al. (2001), Komlos and Kriwy (2003); Bavaria: Baten (1999), Baten and Murray (2000), Harbeck (1960); Württemberg: Twarog (1997); Palatinate: Baten (1999), Baten and Murray (2000); Northrhine-Westphalia: Blum (2011); (Blum, 2012). Average height is organized by birth date, reflecting socioeconomic conditions around birth since this is the most important period for the determination of final average adult height.

Data in **infant mortality rates** are provided by Mitchell (2007) and measures the share number of infants (by 1000) who died within the first 12 months after birth.

Forestry: Germany had an established reputation as one of the most advanced nations involved in forestry management and inspired British and U.S. developments in silviculture (e.g. see Schlich (1904), Zon (1910), Hiley (1930), B.P.P. (1942-43), Heske (1938). Information on German forestry stock were taken from Zon (1910), Zon et al. (1923), Hoffmann et al. (1965), and Endres (1922).

Non-renewable resources: Fischer (1989) and Fischer and Fehrenbach (1995) provide detailed data on German mining activities including the number of employees in mining, covering the period until the 1970s. Information on quantities and market prices by commodity on an annual basis are available. Additional information were collected from Mitchell (2007). Data provided by Fischer (1989) and Fischer and Fehrenbach (1995) are also available by German state, which allows subtracting contemporary contributions of the mining sector of Alsace-Lorraine between 1871 and 1918. Moreover, the statistical offices of the German Empire and the Federal Republic of Germany provide information on the 1914 to 1923 as well as the post-1962 periods, respectively (Bundesamt, 2013; Germany. Statistisches Reichsamt., 1925).

To assess the costs of depletion the number of employees in mining and their average wage were used. Data on the labour force in mining is provided by Fischer (1989), Fischer and Fehrenbach (1995), and the German Statistical Office (2013). Wages of mining workers are reported by Hoffmann et al. (1965), Kuczynski (1947), Mitchell (2007), and official contemporary statistics (Germany. Statistisches Reichsamt., 1925).

Expenditure on schooling: Data on education expenditure is provided by Hoffmann et al. (1965) and Diebolt (1997, 2000). For the post-1990 period we use World Bank data on education expenditure. Missing values for the periods 1922-24 and 1938-48 have to be estimated. For the former period, we assume that expenditures between 1921 and 1925 developed gradually and apply linear interpolation. For the latter period we use Flora et al. (1983) who reports that the number of pupils and students in Germany dropped by 16.3 per cent between 1936 and 1950 – this occurred most likely due to population losses after WWII. The corresponding drop in education expenditure was 16.5 per cent. We assume that the 1939 expenditure level was maintained until 1945, when the number of students plummeted. Therefore, we assume that the expenditure level between 1946 and 1948 was equal to the 1949 figure.

Carbon emissions: German carbon pollution estimates were taken from Andres et al. (1999) and Boden et al. (1995).

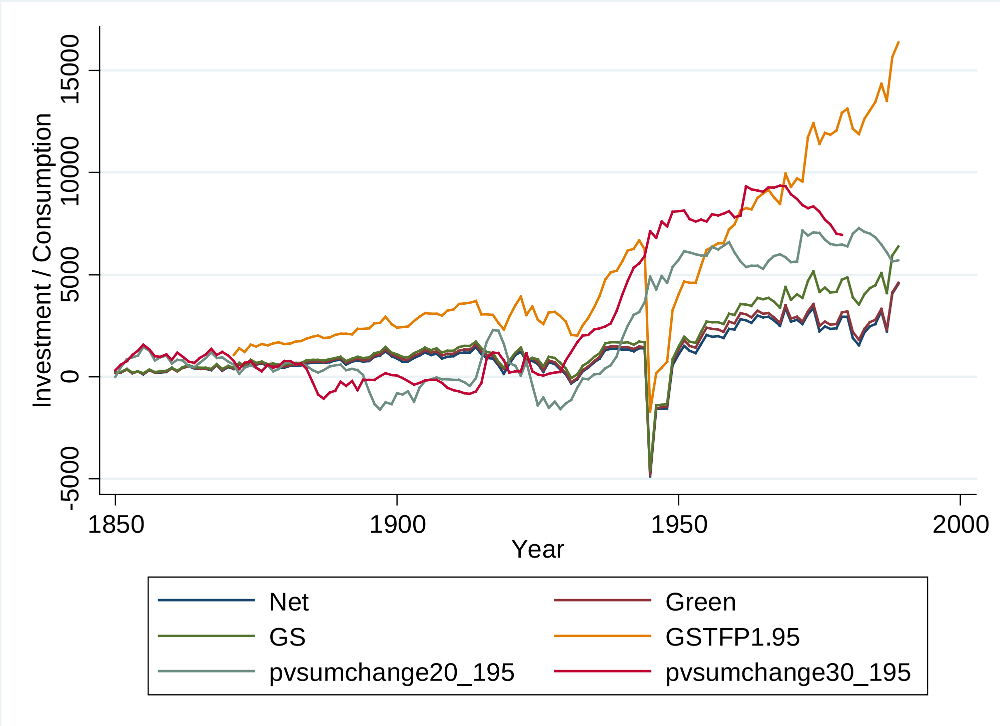
TFP: Data on labour hours worked and real GDP is taken from Greasley and Madsen (2006). Information on capital stock for the period 1850 through 2000 is provided by Metz (2004). Missing values during and after the Second World War have been estimated on the basis of Krengel (1958). Factor shares used were from Greasley and Madsen (2006), capital share is

0.60 and labour 0.40. A Kalman filter of the TFP growth rate was estimated and this was forecast using an ARIMA (2,1).

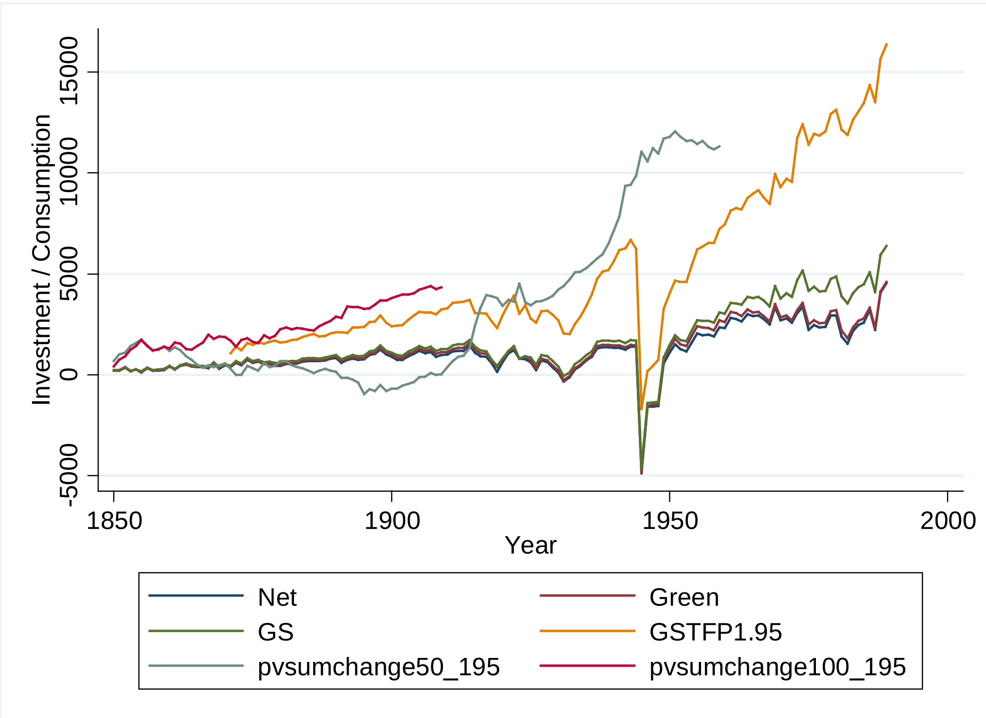
Discount rates: Data on historical interest rates and government bond yields were taken from Homer and Sylla (2005) and Deutsche Bundesbank (2013).[11]

[11] Data download from http://www.bundesbank.de, accessed 23/9/2013

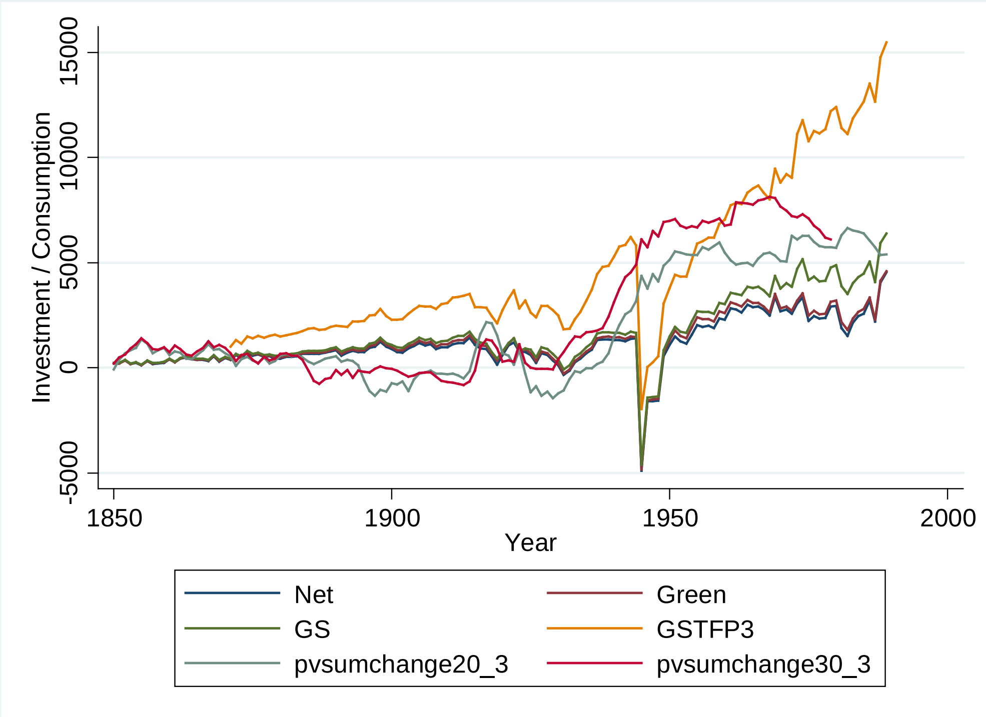
Sustainable development indicators and present value consumption, 1.95 per cent discount rate over 20 and 30 years



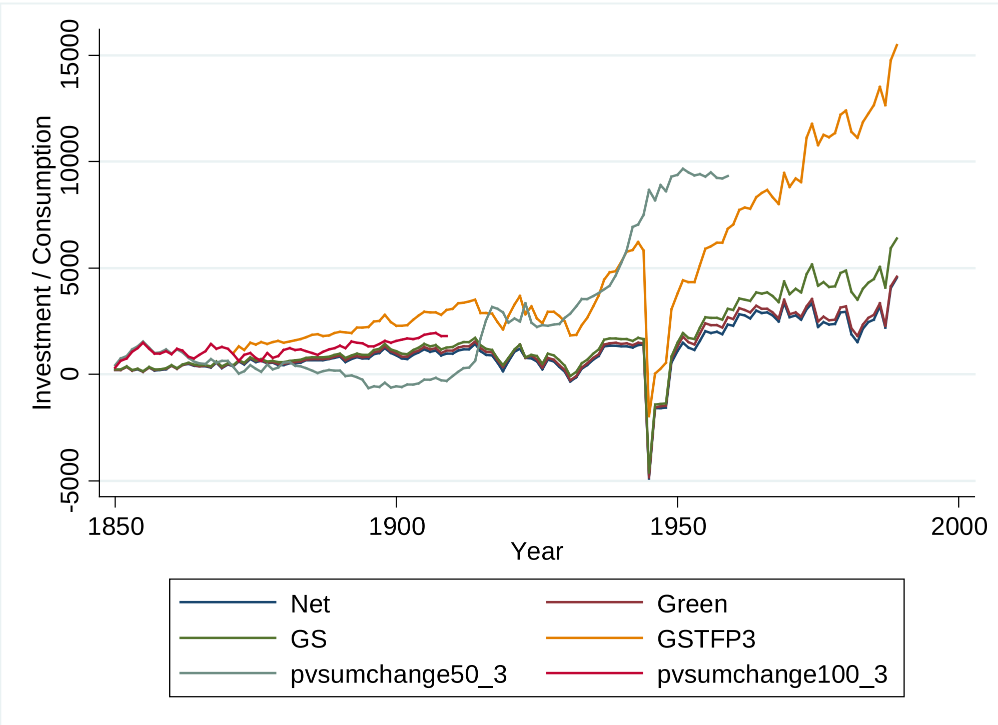
Sustainable development indicators and present value consumption, 1.95 per cent discount rate over 50 and 100 years



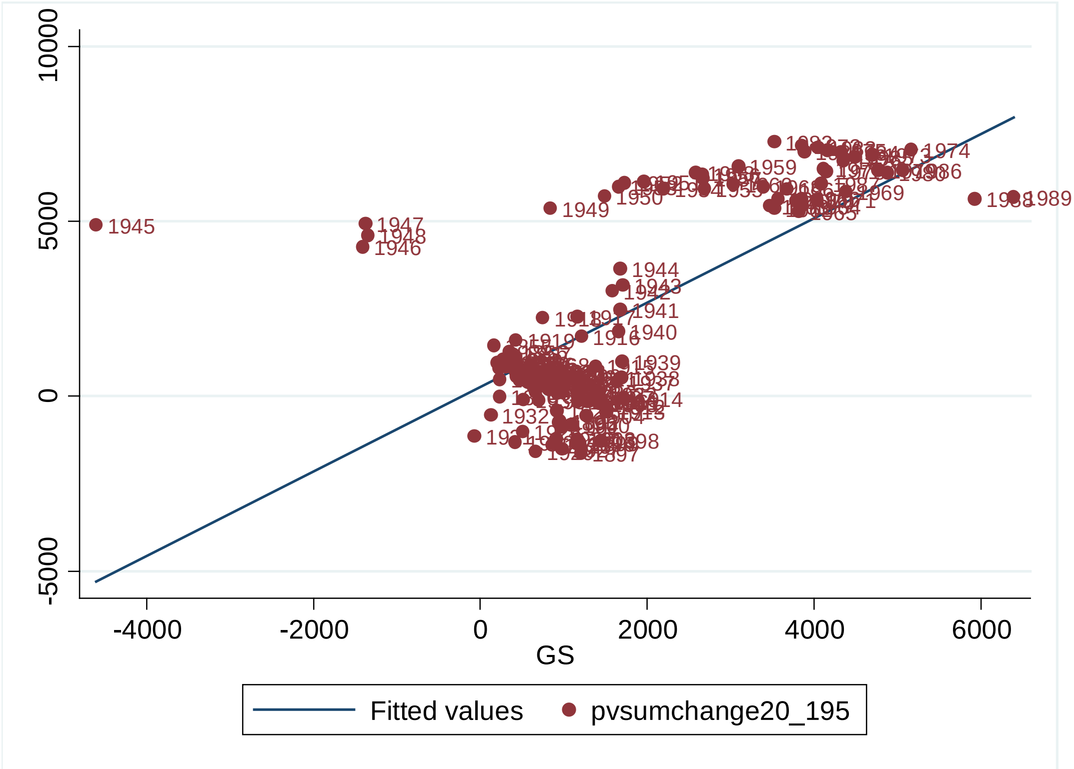
Sustainable development indicators and present value consumption, 3 per cent discount rate over 20 and 30 years

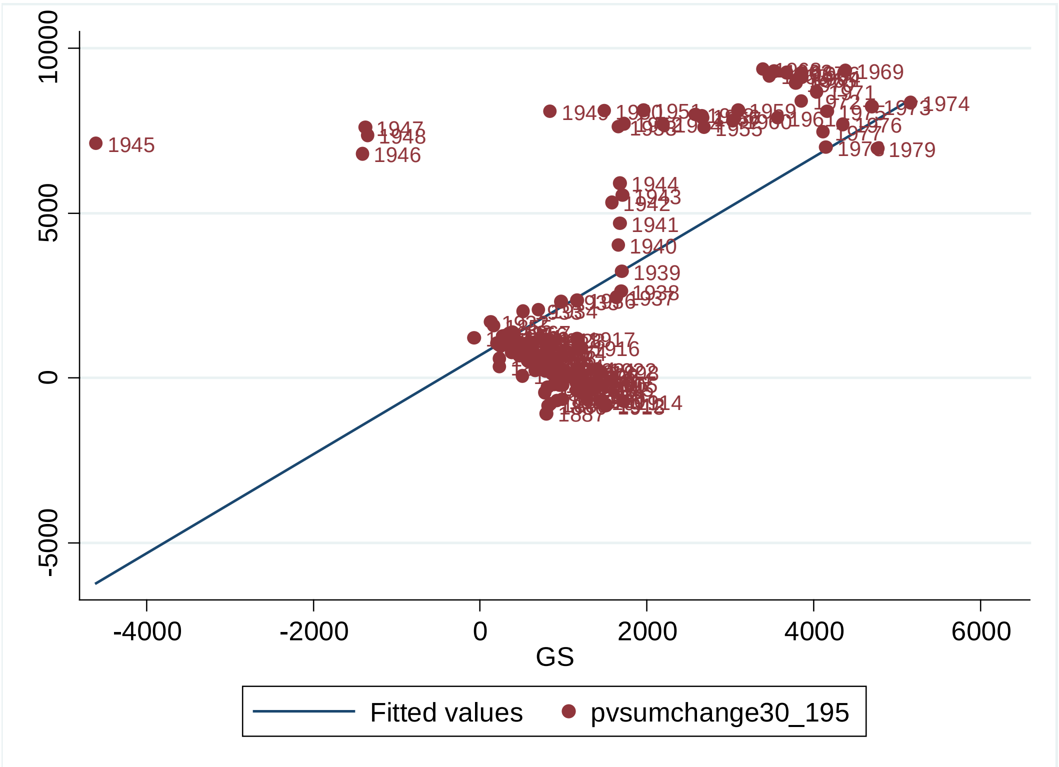


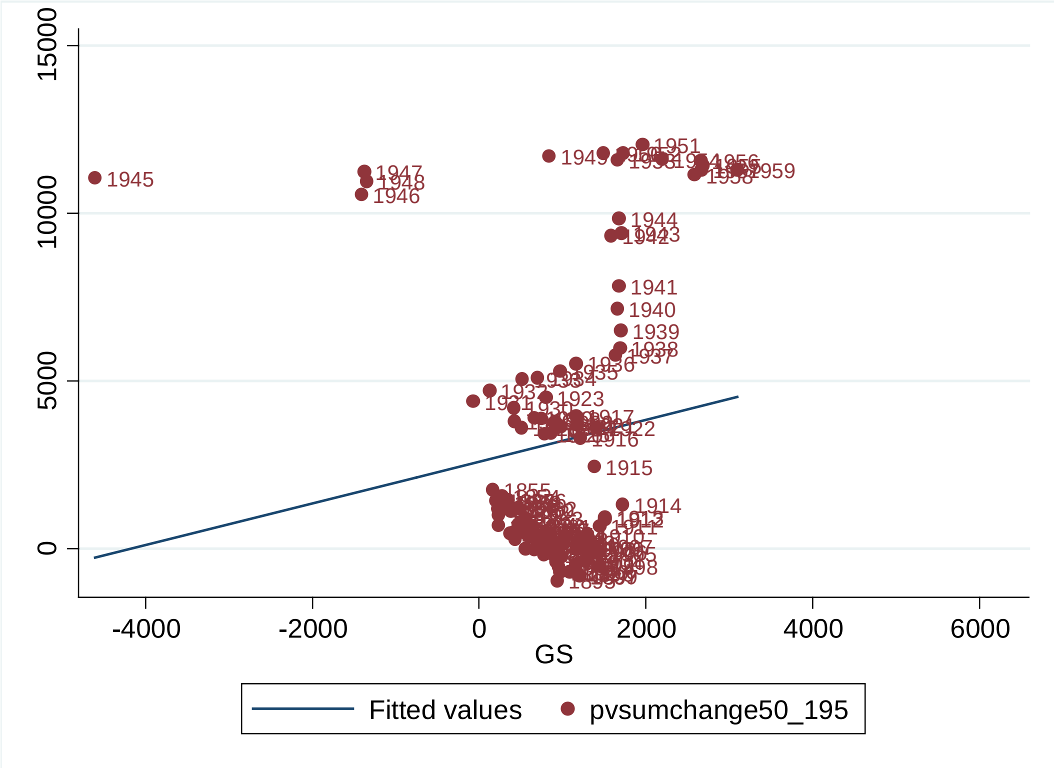
Sustainable development indicators and present value consumption, 3 per cent discount rate over 50 and 100 years

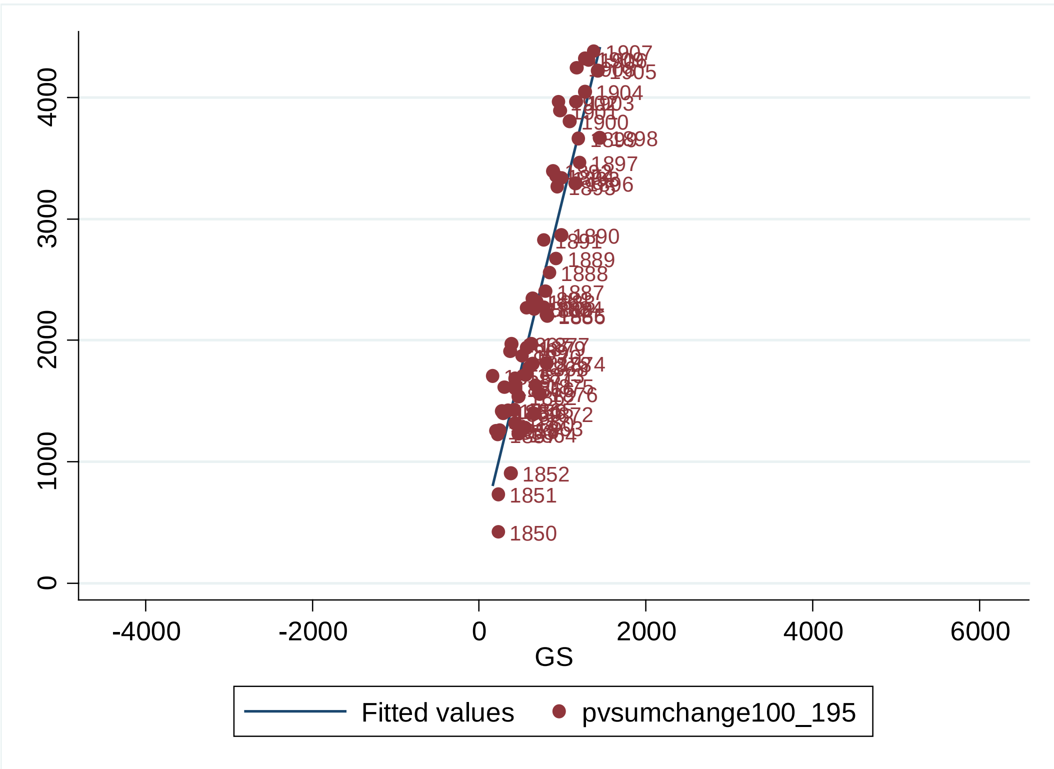


Scatterplots, GS and PV consumption, 1.95 per cent discount rate

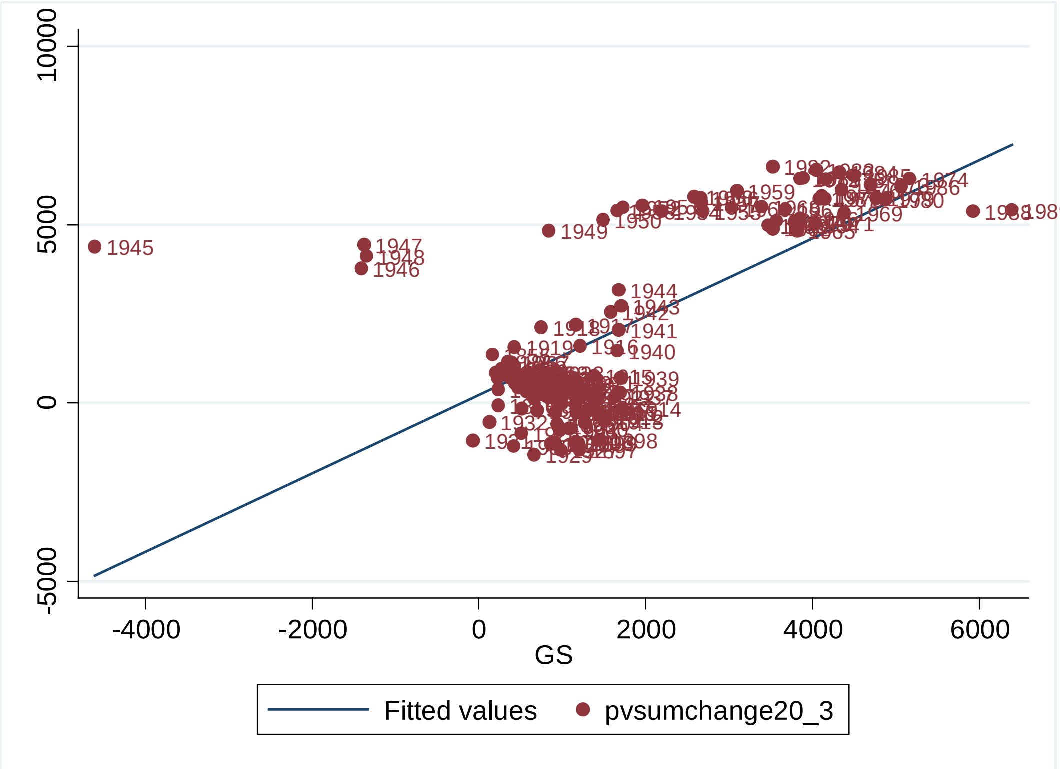


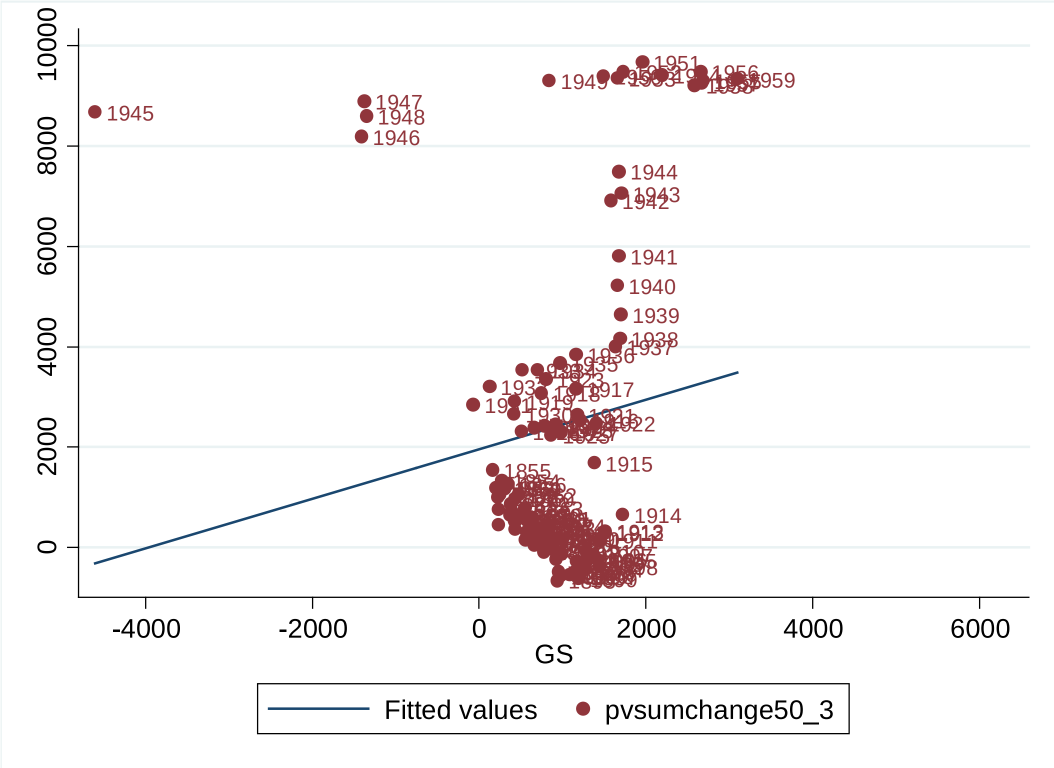



15000
10000
5000
0
-4000
-2000
0
2000
4000
6000
GS
Fitted values
pvsumchange50_195
1945
1947
1946
1949
1951
1959
1944
1941
1940
1939
1923
1915
1914

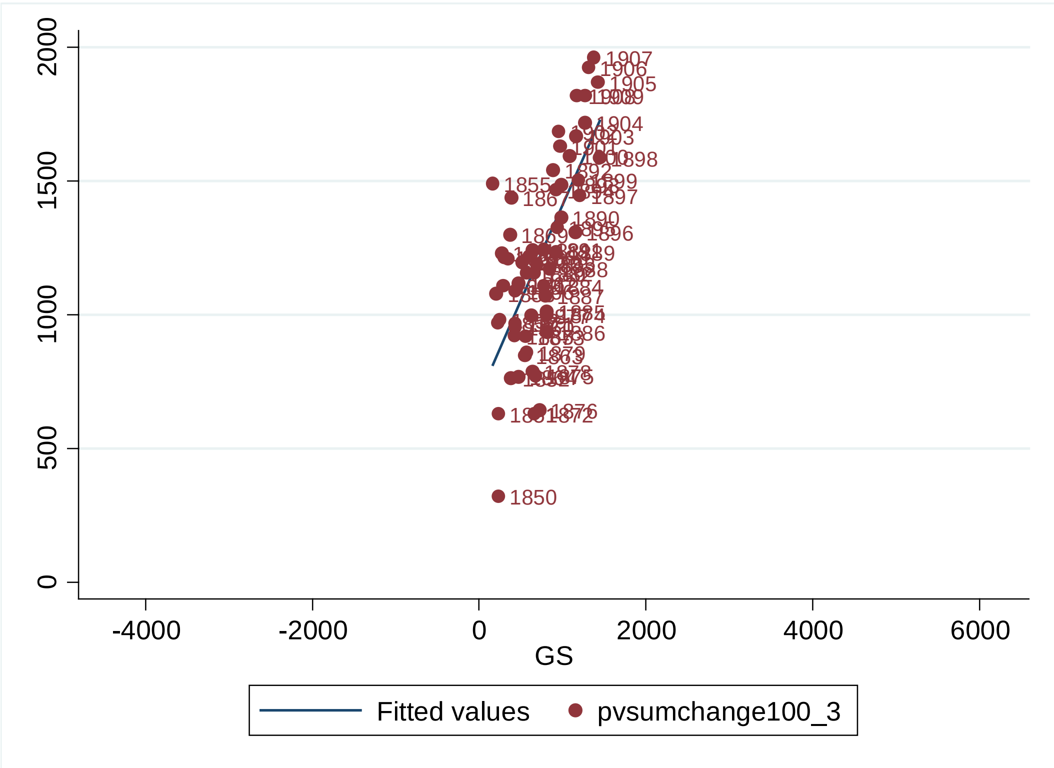

4000
3000
2000
1000
0
-4000
-2000
0
2000
4000
6000
GS
Fitted values
pvsumchange100_195
1907
1905
1904
1900
1897
1890
1889
1888
1887
1852
1851
1850

Scatterplots, GS and PV consumption, 3 per cent discount rate





10000
8000
6000
4000
2000
0
-4000
-2000
0
2000
4000
6000
GS
1945
1947
1948
1946
1949
1951
1956
1959
1944
1943
1942
1941
1940
1939
1938
1937
1917
1915
1914
1855
Fitted values
pvsumchange50_3



2000
1500
1000
500
0
-4000
-2000
0
2000
4000
6000
GS
1907
1906
1905
1904
1898
1855
1897
1890
1896
1887
1886
1876
1850
Fitted values
pvsumchange100_3

References:

Abelshauser, W., 1998. Germany: guns, butter, and economic miracles, in: Harrison, M. (Ed.), Economics of World War II. Cambridge University Press, Cambridge, pp. 122-176.

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., Dasgupta, P., Goulder, L.H., Mumford, K.J., Oleson, K., 2012. Sustainability and the Measurement of Wealth. Environment and Development Economics 17, 317-353.

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

Bank, W., 2006. Where is the wealth of nations? Measuring Capital for the 21st century. World Bank, Washington D.C.

Bank, W., 2011. The Changing Wealth of Nations Measuring Sustainable Development in the New Millennium. World Bank, Washington D.C.

Barbier, E.B., 2011. Capitalizing on Nature. Cambridge University Press, Cambridge.

Baten, J., 1999. Ernährung und wirtschaftliche Entwicklung in Bayern, 1730–1880. Steiner, Stuttgart.

Baten, J., Blum, M., 2012. Growing Tall but Unequal: New Findings and New Background Evidence on Anthropometric Welfare in 156 Countries, 1810–1989. Economic History of Developing Regions 27, 66-85.

Baten, J., Blum, M., 2013. On the Importance of Protein Production for biological Living Standards, 1810-1989, Working Paper.

Baten, J., Murray, J.E., 2000. Heights of men and women in 19th-century Bavaria: Economic, nutritional, and disease influences. Explorations in Economic History 37, 351-369.

Baten, J., Wagner, A., 2003. Autarchy, market disintegration, and health: the mortality and nutritional crisis in Nazi Germany, 1933-1937. Economics and human biology 1, 1-28.

Blum, M., 2011. Government decisions before and during the First World War and the living standards in Germany during a drastic natural experiment. Explorations in Economic History 48, 556-567.

Blum, M., 2012. War, food rationing and socioeconomic inequality in Germany during World War One. The Economic History Review (forthcoming).

Blum, M., 2013. The Influence of Inequality on the Standard of Living: Worldwide Anthropometric from the 19th and 20th centuries. Economics and human biology (forthcoming).

Boden, T.A., Marland, G., Andres, R.J., 1995. Estimates of Global, Regional, and Naitonal Annual CO2 Emissions from Fossil-Fuel Burning, Hydraulic Cement Production, and Gas Flaring: 1950-1992. ORNL/CDIAC-90, NDP-030/R6.

Bolt, K., Matete, M., Clemens, M., 2002. Manual for Calculating Adjusted Net Savings. Environment Department, World Bank.

Bundesamt, S., 2013. Database of the German Statistical Office.

Carreras, A., Josephson, C., 2010. Aggregate growth, 1870-1914: growing at the production frontier, in: Broadberry, S., O'Rourke, K.H. (Eds.), The Cambridge History of Modern Europe. Volume 2: 1870 to the present. Cambridge University Press, Cambridge.

Crafts, N., Toniolo, G., 2010. Aggregate growth, 1950-2005, in: Broadberry, S., O'Rourke, K.H. (Eds.), The Cambridge History of Modern Europe. Volume 2: 1870 to the present. Cambridge University Press, Cambridge.

Dalton, H., 1920. The Measurement of the Inequality of Incomes. The Economic Journal 30, 348-361.

Dasgupta, P., Maler, K.-G., 2000. Net national product, wealth, and social wellbeing. Environment and Development Economics 5, 69-93.

DeutscheBundesbank, 1976. Deutsches Geld- und Bankwesen in Zahlen 1876-1975. Fritz Knapp GmbH, Frankfurt am Main.

DeutscheBundesbank, 1998. 50 Jahre Deutsche Mark. Monetäre Statistiken 1948-1997 auf CD-ROM. C.H. Beck & F. Vahlen.

DeutscheBundesbank, 2005. Zahlungsbilanzstatistik, Frankfurt am Main.
DeutscheBundesbank, 2013. Deutsche Bundesbank Statistical database. Deutsche Bundesbank.
Diebolt, C., 1997. L'évolution de longue période du système éducatif allemand: 19ème et 20ème sècles. Economies et Sociètès Sèrie AF, 1-370.
Diebolt, C., 2000. Die Erfassung der Bildungsinvestitionen im 19. und 20. Jahrhundert. Deutschland, Frankreich, Großbritannien und Spanien im Vergleich. Zeitschrift für Erziehungswissenschaft 3, 517-538.
Endres, M., 1922. Handbuch der Forstpolitik, mit besonderer Berücksichtigung der Gesetzgebung und Statistik, 2., neubearb. Aufl. ed. J. Springer, Berlin,.
Fankhauser, S., 1994. The Social Costs of Greenhouse-Gas Emissions - an Expected Value Approach. Energy J 15, 157-184.
Ferreira, S., Hamilton, K., Vincent, J.R., 2008. Comprehensive wealth and future consumption: Accounting for population growth. World Bank Econ Rev 22, 233-248.
Ferreira, S., Vincent, J.R., 2005. Genuine savings: Leading indicator of sustainable development? Economic development and cultural change 53, 737-754.
Fischer, W., 1989. Statistik der Bergbauproduktion Deutschlands 1850-1914. Scripta Mercaturae Verlag, St. Katharinen.
Fischer, W., Fehrenbach, P., 1995. Statistik der Montanproduktion Deutschlands 1915-1985. Scripta Mercaturae, St. Katharinen.
Flora, P., Kraus, F., Pfenning, W., 1983. State, economy, and society in Western Europe 1815-1975 : a data handbook in two volumes. Campus Verlag; St. James Press, Frankfurt am Main, Chicago.
Floud, R., Fogel, R.W., Harris, B., Hong, S.C., 2011. The changing body : health, nutrition, and human development in the western world since 1700. Cambridge University Press, Cambridge.
Fogel, R.W., Engerman, S.L., Trussell, J., 1982. Exploring the Uses of Data on Height: The Analysis of Long-Term Trends in Nutrition, LaborWelfare, and Labor Productivity. Social Science History 6.
Germany. Statistisches Reichsamt., 1925. Zahlen zur Geldentwertung in Deutschland 1914 bis 1923. R. Hobbing, Berlin,.
Gnegne, Y., 2009. Adjusted net saving and welfare change. Ecol Econ 68, 1127-1139.
Greasley, D., Hanley, N., Kunnas, J., McLaughlin, E., Oxley, L., Warde, P., 2013. Comprehensive investment and future well-being in the USA, 1869-2000, Stirling Economics Discussion Paper 2013-06.
Greasley, D., Hanley, N., McLaughlin, E., Oxley, L., Warde, P., 2012. Testing for long-run "sustainability": Genuine Savings estimates for Britain, 1760-2000. Stirling Economics Discussion Papers.
Greasley, D., Hanley, N., McLaughlin, E., Oxley, L., Warde, P., Kunnas, J., 2014. Testing Genuine Savings as a forward-looking indicator of future well-being over the (very) long-run. Journal of Environmental Economics and Management (forthcoming).
Greasley, D., Madsen, J.B., 2006. Employment and total factor productivity convergence. KYKLOS 59, 527-555.
Hamilton, K., Clemens, M., 1999. Genuine savings rates in developing countries. World Bank Econ Rev 13, 333-356.
Hamilton, K., Withagen, C., 2007. Savings and the Path of Utility. Canadian Journal of Economics 40, 703-713.
Hanley, N., Shogren, J.F., White, B., 2006. Environmental Economics in theory and practice. Palgrave Macmillan.
Harbeck, R., 1960. Die Körpergrößen 20jähriger Männer, Wehrdienst und Gesundheit: Abhandlungen aus Wehrmedizin, Wehrphannazie und Wehrveterinarwesen. Wehr und Wissen, Darmstadt.
Hardach, G., 1973. Der Erste Weltkrieg: 1914-1918, Orig.-Ausg. ed. Deutscher Taschenbuch-Verlag, München.

Harrison, M., 1988. Resource mobilisation for World War II: The USA, UK, USSR, and Germany, 1938-1945. Econ Hist Rev 61, 171-192.
Hartwick, J.M., 1977. Intergenerational Equity and the investing of rents from Exhaustible Resources. . American Economic Review 67, 972-974.
Heske, F., 1938. German Forestry. Yale University Press.
Hiley, W.E., 1930. The economics of forestry. Clarendon Press, Oxford,.
Hoffmann, W.G., Grumbach, F., Hesse, H., 1965. Das Wachstum der deutschen Wirtschaft seit der Mitte des 19. Jahrhunderts. Springer-Verlag, Berlin, Heidelberg, New York.
Homer, S., Sylla, R.E., 2005. A history of interest rates, Wiley finance, 4th ed. Wiley,, Hoboken, N.J., pp. 1 online resource (xx, 710 p.
Jaeger, U., Zellner, K., Kromeyer-Hauschild, K., Lüdde, R., Eisele, R., Hebebrand, J., 2001. Körperhöhe, Körpergewicht und Body Mass Index bei deutschen Wehrpflichtigen. Historischer Rückblick und aktueller Stand. Anthropologischer Anzeiger 59, 251-273.
KaiserlichesStatistischesAmt, 1915. Statistik des deutschen Reiches. Verlag von Puttkammer & Mühlbrecht, Berlin.
Kirner, W., 1968. Zeitreihen für das Anlagevermögen der Wirtschaftsbereiche in der Bundesrepublik Deutschland. Duncker & Humblot, Berlin,.
Komlos, J., Baten, J., 2004. Looking backward and looking forward - Anthropometric research and the development of Social Science History. Social Science History 28, 191-210.
Komlos, J., Kriwy, P., 2003. The Biological Standard of Living in the Two Germanies. German Economic Review 4, 459-473.
Krengel, R., 1958. Anlagevermögen, Produktion und Beschäftigung der Industrie im Gebiet der Bundesrepublik von 1924 bis 1956. Duncker & Humblot, Berlin,.
Kuczynski, J., 1947. Die Geschichte der Lage der Arbeiter in Deutschland von 1880 bis in die Gegenwart. Verlag die Freie Gewerkschaft, Berlin,.
Lindert, P., 2004. Growing Public. Cambridge University Press, Cambridge.
Lindmark, M., Acar, S., 2012. Sustainability in the making? A historical estimate of Swedish sustainable and unsustainable development 1850-2000. Ecological Economics in press.
Lindmark, M., Acar, S., 2013. Sustainability in the making? A historical estimate of Swedish sustainable and unsustainable development 1850–2000. Ecol Econ 86, 176-187.
Maddison, A., 1995. Monitoring the World Economy 1820-1992, Paris.
Metz, R., 2004. Säkulare Trends der deutschen Wirtschaft., in: North, M. (Ed.), Deutsche Wirtschaftsgeschichte. Ein Jahrtausend im Überblick. Beck, München.
Mitchell, B.R., 2007. International historical statistics. Europe, 1750-2005, 6th ed. Palgrave Macmillan, Houndmills, Basingstoke, Hampshire ; New York, N.Y.
Neumayer, E., 2010. Weak Versus Strong Sustainability: exploring the limits of two paradigms. Edward Elgar, Cheltenham.
Pearce, D.W., Atkinson, G., 1993. Capital theory and the measurement of sustainable development: an indicator of weak sustainability. Ecol Econ 8, 103-108.
Pezzey, J.C.V., 2004. One-sided sustainability tests with amenities, and changes in technology, trade and population. Journal of Environmental Economics and Management 48, 613-631.
Pezzey, J.C.V., Burke, P., 2013. Measuring global sustainability using a precautionary valuation of CO2 emissions, Paper to the Australian Association of Agricultural and Resource Economists' conference, Sydney.
Pezzey, J.C.V., N., H., K., T., D., T., 2006. Comparing augmented sustainability measures for Scotland: Is there a mismatch? Ecol Econ 57, 70-74.
Ritschl, A., 2005. The Pity of Peace: Germany's Economy at War, 1914-1918, in: Broadberry, S.N., Harrison, M. (Eds.), The Economics of World War I. Cambridge University Press, Cambridge, pp. 41-76.

Ritschl, A., Spoerer, M., 1997. Das Bruttosozialprodukt in Deutschland nach den amtlichen Volkseinkommens- und Sozialproduktsstatistiken 1901 - 1995. Jahrbuch für Wirtschaftsgeschichte 2, 27-54.
Roses, J., Wolf, N., 2010. Aggregate growth, 1913-1950, in: Broadberry, S., O'Rourke, K.H. (Eds.), The Cambridge History of Modern Europe. Volume 2: 1870 to the present. Cambridge University Press, Cambridge.
Scherner, J., 2013. 'Armament in depth' or 'armament in breadth'? German investment pattern and rearmament during the Nazi period. The Economic History Review 66, 497-517.
Schlich, W., 1904. Forestry in the United Kingdom. Bradbury, Agnew, & Co, London.
StatistischesBundesamt, 1999. Statistisches Jahrbuch für die Bundesrepublik Deutschland 1999. Metzler-Poeschel, Stuttgart.
StatistischesBundesamt, 2008. Statistisches Jahrbuch für die Bundesrepublik Deutschland 2008. Metzler-Poeschel, Stuttgart.
Steckel, R.H., 1995. Stature and the standard of living. J Econ Lit 33, 1903-1940.
TheWorldBank, 2013. The World Bank statistical database.
Tol, R.S.J., 2012. On the Uncertainty About the Total Economic Impact of Climate Change. Environ Resource Economics.
Twarog, S., 1997. Heights and Living Standards in Germany, 1850-1939: The Case of Wurttemberg, in: Steckel, R.H., Floud, R. (Eds.), Health and Welfare during Industrialization. University of Chicago Press, Chicago, pp. 285-330.
UNEP, 2012. Inclusive Wealth Report 2012. Measuring Progress Toward Sustainability, in: Programme, U.N.E. (Ed.). United Nations.
UNSD, 2013. United Nations Statistical Division Database.
US, 2010. Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, Technical Support Document:

. Interagency Working Group on Social Cost of Carbon, United States Government.
Vonyó, T., 2012. The bombing of Germany: the economic geography of war-induced dislocation in West German industry. European Review of Economic History 16, 97-118.
Weitzman, M.L., 1997. Sustainability and technical progress. Scand J Econ 99, 1-13.
Zon, R., 1910. The forest resources of the world. Govt. print. off., Washington,.
Zon, R., Sparhawk, W.N., National Research Council (U.S.), 1923. Forest resources of the world, 1st ed. McGraw-Hill Book Company, Inc., New York etc.