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Empirical testing of genuine savings as an indicator of weak sustainability: a three-country analysis of long run trends.

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Abstract:

Genuine Savings has emerged as a widely-used indicator of sustainable development. In this paper, we use long-term data stretching back to 1870 to undertake empirical tests of the relationship between Genuine Savings (GS) and future well-being for three countries: Britain, the USA and Germany. Our tests are based on an underlying theoretical relationship between GS and changes in the present value of future consumption. Based on both single country and panel results, we find evidence supporting the existence of a cointegrating (long run equilibrium) relationship between GS and future well-being, and fail to reject the basic theoretical result on the relationship between these two macroeconomic variables. This provides some support for the GS measure of weak sustainability. We also show the effects of modelling shocks, such as World War Two and the Great Depression.

Keywords:

Weak sustainability; Genuine Savings; comprehensive investment; economic history; indicators; cointegration.

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1. Introduction

Anil Markandya's name is associated with some of the most important work on the economics of sustainable development. Along with David Pearce and Edward Barbier, Markandya developed the idea of weak sustainability, and of how changes in a nation's total capital stock (referred to today as comprehensive wealth) can indicate whether a country's development is weakly sustainable (Pearce et al, 1989; Markanya et al, 1990; Barbier et al, 2013). This led to the proposing of a specific test for weak sustainability by Pearce and Atkinson (1993) known as "Genuine Savings."[1]

In this paper, we use long-run data sets for changes in a country's total capital – the sum of its produced, natural and human capital, plus an adjustment for changes in Total Factor Productivity – to test whether these predict changes in future well-being in a manner consistent with theory underlying the Genuine Savings indicator. The countries are Britain, the USA and Germany, and the data we use here starts in 1870 for all three. The economies in our panel include the industrializing pioneer and two of its most prominent followers. They are today at an advanced stage of economic development and their economic history may serve as an orientation guide for modern-day economies with respect to their investment decisions. Moreover, the history of these economies offers a series of natural experiments, allowing us to investigate effects associated with economic shocks such as two world wars and the Great Depression. They represent a range of phases and speeds of industrialisation and a range of natural resource abundances. Our measure of changes in future well-being is the present value of changes in consumption over a range of future time periods. Empirical tests are undertaken using the framework suggested by Ferreira, Hamilton and Vincent (2008). We also test whether GS and the PV of changes in consumption are cointegrated. Evidence of cointegration is taken to be evidence of a long-run equilibrium relationship.

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

2. Evolution of genuine savings as an indicator of weak sustainability.

One of the first publications to explore the concept of weak sustainability was Pearce et al (1989), in *Blueprint for a Green Economy.* They define sustainable development as a situation where well-being for a given population is not declining, or preferably is increasing over time. Based on Solow (1986), they state that this requires that each generation passes on an undiminished stock of total capital to the next generation, meeting a requirement for intergenerational fairness and non-declining consumption over time. They note arguments over the extent to which a decline in natural capital, e.g. a loss of forests, can be compensated for by an increase in produced or human capital, leading to two cases for this intergenerational rule:

1. Sustainable development requires non-declining total wealth
2. Sustainable development requires non-declining natural wealth.

We now view the first as representing the idea of weak sustainability, and the second as representing the idea of strong sustainability.[2] Interestingly, whilst most focus today is on the degree of substitutability between produced, human and natural capital in deciding which of the above is consistent with non-declining wellbeing over time, Pearce et al (1989) provide four reasons why we might need to impose rule (2) rather than rule (1) for welfare to be non-declining. These are (i) lack of sufficient substitutability (ii) irreversibility (iii) uncertainty and (iv) intra-generational equity, on the grounds that the poor are often more adversely affected by poor environmental quality than the rich. There are indications in the text that Pearce et al thought that constraint (2) should be taken into some kind of account, and that sustainability could not be assured regardless of the state of a country's natural capital. For

[2] Note that Pearce et al (1989) use these terms rather differently: they define weak sustainability as a situation where, across a portfolio of projects and over time, the net environmental cost of implementing the portfolio is zero or negative. For strong sustainability, they require this non-positive condition to hold for every time period: see Chapter 5. It is interesting that by the time the "new blueprint" was published Barbier and Markandya, 2013), the difference between weak and strong sustainability revolves around the substituteability of different forms of capital for each other. Thus, weak sustainability takes rule (1) as being the relevant rule; strong sustainability takes rule (2).

example, on page 48 they note: ”..*there are strong reasons to think of sustainable development as involving….that the stock of environmental assets as a whole should not decrease”*. This is more consistent with the idea of strong sustainability than weak sustainability. Later on, they propose implementing this at the level of programmes of investment by requiring shadow projects which offset the value of environmental losses.

The idea that sustainable development *requires* non-declining natural capital is stated more clearly in Pearce et al (1990). They define natural capital as “..*the stock of all environmental and natural resource assets...from oil in the ground to the quality of soil and groundwater, from the stock of fish in the oceans to the capacity of the globe to recycle and absorb carbon”* (page 1). How this natural capital stock can be maintained as non-declining is put in terms of the net value of environmental damages. When evaluated at the programme level, this net environmental damage value should be zero or negative, either when discounted across time or at each point in time. This outcome, they wrote, could be achieved by commissioning shadow projects which have the purpose of off-setting environmental damages from other projects in the programme. Such shadow projects might well yield negative NPVs when appraised in isolation, implying that there is a sustainability “price” being paid by the economy, which is the marginal cost of the constraint of no positive environmental damage.

The work of Pearce and Atkinson (1993) in developing the idea of Genuine Savings as an indicator of sustainability moves away from the notion that sustainability by definition requires zero net loss of natural capital (zero environmental damage, in the language of the previous paragraph), since GS allows for reductions in natural capital to be offset by increases in human or produced capital. In the words of Neumayer (2010), GS is a weak sustainability indicator as it presumes that natural capital can be substituted for by other forms of capital[3] (so long as changes in each are correctly priced), and that non-declining consumption over time is possible so long as the *total* capital stock is non-declining. 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 be subtracted from the index, valued using marginal damage costs. Changes in human capital can be approximated using expenditures on education, as a rate of return on time spent in education, or as a measure of discounted lifetime earnings by skill level. The effects of technological change, resource price appreciation (capital gains/losses) for resource exporters and importers, and population change can also be incorporated into the GS indicator (Pezzey et al, 2006; Ferreira et al, 2008).

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. Concomitantly, countries with negative GS values would be experiencing un-sustainable development. As they stated: *"…even on (such) a weak sustainability rule, many countries are unlikely to pass a (stronger) sustainability test"* (page 105). The theoretical nature of the link between genuine savings and future consumption has since been investigated by a number of authors, including Hamilton and Clemens (1999), Hamilton and Hartwick (2005) and Hamilton and Withagen (2007), see Neumayer (2010) for an excellent overview. Pezzey (2004) argues that GS is a one-sided indicator which can only indicate un-sustainability, due to the failure to use what have been termed "sustainability prices" which include sustainability constraints to value changes in

[3] Pearce and Atkinson state: "To do this we adopt a neoclassical stance and assume the possibility of substitution between 'natural' and 'man-made' capital" (page 104).

capital stocks. A positive value of GS could give a misleading signal of weak sustainability if natural resources are under-priced or being harvested unsustainably (Neumayer, 2010). Moreover, he argues that there is no theory linking negative GS with un-sustainability away from an optimal path. An alternative perspective offered by Dasgupta and Maler (2004) shows that a measure of change in wealth stocks (GS, in our terminology) year-on-year can be used as an indicator of sustainable increases in well-being in non-optimising economies. Arrow et al (2012) define comprehensive investment as the change in comprehensive wealth at time *t*, and claim that intergenerational well-being is rising over future periods if comprehensive investment – GS, in our terminology – is positive when evaluated at the correct shadow prices in the current period. There is thus a theoretical claim about the signal which a positive or negative value of GS sends which seems worthy of empirical investigation.

3. Empirical tests of Genuine Savings

Empirical work to date in estimating GS includes World Bank (2006, 2011) which reports GS calculations for most countries. However, 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.

Ferreira and Vincent (2005) base their econometric testing on a representation of an underlying theoretical relationship between GS and future well-being:

$$\Delta_{it} = \beta_0 + \beta_1 S + \varepsilon_{it} \qquad (1)$$

where Δ_{it} is given by $((\overline{c}) - c_t)$, with the former term representing average (per capita) consumption over some time period, and the latter consumption in the current period; where S is a measure of investment, and ε is an error term. Δ_{it} thus represents the difference between current period consumption at time *t* and average future consumption. Equation (1) implies that consumption will only grow over time if investment *S* (measured at the correct shadow prices) is positive. A test for the validity of this relationship as a predictor of future well-being is then whether or not $\beta_0 = 0$ and $\beta_1 = 1$. Using World Bank data for 136 countries over the period 1970-2000, Ferreira and Vincent initially calculate Δ_{it} over 10 years, so that their estimation period is 1970-1991. The authors propose 4 alternative measures of *S*; gross investment in produced capital; net investment in produced capital; net investment adjusted for depletion of natural capital (green net savings), and finally green net savings augmented by investment in education, which they term *Genuine Savings*. These 4 measures represent an increasingly comprehensive view of what is counted as part of a country's capital stock. Based upon this approach, they then test four hypotheses:

H1: $\beta_0 = 0$; and $\beta_1 = 1$ (jointly).

H2: $\beta_1 > 0$ and $\rightarrow 1$ as *S* includes more types of capital.

H3: $\beta_1 > 0$.

H4: The predictive power of S improves as more types of capital are added.

To test H1-H3, the authors estimate a series of 2SLS panel models with and without country fixed effects using the different definitions of *S* as noted above. Their results suggest that H1 is rejected for all definitions of *S*. For H2, they find that β_1 is sometimes positive (although negative for OECD countries), and that its absolute value increases as more comprehensive measures of the capital stock are used, although it falls when education spending is included. The authors speculate that this reflects the extent to which current education spending is a poor measure of changes in the stock of human capital. H3 is not rejected. Changing the time period over which equation (1) is tested to 20 years, rather than 10 years results in higher values for β_1. H4 is evaluated by generating a set of one-step-ahead forecasts of Δ_{it}, with forecasts compared using the Theil inequality statistic for each country [23]. As postulated, the results show that the predictive accuracy of *S* improves as one adds more types of capital to its calculation. However a pure ARIMA time series model outperforms even the most comprehensive definition of *S.* A similar test of the predictive power of GS in terms of future well-being, using the same data set, is reported in World Bank (2006). Based on Hamilton and Hartwick (2005), the authors show that the change in the Present Value of future changes in consumption (PVC) in a competitive economy *i* where externalities are internalised should be determined by:

$$PVC_i = \beta_0 + \beta_1 G_i + \varepsilon_i \qquad (2)$$

where G_I is a measure of investment in country *i* (corresponding to *S* in equation 1), with $\beta_0 = 0$ and β_1=1 (note here the similarity to (1) above, where only the dependent variable differs). Thus, this study uses a different future welfare measure to Ferriera and Vincent. The authors then test (2) using three of the definitions of investment used by Ferreira and Vincent: gross investment in produced capital; net investment in produced capital; and finally, net investment after allowing for natural resource depletion. Education spending was excluded. Using simple OLS regressions for each year from 1976-1980 across the countries in the sample and a measurement period for PVC of 1976-2000, they found that they could not reject the hypothesis that $\beta_1 = 1$ for the Genuine Savings measure of G, where net investment included depletion of natural resources. They also found, however, that this gave a number of false positive and false negative signals about the future path of consumption. Overall, they concluded that *"…Genuine Savings is a good predictor of change in future welfare as measured by consumption per capita*" (page 82).

Ferreira, Hamilton and Vincent (2008) allow for population growth in testing the relationship between the present value of changes in future consumption and genuine savings. They employ a World Bank data set of 64 developing countries over the period 1970-2003, which implies an estimation period of 1970-1982 to measure discounted changes in future consumption over a 20 year period. This study again used increasingly-comprehensive measures of changes in a country's assets: gross savings, net savings (i.e. net investment in produced capital), green savings (net savings minus depreciation of elements of natural capital) and population-adjusted savings (green savings adjusted by a "wealth dilution" term). They tested the joint hypothesis that $\beta_0 = 0$ and $\beta_1 = 1$; and a weaker hypothesis that $\beta_1 > 0$. Their most "striking result" is that the hypothesis $\beta_1 > 0$ is supported only for green savings and its population-adjusted equivalent. However, the estimates of β_1 remain "significantly below 1" in all four models. They also concluded that there was a "lack of significant impact for the adjustment for wealth dilution" (p.246).

The most recent test of GS as a predictor of future well-being is Greasley et al (2014), who use the same British data that is used in the present paper (albeit over a longer time period.)[4] They found that the choice of time horizon and discount rate had sizeable effects on the estimated parameters, not just the alternative measures of changes in capital. They also found that the inclusion of measures of technological change, which they proxied using the present value of Total Factor Productivity change, 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.

4. Data

The data sources used in this paper are outlined in Greasley et al (2013, 2014) and Blum et al (2013). The main difference between the data analysed in this paper is that the data for the respective countries are converted into 1990 international Geary-Khamis dollars following methodology outlined by Maddison (2001, table A1). Prices in each of our countries were

[4] Note that our British data goes back to 1760, but for the present paper we restrict our attention to the period from 1870 onwards, since that allows a comparison on a like-for-like basis between the three countries.

converted to 1990 levels and transformed to 1990 prices used the benchmark levels from Maddison (2001). This is a common transformation used in comparative economic analysis. For each country we have constructed measures of Genuine Savings comparable to Clemens and Hamilton (1999), using long-run data on net fixed capital formation, net overseas investment, natural resource extraction and public education expenditure. Our data presented here do not include CO2 emissions, for a treatment of the inclusion of CO2 in this framework see Kunnas et al (2014) and Blum et al (2013). The data used in the paper are shown in figure 1, and are presented in per capita terms. As will be recalled from section 2, a negative value for GS signals unsustainability.

Figure 1 here

Britain has a negative GS during the two world wars, but it is otherwise positive. For the United States, GS is negative during the Great Depression, and at the end of WW2, but otherwise positive. For Germany, there is a large crash in GS during and just after WW2, but then a sharp recovery. All countries show no signal of unsustainable development in the last 50 years.

In addition, we have augmented our GS measures by incorporating an exogenous value of technological progress as proxied by changes in Total Factor Productivity (TFP). We construct country specific trend TFP rates and calculate the net present value of the contribution of TFP growth to future GDP. This is added to our GS measure. Weitzman (1997) suggested that such a technological change premium could be as high as 40 per cent of Net National Product, and that omitting a technological progress measure would mis-state the degree of sustainability of an economy. We have estimated trend TFP growth and use this to simulate the present value of the change in GDP over the coming 20 year period in any accounting period to proxy the “value of time” or value of exogenous technological progress following Pezzey et al. (2006). We find that the present value of TFP averages 26%, 19%, and 34% percent of GDP in the US, Britain and Germany respectively over the period 1869-1990. GSTFP values (that is, Genuine Savings with this adjustment for technological progress) are illustrated in figure 2. They show a more positive signal of sustainability for all three countries: Britain and USA now have no periods where GS is negative.

Figure 2 here

Our measure of future well-being is derived from data on consumption per capita. From the underlying data in figure 3, the net present value of future changes in consumption was calculated using country specific discount rates. These rates in all cases were 3.5 per cent for the US, 2.5 per cent for Britain and 1.95 per cent for Germany; in each case these are average real interest rates. Three time horizons were constructed, 20, 30, and 50 years.[5] For example the 20 year horizon is the present value of changes in consumption per capita in 1988 to 2008, and so forth for the respective time horizons.

Figure 3 here

5. Econometric Approach

The long spans of the univariate macroeconomic time series data used in the estimation and testing of the various models have the potential to exhibit non-stationary properties. Thus, without appropriate methods, estimates may be inefficient or spurious and the usual significance tests may be invalid. Engle and Granger (1987) show that a linear combination of two or more series that are integrated of order 1 may be stationary. The linear combination,

[5] Note that we have adopted a slightly different convention to calculating the consumption variable here compared to Greasley et al (2014). In the present paper, we add up the discounted values of differences between pairs of years (t) and (t+1) over the requisite time interval, as per Ferreira et al, 2008. Greasley et al took the present value of the difference between the first year and the last year of each interval. This actually makes little difference to the results.

if it exists, defines a cointegrating relationship where the resulting vector characterises the long-run relationship between the variables. A cointegration estimation approach: (i) resolves the problem of non-stationary time series data and the inference issues of its neglect, (ii) has the interpretation that the cointegrating relationship (if it exists) can be regarded as a (potentially) unique long-run economic equilibrium relationship, (iii) has the properties that the estimates are 'super-consistent' i.e. they are consistent with much smaller sample sizes, (iv) 'washes-out' in the long-run random errors that may exist in one or both series and, (v) means inferences can be made on the levels of the series. If cointegration exists, the power of its long-run properties dominates short-run variations, which by definition are going to be stationary.

Cointegrating relationships, however, and their benefits and properties, do not exist with all combinations of non- stationary series – there is a need to test for their existence. There are a range of methods available to test for the existence of cointegration ranging from the simple and popular Engle-Granger (1987) 'two-step' approach which appraises the time series properties of the residuals in a levels OLS regression and where the null hypothesis is of no-cointegration; to the maximum likelihood-based tests of Johansen (1997) and the adjustments made by Phillips and Hansen's (1990) Fully Modified OLS (FMOLS). Panel cointegration variants include Kao (1999). Tests that use the residuals derived from e.g., the two step process of Engle-Granger have the property of a generated regressor (Oxley and McAleer, 1993; Greasley and Oxley, 2010). The critical values of the ADF test when used in the results' tables below adjust for this property. However, the ADF test is also known to biased in favour of non-rejection of the null hypothesis of non stationarity if structural change occurs within the estimation sample period. This issue was addressed in terms of univariate series by Perron (1989, 1997), Zivot and Andrews (1992) and Lumsdaine and Pappell (1997), by explicitly modelling the breaks during estimation necessitating revisions to standard ADF critical values.

When translated into a (potentially) cointegrating regression environment, the approaches of Engle and Granger (1987), Phillips and Ouliaris (1988) and Johansen (1997) are not the best to use if there are breaks in the cointegrating vector as the methods (once again) fail to reject the null hypothesis of no cointegration less often than they should. In an attempt to counteract this potential problem we consider the cointegration test associated with Hansen (1992) which explicitly involves testing the cointegrating relationship for parameter stability. In contrast to the residual based tests underpinning Engle-Granger, etc., Hansen's test does not rely on estimates from the original equation.

In addition to the single equation tests of H1 - H4 above, which are derived from OLS or FMOLS-based estimation, we also consider panel based estimation by combining the three country samples into a balanced panel. This allows us to consider tests of the various hypotheses with the combined data and any additional restrictions for example, fixed effect estimation and finally, the existence, or otherwise, of panel cointegration. Given the transition from single equation, to panel, we have utilised the test of Kao (1999), which explicitly specifies cross-section specific intercepts.

It should be stressed however, that a case of non-cointegration does not necessarily invalidate the results, but they are less robust. As will be seen in what is presented below, coefficient estimates in (statistically) non-cointegrated models, and the inferences made, are generally very similar to cases where cointegration has been established. At this point we also reiterate that in the results presented below are specifically and solely concerned with consideration of the results as tests of the size and signs of $\beta 0$ and $\beta 1$; these results are not models of the growth process.

6. Results and Discussion

In their landmark paper, Ferreira and Vincent did not find that GS had positive and significant effects on the future consumption of OECD countries, a result they attribute to their measure of GS excluding technical change. The longer spans of data deployed here for three countries yield results which reverse their findings (Table 1). In the British case, for GS, the estimates of β_1 in the upper panel of Table 1 are positive and, ostensibly, statistically significant over 20 and 30 year horizons. Perversely, over the 50 year horizon, the estimate of β_1 is lower and loses statistical significance. The statistical significance of the estimated parameters for GS needs to be treated with caution in the absence of cointegration where the ADF statistics do not reject the hypothesis of non cointegration at conventional levels of significance. The results also highlight that GS may be too narrow a measure of changes in capital, especially over longer horizons.

The longer time horizon results reinforce the importance of including technology in measures of wealth. The technology-augmented results for GSTFP presented in the lower panel of Table 1, provide more robust results, given they reject the null of non-cointegration, and yield estimates of β_1 over 30-50 years horizons that cluster around 0.78-1.18. However, the hypothesis $\beta_1 = 1$ is rejected, as is the stronger joint hypothesis $\beta_0 = 0$; $\beta_1 = 1$. These results conform to those of Greasley et al (2014, Table 5) where GSTFP20 incorporates estimates of the technology premium looking forward over 20 years. In contrast, the Greasley et al (2014) results for GSTFP30, which measures the technology premium over 30 years, do not reject the $\beta_1 = 1$ sustainability hypothesis for changes in future consumption over 50 years. Collectively, the British results provide support for using the broader genuine savings measure GSTFP as an indicator of weak sustainability over future consumption horizons up to 50 years. They highlight the importance of including the value of changes technology in the measure of genuine savings.

Turning to the US results presented as Table 2, where, over the 20 and 30 years consumption horizons, the estimates of β_1 suggest a near one to one relationship between GS and the present value of changes in future consumption. In neither case is hypothesis $\beta_1 = 1$ rejected, but the robustness of these results needs to be judged in the context of the non-cointegration finding. In contrast, over the 50 years horizon, a negative, but statistically insignificant estimate of β_1 is observed. The likely reason for the perverse US GS results over the 50 years horizon is worth spelling out. US GS per capita shows a long period of decline from a peak around 1907 to low points during the Great Depression and World War Two (Figure 1). The long GS per capita decline principally reflected low rates of produced investment, which were exacerbated by natural resource depletion. Indeed, it was not until the mid-1960s that US real GS per capita exceeded the peak of 1907. In contrast, over a 50 years horizon, the changes in the present value of future consumption show a steady upward trajectory (Figure 4). Over shorter horizons the vagaries of annual shifts in GS and the value of future changes in consumption are more closely aligned, but the symmetry sometimes disappears over the longer horizon. To reiterate, for the GS measure, the negative estimate of $\beta_1 = -0.06$ over the 50 years horizon arises from a correspondence between diminished investment and higher future changes in consumption which persisted in the USA for much of the twentieth century.

Figure 4 here

The reason why the upward movement in the future changes of consumption continued, despite the long period of GS per capita decline, is readily explained by technological progress. In Table 2, GS augmented with exogenous technology, GSTFP, yields estimates which are more favourable to the sustainability hypotheses, especially over the 50 years horizon. Both the weaker hypothesis $\beta_1 = 1$ and the strong joint form, $\beta_0 = 0$; $\beta_1 = 1$, are not rejected looking 50 years ahead. However, an important caveat is that the null of non-cointegration is not rejected for any variant of the results in Table 2.

To consider the apparent issue of non-cointegration further we investigate two variants of the approach used to produce the results presented as Table 2. Firstly, it is well known that ADF 'unit root' tests are fragile in the presence of breaks in levels, including those associated with wars or the Great Depression (Perron 1989, Greasley and Oxley 1996), and accordingly the results in Table 3 include a dummy variable to allow for a levels shift around the Great Depression. This dummy effectively captures the idiosyncratic vagaries in the series discussed above. In all the cases of the GSTFP results, the null of non-cointegration is now rejected. Over the 50 years horizon the estimate of β_1 increases to 1.13. The second approach considered estimates the model using FMOLS and applies the Hansen (1992) test for cointegration. The results, not presented here due to space considerations, confirm all the qualitative conclusions on cointegration (and hence robustness) of Table 3 above and re-establish the weak sustainability conclusion, over the 50 year horizon, for the GSTFP variant with the non-rejection of $\beta_0=0$; & $\beta_1=1$ and $\beta_1=1$.

The results for Germany[6] in Tables 4 and 5 investigate discontinuities in the time series, although in this case the effects are associated with World War Two. Without a wartime shift dummy variable, the results in Table 4 all reveal estimates of $\beta_1 > 0$ and in the cases of GSTFP over 30 and 50 years horizons the hypothesis $\beta_1 = 1$ is not rejected.[7] To an extent the German results support those for Britain and the USA, highlighting that, over longer horizons, the augmenting of GS with measures of the value of technological progress yield findings most supportive of using GS as an indicator of weak sustainability. Of course this judgement

[6] Please note that these German results do not coincide exactly with those in Blum et al (2013) due to some differences in estimation and a longer time-span used by Blum et al (2013) starting in 1850

[7] In this case, utilising FMOLS and Hansen (1992) does not resolve the issue, as it did with the US. This is likely due to the size of the discontinuity experienced by Germany vis a vis the US: contrasting the effects of World War 2 on Germany with those of the Great Depression on the USA.

must be tempered in light of the null of non-cointegration not being rejected for any result reported In Table 4. In contrast, the results in Table 5, which incorporate the war-related shift dummy variable, are likely to be more robust, as non-cointegration is rejected in the majority of cases.

The chief effect of including the wartime dummy variable is to increase the size of the β_1 estimates. For GS the average of the β_1 estimates for the three time horizons exceeds 2, pointing to a much faster growth of future consumption than expected. The theory postulates a one to one relationship between GS and the present value of future changes in consumption, but the results show the value of future consumption rose more quickly. By implication, natural resource depletion has not been a barrier to higher consumption in Germany. Resource-use was more than offset by investment in produced capital and education. Additionally, the GS results reinforce the view that a value of technology should be included in indicators of sustainable development. The broader GSTFP measure yields lower estimates of β_1 and over the thirty years horizon the hypothesis $\beta_1 = 1$ is not rejected. However, over the 50 years horizon the more robust (given the rejection of non cointegration in this case) estimate of β_1 is 1.88, which also indicates unexpectedly high future consumption. The puzzle of the German data does not relate to the existence of sustainability, but rather to that future consumption has grown more quickly than indicated by the measures of sustainability.

A range of factors may account for the idiosyncratic German results, which partly depend on how disinvestment due to war-related destruction and the subsequent capital dismantlement are incorporated in the analysis. Further, Germany experienced dramatic institutional change following World War Two, with possibly profound consequences for its intangible or social capital. Social capital may be an important part of investment, but it is omitted from conventional GS metrics, and may not be fully captured by GSTFP. Germany’s post-war institutional capital was influenced by the continuing presence of Allied forces and wider

European integration, for example via the European Coal and Steel Community. In principle, the measure of TFP embedded in GSTFP, should reflect social and institutional capital, but the horizon over which the value of intangible capital persists and the appropriate discount rates are uncertain.

Carr (1991) illustrates some of Germany's post-war institutional changes, including Marshall Aid and the Federal elections in 1949. The reconstruction of West Germany included democratization and significant amounts of financial assistance (calculated at $200 (2001 prices) per capita) which contrasts strongly with the Soviet occupation of the East where asset stripping was the norm. Dumke (1990) argues that institutional change and social capabilities were important factors in the German recovery. For De Long and Eichengreen (1991) the resurgent German post-war economy surpassed historical experience, with the Marshall Plan facilitating a pro-growth 'social contract'. Germany, in the post-war period, had multi-faceted institutional change, which helped to shape future incomes and consumption, whereas British and American institutions show greater continuity. In contrast to Germany and most West European economies, there are no trend breaks in British and US GDP per capita around World War Two (Greasley et al, 2013). Within our three country comparison, World War Two is likely to have been a more significant discontinuity for Germany, although its experience may have been less distinctive within a wider European context.

The possibility that GS and GSTFP understate the changes in the comprehensive wealth of Germany around the years of World War Two, by giving insufficient attention to social and institutional capital, provides one explanation of Germany's unexpectedly fast future consumption growth over the 50 year horizon. There are alternatives, for example Blum et al (2013) investigate how German territorial adjustments, including those in 1945 may have influenced longer-term consumption trends, but they play down the importance of boundary changes. An important issue for all tests of genuine savings as an indicator of future consumption is the choice of discount rates. The discount rates used here vary between countries, from 1.95%/year for Germany to 2.5%/year for Britain and 3.5%/year for the USA, reflecting the cross-country variations in long-term real interest rates. Over long periods, these variations in discount rates have substantial effects on the present value of future changes in consumption. Blum et al (2013) conduct sensitivity tests for Germany using a 3%/year discount rates (which corresponds to the long-run real GDP growth rate) and report an estimate of $\beta_1 = 1.01$ for a 50 years future consumption horizon, and indeed their results, ostensibly, do not reject the strong joint hypothesis $\beta_0 = 0$; $\beta_1 = 1$. However, their findings do not reject non-cointegration and the inclusion of war-related level shift dummy in the model led to an estimate of $\beta_1 = 1.18$ The conflicting results make it unclear if the finding of unpredictably fast German consumption growth arises from the choice of discount rate or from the understatement of its social and institutional capital.

Finally, we consider the key sustainability hypotheses within the context of panel estimation utilizing data for all three countries. In Table 6 the estimates of β_1 conform to the single country estimates, with that for the technology augmented measure GSTFP showing a higher, closer to unity, value over the 50 years horizon. A feature of the no fixed effects panel estimates is that for GSTFP over the 50 year horizon they do not reject the strong joint hypothesis $\beta_0 = 0$; $\beta_1 = 1$. The likely explanation is that the no fixed effects estimates are inefficient, most especially that the estimate of β_0 is broad to accommodate the wide variation in the single country estimates of the intercept parameter. Accordingly the joint null in the fixed effects estimates is less likely to be rejected, which highlights the possible value of including fixed effects in the panel regression. This is confirmed statistically by the results presented as column 7 of Table 7 below, which include country fixed effects.

Column 7 reports tests that reject the redundancy of the fixed effects in 5 of the 6 equations, including for GSTFP over the 50 years horizon. The fixed effects estimates of β_1 reiterate that GS provides a good indication of future consumption over the shorter 20 and 30 years horizons, where the strong joint null hypothesis is not rejected. The fixed effects estimates of β_1 for GSTFP have similar values to the no fixed effects estimates, and show closer to unity values as the future consumption horizon is extended from 20 to 50 years, although the weaker hypothesis $\beta_1 = 1$ is rejected for all horizons. Finally the robustness of the fixed effects panel estimates is assessed using the Kao test for a cointegrated panel. The results, shown as Table 8, reject the null of no cointegration.

Conclusions to be drawn from the panel estimates appear clear enough; there are country specific characteristics that distinguish Britain, the USA and Germany. As we have seen, for Germany the distinguishing event is likely to have been World War Two, and for the USA it was the Great Depression. The panel estimates re-affirm the main messages of the individual country results. These are that for OECD countries GS can provide a good indicator of future consumption changes over horizons up to 30 years, but augmenting GS with a value of technological progress, labelled here GSTFP, greatly improves the utility of the indicator over longer horizons.

7. Concluding Remarks

The empirical support for using genuine savings as an indicator of sustainability has gained only modest support in the case of OECD countries. Here we extend previous work using long-run British data to include comparisons with the experiences of Germany and the USA, over a common, post-1870 timeframe. The findings widen the support for using genuine savings as a sustainability indicator, but they also show some distinctive country-specific experiences. Conventional measures of genuine saving, labelled here as GS, simply adjust produced investment for resource depletion and human capital formation. The GS results for the three countries show remarkable consistency. Over 20 and 30 years horizons for changes in consumption, the initial, individual country, estimates of β_1 for GS cluster in range 0.9-1.5, to broadly support the theoretical consistency of the indicator. Indeed, in four of the six cases the weaker sustainability hypothesis $\beta_1 = 1$ is not rejected. There are two important caveats. Firstly, over 20 and 30 years horizons, in no case is the null of non-cointegration rejected, which diminishes the robustness of the results. Secondly, over the 50 years horizons the initial estimates of β_1 for GS are lower and fall in the range -0.06-0.39, to cast some doubt on the utility of the indicator over longer horizons.

Equally clear from the findings for all countries is the importance of including a value for technological progress in genuine savings, labelled here GSTFP, especially over longer horizons. In the case of the 50 years horizons the initial estimates of β_1 for GSTFP cluster in the range 1.07-1.39, and in two cases the hypothesis $\beta_1 = 1$ is not rejected. However, the hypothesis of non-cointegration is only rejected in the British case, highlighting that there are country-specific features of the results. For Britain, we have identified a stable long-run relationship between GSTFP and the present value of future changes in consumption, which corresponds to the earlier results of Greasley et al (2014). This finding does not carry over straightforwardly to the cases of Germany and the USA. The characteristics of the USA and Germany that create the conflicting results are connected to discontinuities in their consumption or investment experiences. For the USA it was the Great Depression which disrupted the stability of economic relationships, for Germany it was World War Two.

The robustness of the results for Germany and the USA was further investigated by introducing dummy variables for the years around the likely discontinuities into the analysis and alternatives to tests based upon the ADF statistic. In the key case of GSTFP over the 50 years horizons, the null of non-cointegration was then rejected for both countries, pointing to a long-run stable consumption-investment relationships, albeit ones broken by temporary shifts in the levels. For the USA the new estimate of β_1 for GSTFP is 1.13, which falls within the cluster of the initial estimates, for Germany the new estimate is 1.88. The German result incorporating the wartime dummy variables creates an interesting puzzle, since future changes in consumption are noticeably higher than predicted by a one to one relation with GSTFP. One possibility is that the measure GSTFP understates the gains in Germany's social capital post- World Two as the Nazi regime was replaced by new institutions.

More generally, the long horizon results for the USA and Germany highlight that major discontinuities are likely over long spans of history, and that these may have implications for using genuine saving measures as indicators of sustainability over very long time frames. The panel-based estimates reinforce the likely existence of country-specific effects, but they also re-affirm the merit of genuine savings as an indicator of sustainability. Over shorter 20 or 30 years horizons our findings support using conventional GS measure as an indicator of weak sustainability, but over longer horizons they highlight the need for augmenting the conventional measure with a value of technological progress.

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Figure 1: GS per capita, Britain, US and Germany, 1860-2000

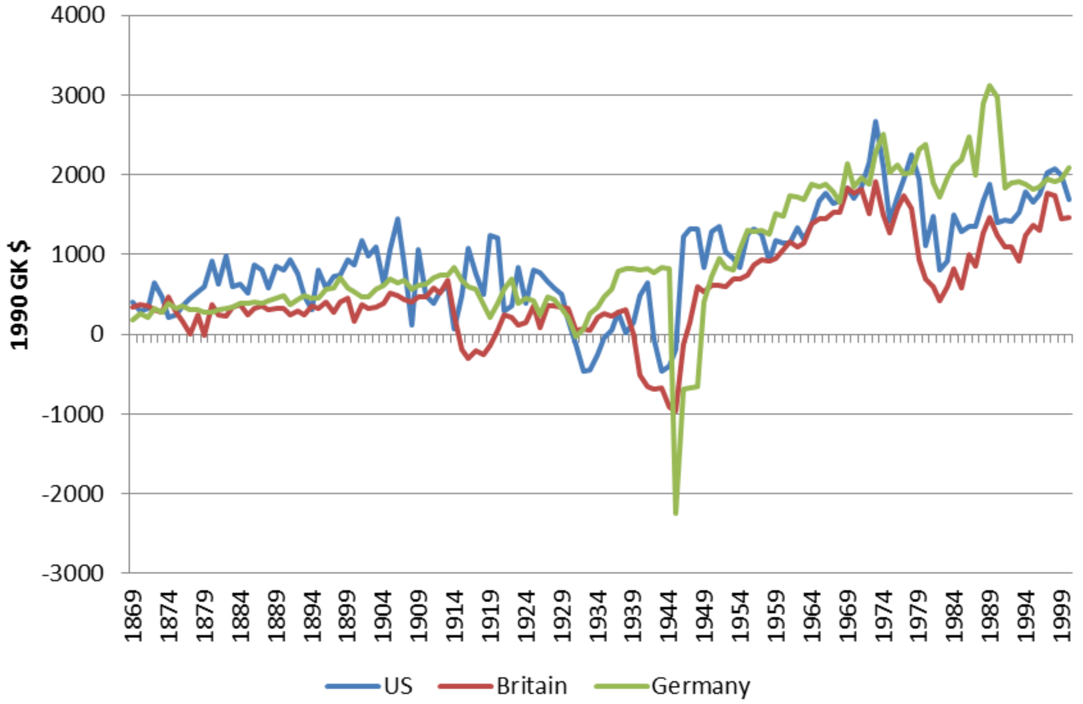
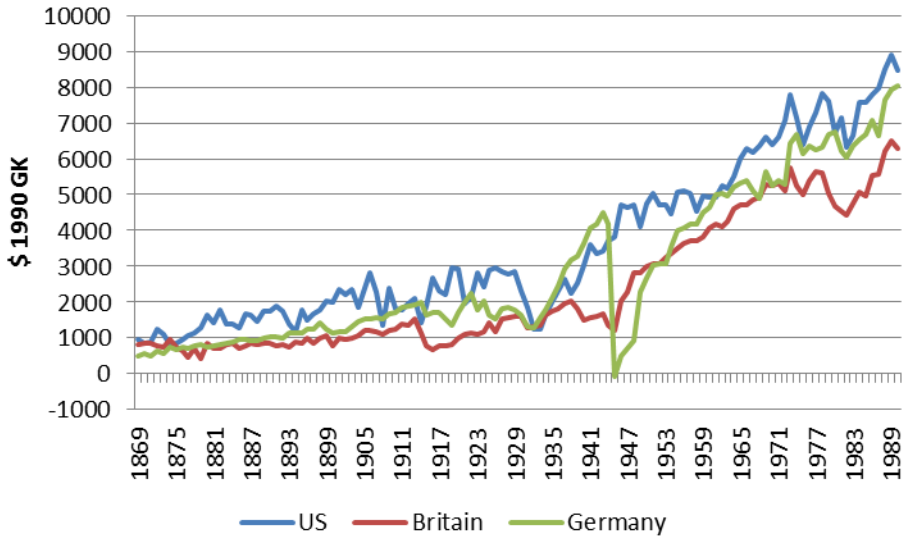


Figure 2: GSTFP per capita, US, Britain and Germany



Note: Labour shares in TFP calculations for US, Britain and Germany are 0.6, 0.65, 0.63; discount rates for US, Britain and Germany are: 3.5%, 2.5%, and 1.95%.

Figure 3: Consumption per capita, US, Britain and Germany 1870-2008

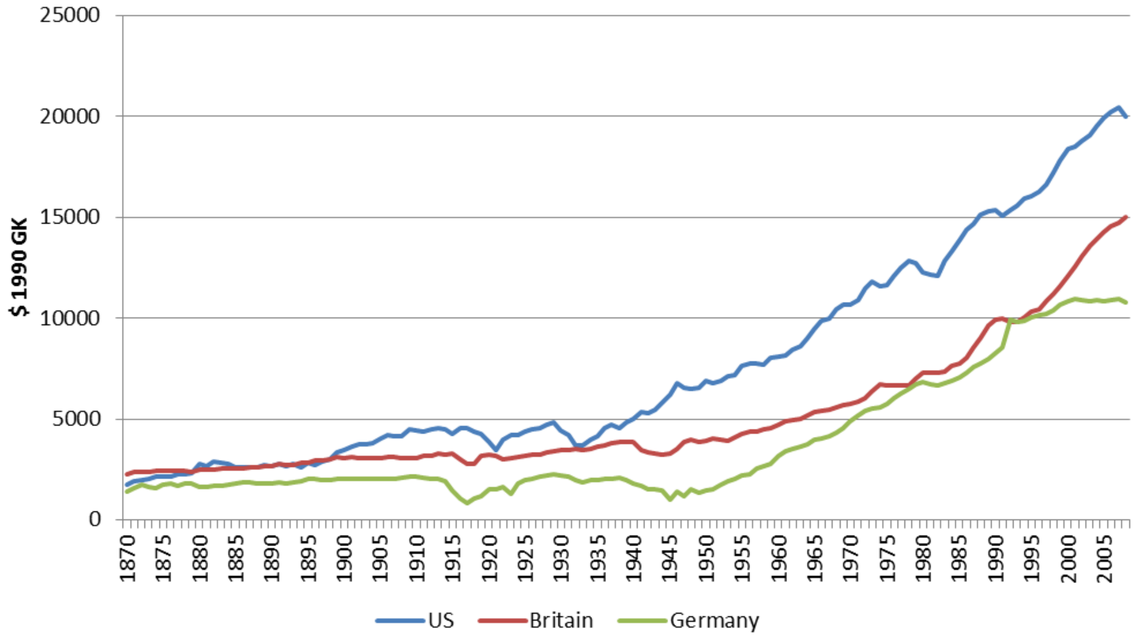


Figure 4: Present value of future changes in US consumption per capita ($ 1990 GK)

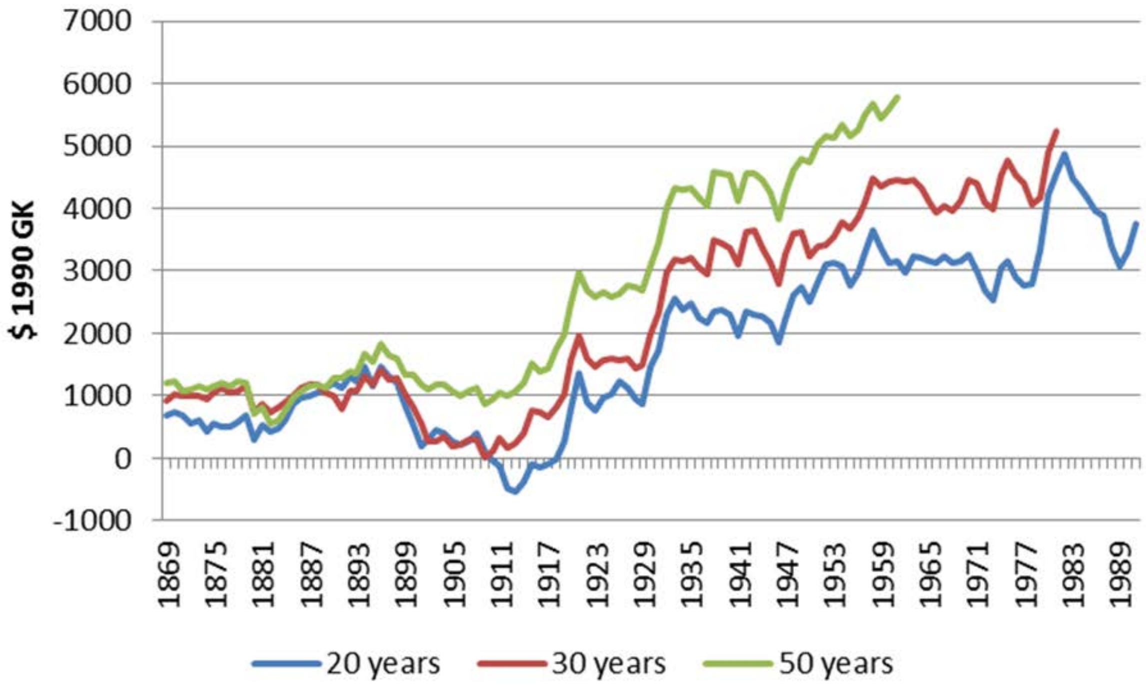


Table 1
Estimates of β_0 and β_1 for Great Britain (2.5% per annum discount rate)

1.	2.	3.	4.	5.	6.	7.	8.
Dependent	Independent	β_0	β_1	β_0=0; & β_1=1	β_1=1	Sample	ADF
Cons20	GS	496.9* (0.00)	1.22* (0.00)	47.1* (0.00)	1.96 (0.16)	1870-1990	-2.64
Cons30		538.6* (0.00)	1.55* (0.00)	95.2* (0.00)	13.1* (0.00)	1870-1980	-1.80
Cons50		1159.9* (0.00)	0.389 (0.22)	74.9* (0.00)	3.51** (0.06)	1870-1960	-0.15
Cons20	GSTFP	-333.4* (0.00)	0.616* (0.00)	896.9* (0.00)	210.2* (0.00)	1870-1990	-3.93*
Cons30		-342.8* (0.00)	0.777* (0.00)	609.3* (0.00)	98.5* (0.00)	1870-1980	-3.63*
Cons50		-436.2* (0.00)	1.17* (0.00)	24.8* (0.00)	10.0* (0.00)	1870-1960	-3.54*

Notes: Dependent = the present values of future changes in real wages measured over 20-100 year horizons. For column 3, H_0: β_0=0; H_1: $\beta_0 \neq 0$ and for column 4 H_0: β_1=0; H_1: $\beta_1 \neq 0$ are tested using a t test where * denotes significantly different from zero at the 5% level and figures in parentheses are p values. For column 5 H_0: β_0=0 and β_1=1; H_1: $\beta_0 \neq 0$ and $\beta_1 \neq 1$ are tested jointly using a Wald test where * denotes significantly different from zero and unity respectively at the 5% level. For column 6, H_0: β_1=1; H_1: $\beta_1 \neq 1$ is tested using a t test where * denotes significantly different from unity at the 5% level. For column 8 ADF represents the Augmented Dickey Fuller statistic (corrected for the problem of Generated Regressors) where the degree of augmentation is determined by the Hannan-Quinn Information Criteria. A * represents rejects the null of non-stationarity at the 5% level and ** at the 10% level.

Table 2
Estimates of β_0 and β_1 for USA (3.5% per annum discount rate)

1. Dependent	2. Independent	3. β_0	4. β_1	5. β_0=0; & β_1=1	6. β_1=1	7. Sample	8. ADF
Cons20	GS	999.1* (0.00)	0.93* (0.00)	73.7* (0.00)	0.15 (0.70)	1870-1990	-2.27
Cons30		1412.3* (0.00)	1.01* (0.00)	114.2* (0.00)	0.003 (0.95)	1870-1980	-1.68
Cons50		2599.1 (0.00)	-0.06 (0.87)	130.9* (0.00)	7.75* (0.00)	1870-1960	0.36
Cons20	GSTFP	73.4 (0.57)	0.48* (0.00)	930.5* (0.00)	278.7* (0.00)	1870-1990	-3.15
Cons30		152.2 (0.33)	0.65* (0.00)	227.0* (0.00)	73.3* (0.00)	1870-1980	-2.89
Cons50		-107.9 (0.65)	1.07* (0.00)	1.04 (0.59)	0.67 (0.41)	1870-1960	-2.75

See Table 1 footnotes for explanations of null/alternative hypotheses and levels of significance.

Table 3
Estimates of β_0 and β_1 for USA including a dummy variable
(3.5% per annum discount rate)

1. Dependent	2. Independent	3. β_0	4. β_1	5. β_0=0; & β_1=1	6. β_1=1	7. Sample	8. ADF
Cons20	GS	536.9* (0.01)	1.29* (0.00)	60.8* (0.00)	2.42 (0.12)	1870- 1990	-3.13
Cons30		792.7* (0.00)	1.50* (0.00)	103.8* (0.00)	5.24* (0.02)	1870- 1980	-2.81
Cons50		1772.5* (0.00)	0.81* (0.00)	94.3* (0.00)	0.21 (0.65)	1870- 1960	-1.05
Cons20	GSTFP	-160.4 (0.19)	0.52* (0.00)	1250.7* (0.00)	305.1* (0.00)	1870- 1990	-3.45**
Cons30		-169.2 (0.19)	0.70* (0.00)	391.5* (0.00)	82.6* (0.00)	1870- 1980	-3.98*
Cons50		-548.6* (0.00)	1.13* (0.00)	13.9* (0.00)	6.59* (0.01)	1870- 1960	-5.3*

See Table 1 footnotes for explanations of null/alternative hypotheses and levels of significance. Dummy for Depression takes value 1 for 1931-1940, zero otherwise.

Table 4
Estimates of β_0 and β_1 for Germany
(1.95% per annum discount rate)

1.	2.	3.	4.	5.	6.	7.	8.
Dependent	Independent	β_0	β_1	β_0=0; & β_1=1	β_1=1	Sample	ADF
Cons20	GS	101.5 (0.49)	1.22* (0.00)	12.09* (0.00)	3.22** (0.07)	1870-1990	-2.72
Cons30		374.1** (0.08)	1.48* (0.00)	32.5* (0.00)	5.73* (0.02)	1870-1980	-2.20
Cons50		1596.1* (0.00)	0.34 (0.49)	34.7* (0.00)	18.4 (0.00)	1870-1960	-0.54
Cons20	GSTFP	-298.4* (0.04)	0.63* (0.00)	236.9* (0.00)	57.6* (0.00)	1870-1990	-2.00
Cons30		-347.9** (0.09)	0.93* (0.00)	18.00* (0.00)	0.78 (0.38)	1870-1980	-2.00
Cons50		-210.4 (0.60)	1.39* (0.00)	5.88** (0.06)	2.53 (0.11)	1870-1960	-1.87

See Table 1 footnotes for explanations of null/alternative hypotheses and levels of significance.

Table 5
Estimates of β_0 and β_1 for Germany including a dummy variable
(1.95% per annum discount rate)

1.	2.	3.	4.	5.	6.	7.	8.
Dependent	Independent	β_0	β_1	β_0=0; & β_1=1	β_1=1	Sample	ADF
Cons20	GS	-372.3* (0.00)	1.58* (0.00)	35.6* (0.00)	30.3* (0.00)	1870-1990	-5.16*
Cons30		-385.8* (0.03)	2.17* (0.00)	76.4* (0.00)	48.4* (0.00)	1870-1980	-5.26*
Cons50		210.2 (0.54)	2.42* (0.00)	36.1* (0.00)	7.78* (0.00)	1870-1960	-3.73**
Cons20	GSTFP	-529.5* (0.00)	0.69* (0.00)	329.3* (0.00)	51.5* (0.00)	1870-1990	-3.01
Cons30		-751.1* (0.00)	1.04* (0.00)	44.8* (0.00)	0.45 (0.50)	1870-1980	-3.37
Cons50		-1190.7* (0.00)	1.88* (0.00)	20.5* (0.00)	20.12* (0.00)	1870-1960	-4.20*

See Table 1 footnotes for explanations of null/alternative hypotheses and levels of significance. War 1944-48=1 zero otherwise

Table 6: Estimates of β_0 and β_1
Panel OLS Results- No fixed effects

1.	2.	3.	4.	5.	6.	7.
Dependent	Independent	β_0	β_1	β_0=0; & β_1=1	β_1=1	Sample
Cons20	GS	515.7* (0.00)	1.12* (0.00)	175.6* (0.00)	9.23* (0.00)	1870-1990
Cons30		703.8* (0.00)	1.38* (0.00)	493.2* (0.00)	12.8* (0.00)	1870-1980
Cons50		1619.4* (0.00)	0.46* (0.00)	31.6* (0.00)	13.6* (0.00)	1870-1960
Cons20	GSTFP	-186.2** (0.06)	0.57* (0.00)	5453.3* (0.00)	126.3* (0.00)	1870-1990
Cons30		-150.4 (0.24)	0.75* (0.00)	115.4* (0.00)	20.4* (0.00)	1870-1980
Cons50		-139.4* (0.41)	1.12* (0.00)	3.55 (0.17)	3.42** (0.06)	1870-1960

Table 7: Estimates of β_0 and β_1
Panel OLS Results - Country fixed effects

1. Dependent	2. Independent	3. β_0	4. β_1	5. $\beta_0=0$; & $\beta_1=1$	6. $\beta_1=1$	7. Fixed effect redundancy[1]	8. Sample
Cons20	GS	509.1* (0.00)	1.13* (0.00)	3288.0 (0.00)	2.58 (0.11)	19.02* (0.00)	1870-1990
Cons30		735.6* (0.00)	1.33* (0.00)	4677.0 (0.00)	5.40* (0.02)	13.70* (0.00)	1870-1980
Cons50		1784.0* (0.00)	0.09 (0.56)	1788.0* (0.00)	30.6* (0.00)	21.49* (0.00)	1870-1960
Cons20	GSTFP	-192.8** (0.09)	0.57* (0.00)	448.9* (0.00)	107.9* (0.00)	0.73 (0.70)	1870-1990
Cons30		-158.2 (0.32)	0.75* (0.00)	226.7* (0.00)	14.3* (0.00)	5.86** (0.06)	1870-1980
Cons50		-211.0 (0.13)	1.16* (0.00)	1130.0* (0.00)	4.11* (0.04)	9.82* (0.00)	1870-1960

[1]The null hypothesis is redundancy of the fixed effects.

Table 8
Kao Residual Panel Cointegration Test

		ADF
Cons50	GS	2.54* (0.00)
Cons50	GSTFP	-1.44** (0.07)

Null hypothesis is no cointegration.