Measuring Sustainable Development: 1750-2000.

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- **Introduction**
- Data
- Results
- Discussion and conclusions

Defining “sustainable development”

(in economics!)

- a pattern over time where “well-being” does not fall ➔ outcome measures, typically non-declining utility (well-being) per capita

- or, a situation where the potential to generate well-being is maintained ➔ capabilities measures, typically non declining total capital **K** :

$$\mathbf{K = Kp + Kn} + (Kh + Ks..)$$

where Kp is produced capital, Kn is natural capital, Kh is human capital and Ks is social capital.

Natural capital?

- All “gifts of nature”
- Renewable and non-renewable resources

- Ecosystems as natural assets, the value of which depend on the flow of ecosystem services they provide over time

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(in economics!)

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- or, a situation where the potential to generate well-being is maintained ➔ capabilities measures, typically non declining total capital **K**, where:

  K = Kp + Kn + (Kh + Ks..)

  where Kp is produced Kn is natural, Kh is human and Ks is social capital

- Inter-generational equity is the key (fairness over time).

- Both of these economic approaches typically involve a working assumption known as "*weak sustainability*", which implies that different elements of K are (perfect) substitutes for each other in terms of maintaining long-term well-being (flow of consumption, the functioning of the system)

- Alternative viewpoint is that of *strong sustainability*: some/all elements of Kn are essential to long term well-being and /or to health/performance of the combined system.

- Criticism of weak sustainability: Kp and Kn are complements rather than substitutes over some range

- Weak sustainability is all about maintaining capital relative to the population level, given a level of technology.

“Sustainable development demands that future generations have no less of the means to meet their needs than we do ourselves; it demands nothing more.”

(Dasgupta, 2006)

Rules for sustainability?

- Hartwick rule: re-invest all rents from natural resource extraction in capital. Allows for constant consumption over time under certain restrictive assumptions.
- World Bank (2006): *“welfare can be sustained indefinitely if gross saving just equals the sum of depreciation of produced assets, depletion of natural resources and pollution damages”*.

rules are different in a strong sustainability world-view

- Maintain natural capital as non-declining in *physical* terms (?)
- Maintain value of ecosystem service flows?
- Maintain critical processes and species?
- Daly's "operational principles“ and the El-Sarafy principle.

Economic indicators of sustainability

- Outcomes- or Ends-based ➔

  green net national product

- Capabilities or Means based ➔

  genuine savings.

  This is what I focus on today.

genuine savings

- Originated with Pearce and Atkinson, Ecol Econ, 1993 and Kirk Hamilton's PhD.
- Also called Comprehensive Investment (Arrow/Dasgupta/Maler), Adjusted Net Savings (World Bank)
- INSIGHT: if wealth is the basis of future welfare, the current changes in wealth must have consequences for future welfare
- World Bank: "Persistently negative genuine savings implies a country is on an unsustainable path, and welfare must fall in the future."

Calculation of GS simply requires us to sum up year-on-year changes in each capital stock, and aggregate these with appropriate shadow prices:

$$GS = \sum_{i=1}^{N} p_i \dot{K}_i$$

where p_i are shadow price for K_i capital stocks [i=1..N]

(p is negative for pollution stocks)

GS as a sustainability test: theory

- Hamilton and Clemens, 1999: if GS is <0, then future utility will be lower than current period utility (ie unsustainable development)
- Pezzey, 2004: a one sided test only, can show unsustainability, but only at correct prices.
- Hamilton and Withagen, 2007: if GS>0 and rising at less than real interest rate, then consumption will rise over time.
- Pezzey and Burke (2013): GS measure only shows (un-) sustainability under a very restrictive set of conditions which are very unlikely to hold in reality.

Our contribution

- new data set, back to 1760 for UK, for three annual changes in 3 forms of capital (produced, natural, human).
- well-being measures: real wages and consumption.
- Time-series tests: does a positive value of GS at time *t* predict increased well-being at times *t*+20, *t*+50 and *t*+100?
- We then extend the testing to two other countries: the USA and Germany

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Data

- *Net Investment* = Net fixed (produced) capital formation, inventories and foreign investment
- *Green Investment* = Net investment + Δforestry - $\sum$depletion of non-renewable natural resources
- *GS* = Green Investment + education expenditure
- *Green investment augmented by technological progress* = Green Investment + the present value of TFP estimated GDP growth over 20 years using TFP growth rates.
- *GS augmented by technological progress* = GS + the present value of TFP estimated GDP growth over 20 years using TFP growth rates.

Net investment

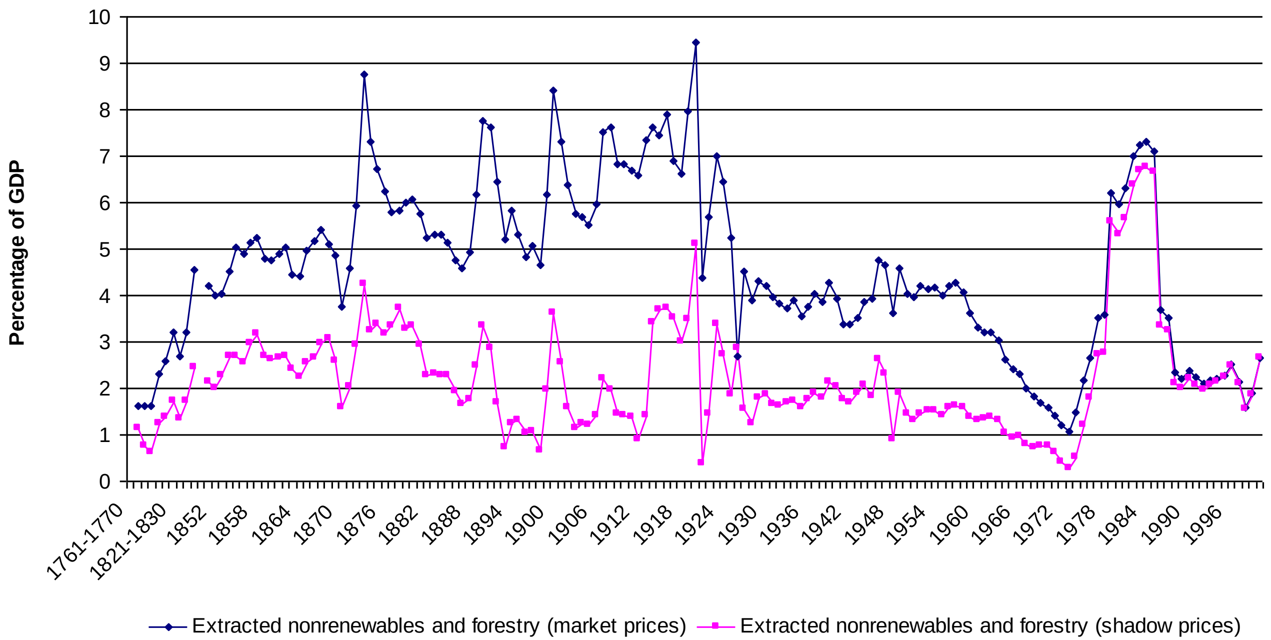
Net Fixed Capital formation, Inventories and Net Overseas investment data for Britain (1760-1860) and UK (1860-1920) were obtained from Feinstein & Pollard, for 1921-1965 from Feinstein and for 1965-2000 from *UK National Income* publications.

Green Investment

Adjustments for:

- Change in volume and value of forestry stock.
- Extraction of coal, iron ore, lead, copper, tin and zinc
- Much data exists for UK coal, rather less for the other resources
- All changes in these resource stocks would ideally be valued at correct shadow prices
- We use rental values (price – average cost)

Figure 2 Extraction of non-renewables (including coal) and forestry as a percentage of GDP, 1761-2000

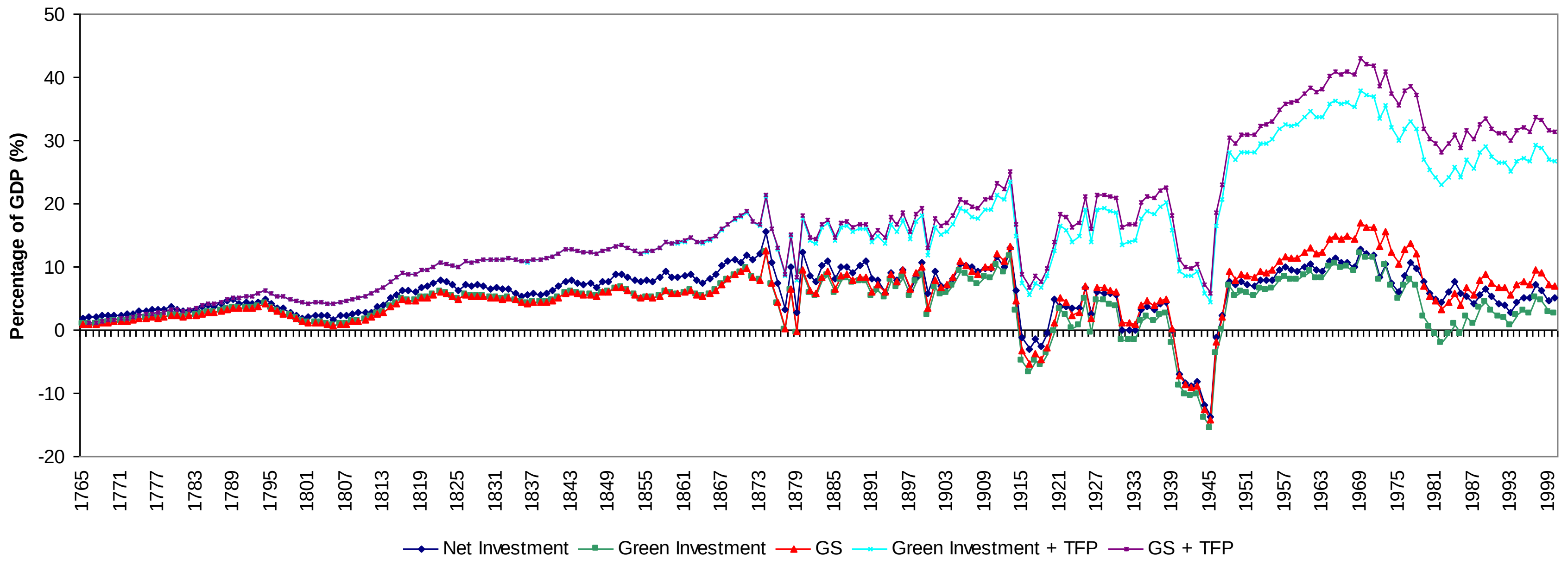


the "natural capital adjustment" is never more than 7% -9% of GDP. However, we note that our measure of natural capital excludes many of the ecosystem service flows which one would like to capture.

Changes in human capital

- We include estimates of public spending on education as a proxy for changes in Kh, as per World Bank etc.
- Data on public expenditure on education were derived from Carpentier for the period 1833-1997, and UNESCO measures of educational expenditure for the remaining years.
- Obviously this only measures aspects of the year-on-year change in Kh: other kinds of investment are occurring (apprenticeships, private education); plus not all spending will be equally productive
- We have computed an alternative time series for Kh based on discounted lifetime earnings adjusted for life expectancy changes, but this seems rather erratic when expressed as year-on-year changes.

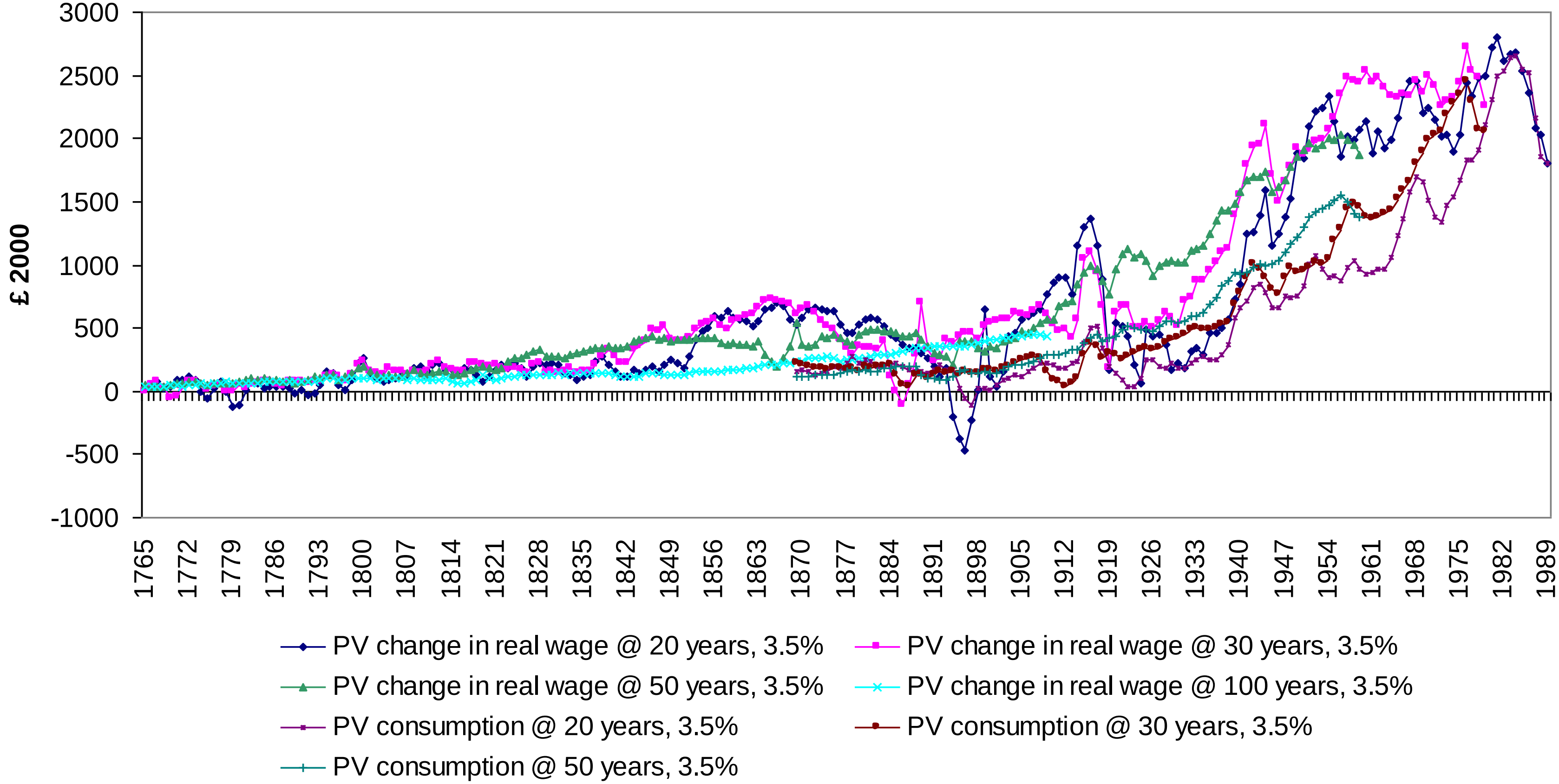
Net Investment, Green Investment, Genuine savings, 1766-2000



Measuring well-being over time

- Following Ferreira, Hamilton and Vincent (2008), we've calculated the present value of changes in consumption over time as a well being measure against which to test the GS indicator.
- Use real wages (1766-2010) and real consumption per capita (1870-2010) as alternative well-being measures
- 3 time horizons for real wages (20, 50, 100)
- 3 time horizons for consumption (20, 50, 100)

Present value of future Δ real wages and future Δ consumption, 1766-2010



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Hypothesis testing

- Two measures of well being: real wages (1750-2011) and consumption per capita (1870-2011)
- 5 measures of real investment per capita
- Theoretical model – infinite time
- We use different time horizons (20, 50, 100)
- $\Delta PV (C) = \beta_0 + \beta_1 GS + \varepsilon$
- *Hypotheses*
  1. $\beta_0 = 0; \beta_1 = 1$
  2. $\beta_1 = 1$
  3. $\beta_1 > 0$.

Table 2: Estimates of β_0 and β_1 for three Investment series and future real wages (2.5% per annum discount rate)

1.	2.	3.	4.	5.	6.	7.
Dependent	Independent	β_0	β_1	$\beta_0=0$; & $\beta_1=1$	$\beta_1=1$	ADF
Real Wage 20 years	NETPINV	280.3* (63.9)	2.32* (0.174)	208.4* (0.00)	57.2* (0.00)	-3.59*
Real Wage 50 years		827.1* (81.2)	0.37 (0.33)	141.1* (0.00)	3.51** (0.06)	0.48
Real Wage 100 years		68.2* (24.4)	2.39* (0.13)	608.8* (0.00)	123.1* (0.00)	-5.10*
Real Wage 20 years	GREENINV	579.4* (68.5)	1.62* (0.23)	141.4* (0.00)	7.49* (0.01)	-2.84
Real Wage 50 years		906.9* (70.9)	-0.20 (0.33)	171.4* (0.00)	13.0* (0.00)	1.08
Real Wage 100 years		108.7* (23.7)	2.89* (0.16)	732.2* (0.00)	140.7* (0.00)	-6.21*
Real Wage 20 years	GS	377.9* (57.0)	1.85* (0.13)	198.3* (0.00)	42.4* (0.00)	-3.56*
Real Wage 50 years		776.7* (73.7)	0.81* (0.31)	151.1* (0.00)	0.37 (0.54)	-0.08
Real Wage 100 years		108.9* (19.9)	2.71* (0.12)	967.2* (0.00)	199.0* (0.00)	-7.13*

Table 4: Estimated parameter values for alternative measures of investment when future well-being is measured by the PV of consumption per capita over 20-100 years horizons, 2.5%/year 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
Cons 20	NETPINV	322.9*	1.46*	56.2*	5.3*	1870-1989	-2.59
Cons 50		871.8*	-0.22	81.5*	16.3*	1870-1979	0.01
Cons 100		381.6*	0.40	52.5*	2.19	1870-1909	-0.50
Cons 20	GREENINV	684.6*	0.65*	61.7*	2.33	1870-1989	-0.73
Cons 50		862.1*	-0.28	104.0*	20.1*	1870-1979	0.11
Cons 100		348.7*	0.68	95.3*	0.75	1870-1909	-1.25
Cons 20	GS	383.7*	1.14*	44.7*	0.91	1870-1989	-3.17**
Cons 50		787.6*	0.20	76.2*	8.46*	1870-1979	-0.02
Cons 100		241.3*	1.04*	91.8*	0.02	1870-1909	-2.33

See Table 2 footnotes for explanations of null/alternative hypotheses and levels of significance. Cons denotes real consumption per capita over 20, 50 and 100 years horizons.

Comment: future consumption

- The estimates of β_1 over the 100 years consumption horizon and over the 20 year time horizon are both close to one, for GS.
- Implies that controlling for changes in education spending are important
- However, the statistical significance of estimated parameters for GS needs to be treated with caution in the absence of cointegration.

Technological progress

- 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.
- Longer time horizons are likely to reinforce the importance of including technology in measures of wealth; whilst a series of theoretical papers have shown how omitting technological progress from the calculation of GS can be misleading
- Moreover, the British economy experienced an Industrial Revolution during our sample period, transforming the technology with which capital of all forms could be used to produce consumption goods

Adjusting "GS" for technical progress

- Two investment measures are augmented with changes in Total Factor Productivity to measure the value of exogenous technology.
- One measure, GSTFP augments the GS measure using the Pezzey *et al* methodology. This computes the PV of technological progress impacts on GNP (part of what Arrow et al (2012, EDE) call "the value of time", time as a capital stock – although see comments by Solow in same issue of EDE).

Table 5: Estimated parameter values for alternative measures of investment when future well-being is measured by the PV of consumption per capita over 20-100 years horizons, 2.5%/year 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
Cons 20	GREENTFP20	-227.4*	0.79*	192.3*	26.9*	1870-1989	-4.25*
Cons 50		-253.0*	1.29*	14.7*	14.6*	1870-1979	-2.53
Cons 100		-128.3	1.13*	6.46*	0.47	1870-1909	-3.49*
Cons 20	GSTFP20	-220.0*	0.69*	434.7*	96.8*	1870-1989	-4.33*
Cons 50		-248.3*	1.18*	13.2*	7.83*	1870-1979	-2.51
Cons 100		-148.3	1.12*	17.0*	0.56	1870-1909	-3.93*
Cons 20	GREENTFP30	-294.1*	0.68*	596.5*	100.2*	1870-1989	-4.23*
Cons 50		-383.5*	1.14*	80.3*	9.09*	1870-1979	-2.85
Cons 100		-190.6*	1.01*	68.7*	0.25	1870-1909	-4.19*
Cons 20	GSTFP30	-260.9*	0.60*	1041.4*	234.3*	1870-1989	-4.28*
Cons 50		-362.2*	1.05*	124.2*	1.50	1870-1979	-2.75
Cons 100		-177.2*	1.00*	114.5	0.00	1870-1909	-4.38*

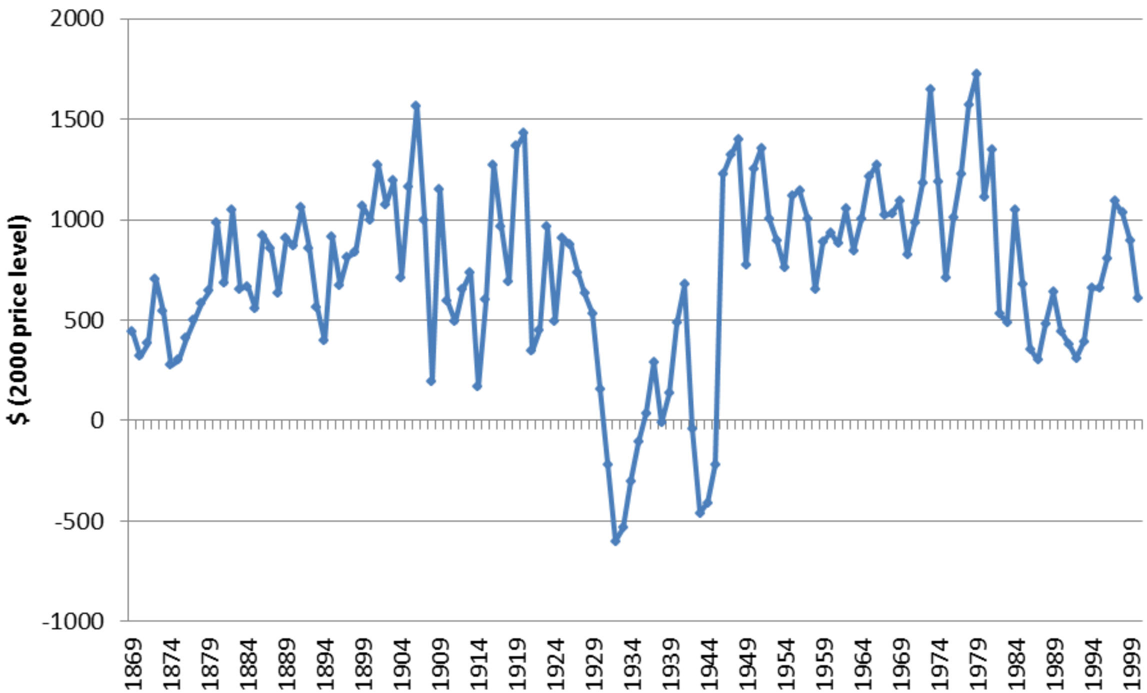
See Table 2 footnotes for explanations of null/alternative hypotheses and levels of significance. Cons denotes real consumption per capita over 20, 50 and 100 years horizons.

- So including a measure of technological progress in our measure of net investment improves the “fit” with theory
- Cannot reject $\beta 1 = 1$ in many cases
- Evidence that GS and changes in future well-being are cointegrated especially for t=50 and t=100
- A long-run equilibrium relationship exists.

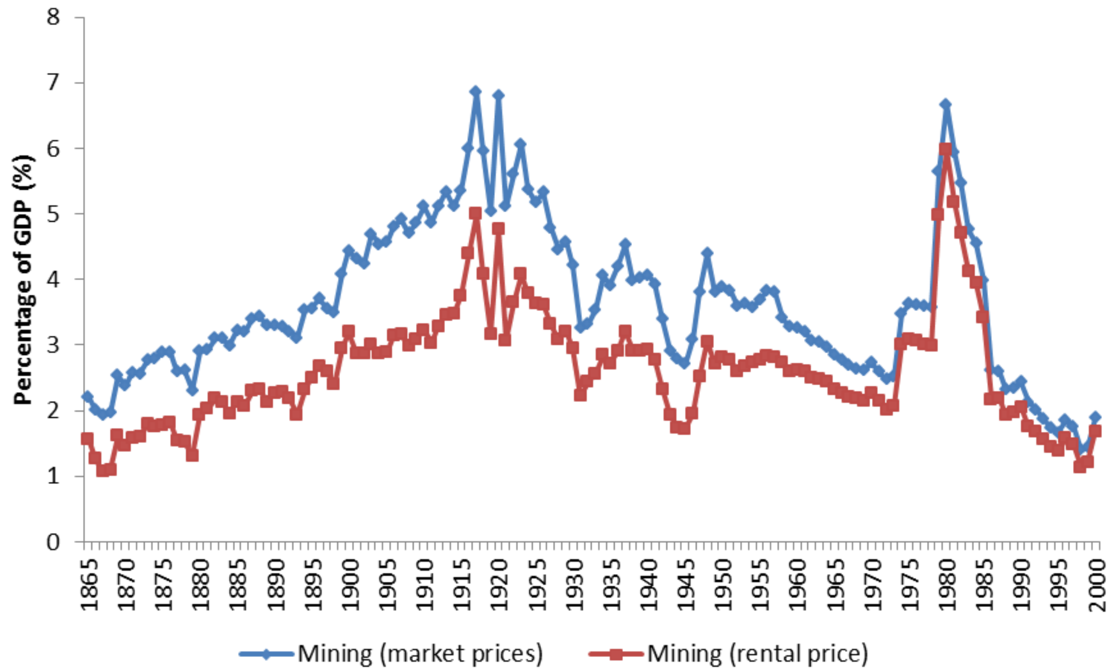
USA results

- Data available for consumption and the various constituents of GS from c.1860

Figure 2: Produced net investment per capita ($ 2000)



Depletion of minerals.



Public investment in education

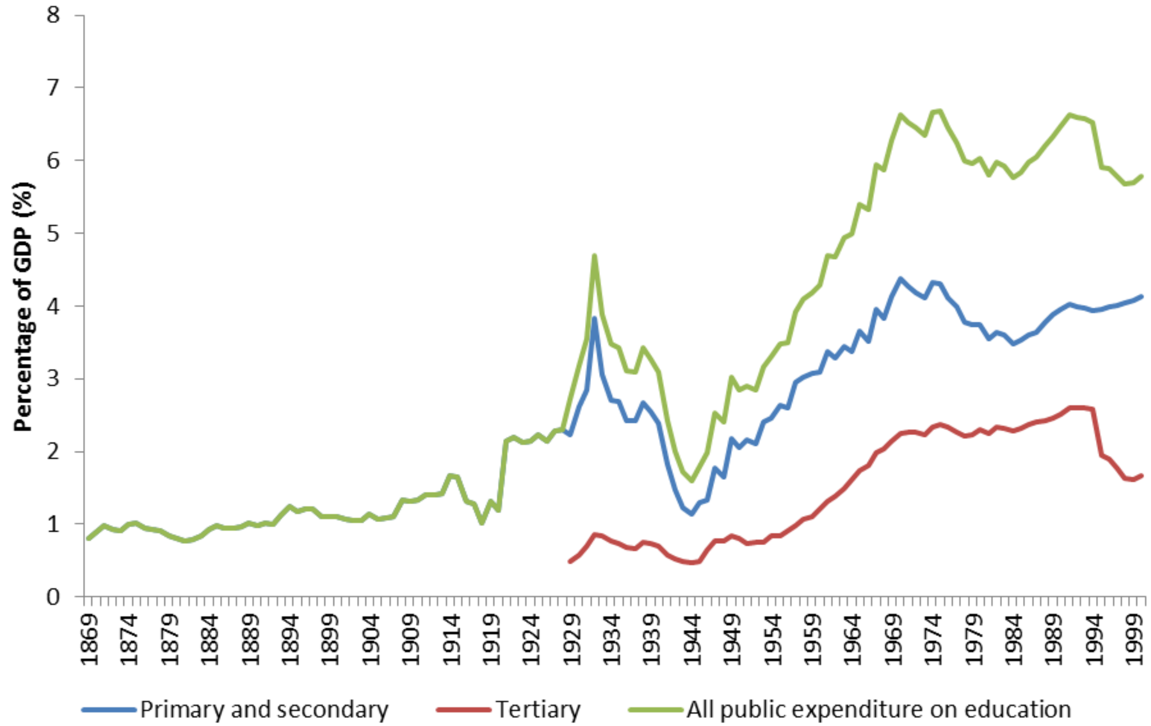
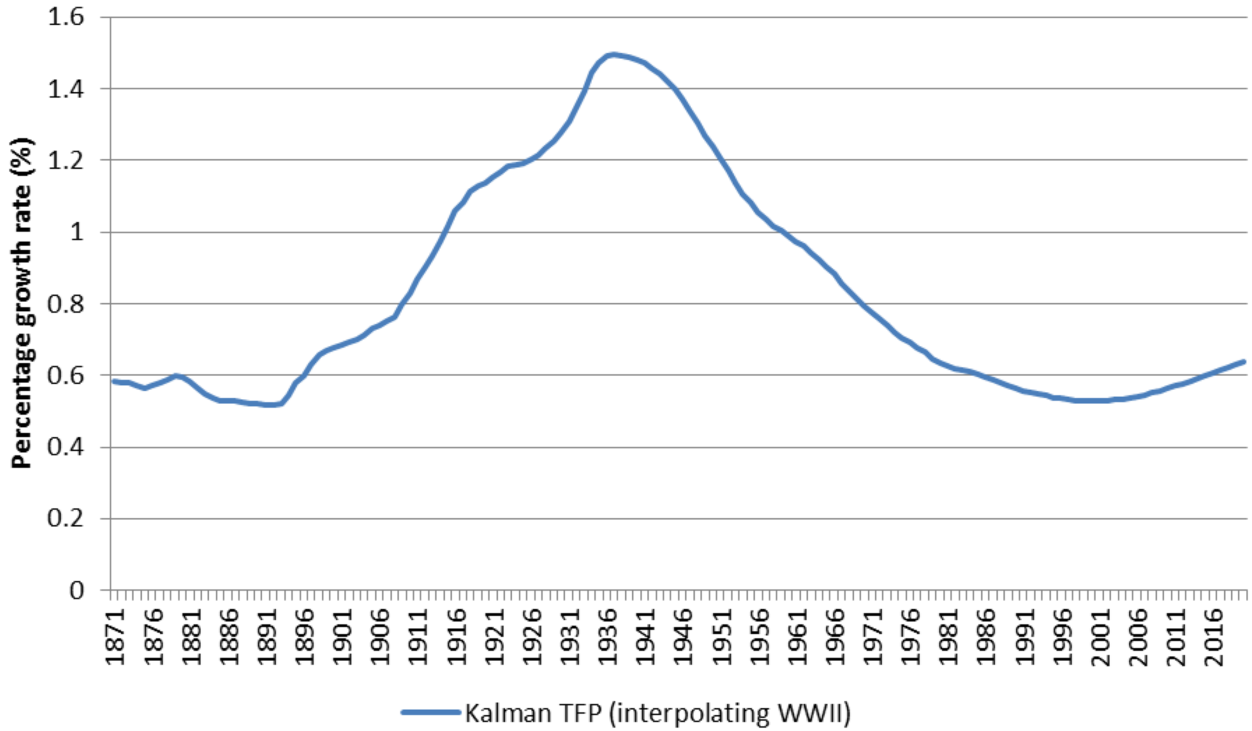
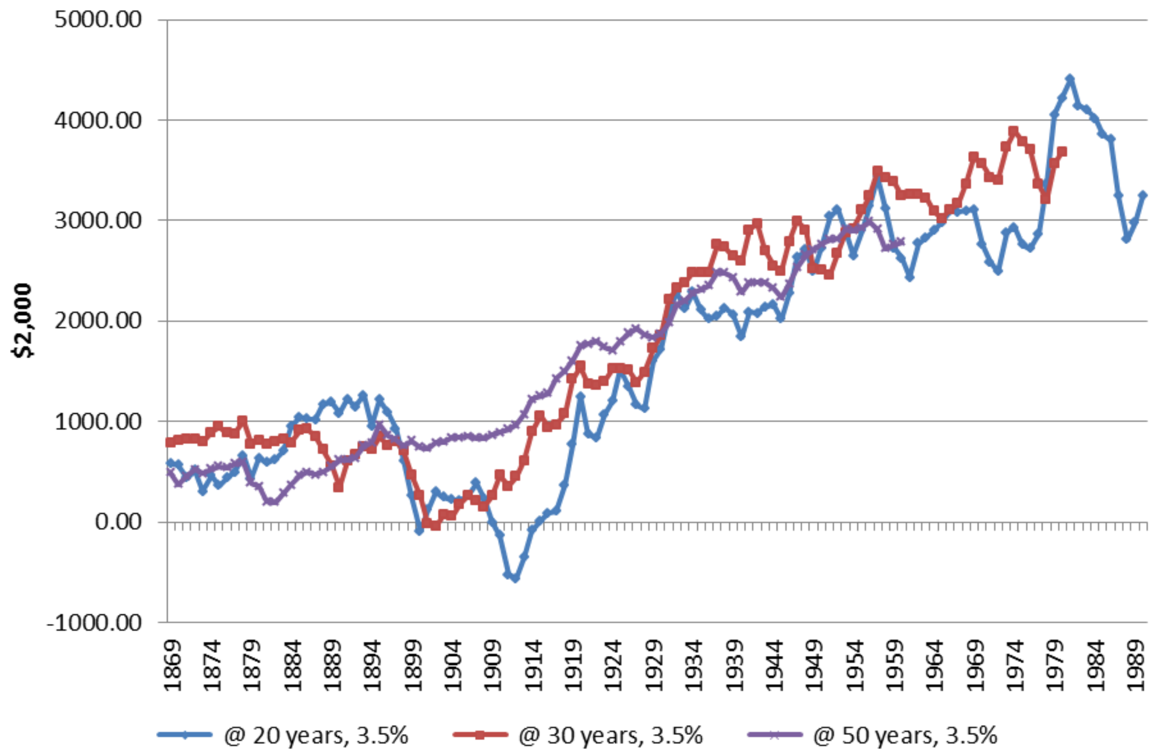


Figure 8: Trend Total Factor Productivity (%)

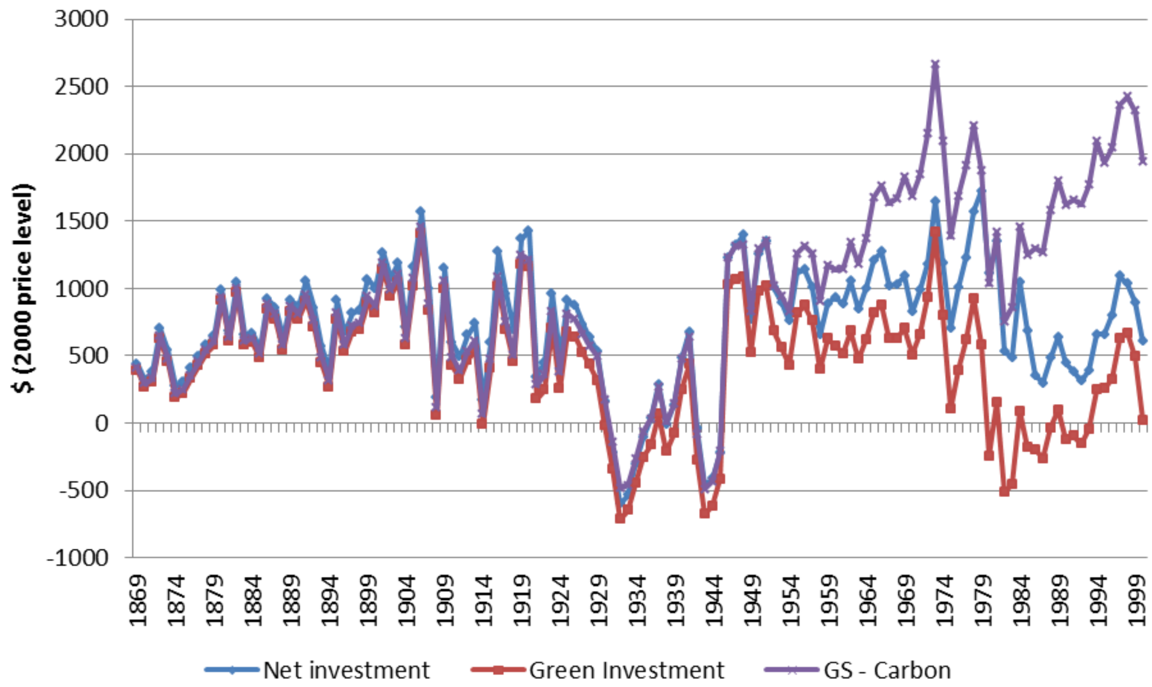


Note: Trend TFP growth rates are estimated for the period 1870 to 2020 using observed data for 1870-2000 data, the Kalman trend of this data was estimated and forecast for the period 2001-2020 using an ARIMA (4,1,0).

Figure 10: Present value of future changes in consumption per capita



GS per capita, USA



Results of hypothesis tests: USA

Table 4: Tests of Sustainability Hypotheses with the inclusion of TFP

1	2	3	4	5	6	7	8
Sample	Dependent	Independent	β_0	β_1	$\beta_0=0$; & $\beta_1=1$	$\beta_1=1$	Cointegration
1869-1990	PVΔFCONS20	CITFP	-185.1	0.926*	21.26*	0.99	Y
1869-1980	PVΔFCONS30		-2.00	0.929*	0.876	4.49	Y
1869-1960	PVΔFCONS50		37.4	0.880*	7.99*	1.85	Y
1869-1990	PVΔFCONS20	GREENTFP	21.12	1.041*	0.953	0.078	Y
1869-1980	PVΔFCONS30		24.25	1.098*	4.74	0.536	Y
1869-1960	PVΔFCONS50		156.6	0.888*	0.987	0.969	Y

Columns 4 and 5 present the coefficient estimate and an indication of the result of the two-sided test that it = 0 where the test statistic is compared with the 't' distribution; Columns 6 and 7 present only the test statistic which is constructed to undertake a Wald test and compared with the relevant χ^2 distribution. * denotes rejects the relevant null at the 5% level. Column 8 indicates whether the estimated equation is cointegrated, Y = yes at the 5% level, using Johansen ML methods (no trends - a range of lags in the VAR used).

- And now including Germany too

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 7: Estimates for Germany, USA and UK of β_0 and β_1
Panel OLS Results - Country fixed effects
The null hypothesis is redundancy of the fixed effects.

1.	2.	3.	4.	5.	6.	7.	8.
Dependent	Independent	β_0	β_1	$\beta_0=0$; & $\beta_1=1$	$\beta_1=1$	Fixed effect redundancy[1]	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

Allowing for changing population.

- UK population rose substantially over the period:

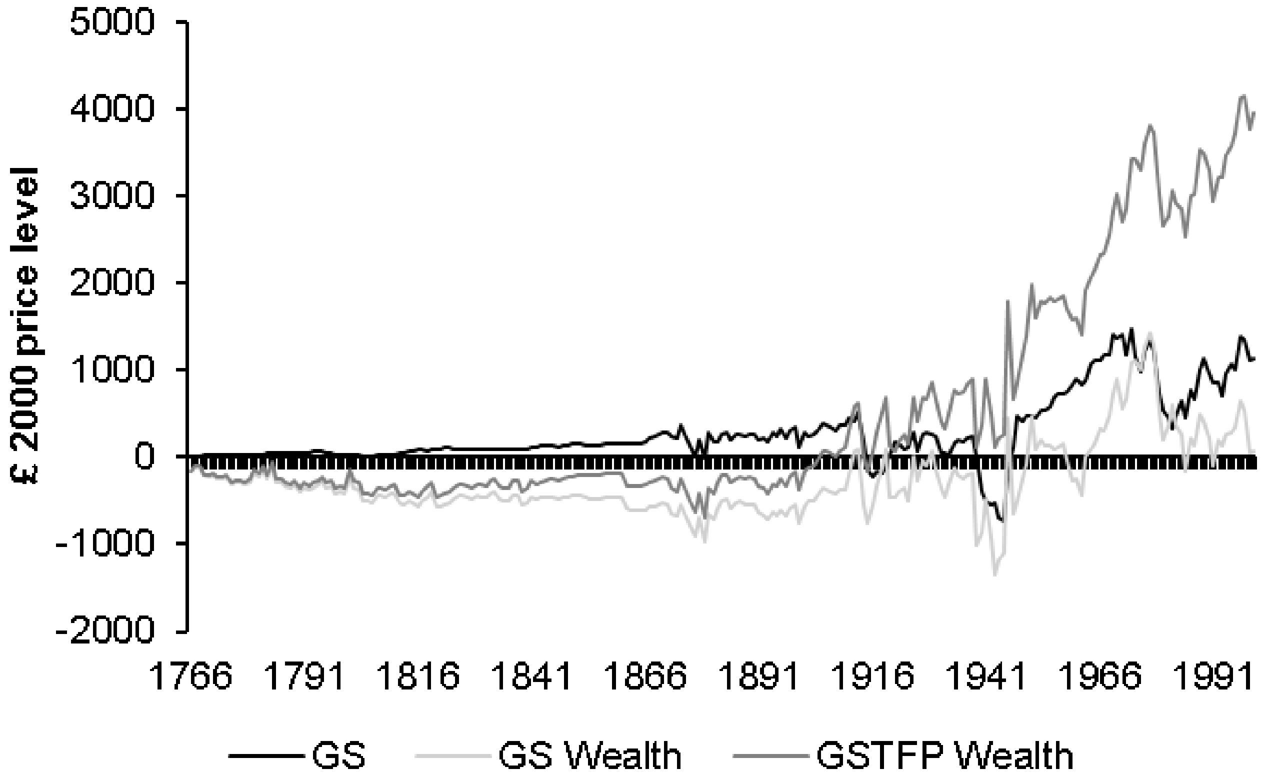
  1760 = 7 million, 2000 = 57 million

- Implies a given level of wealth is spread over more people.

- FHV present a formal model of this “wealth dilution effect”, which we calculate for the UK.
- This changes the well-being measure to: $PV\Delta C_{it} + PV\left(\Delta\gamma_{it}\omega_{it}\right)$ The wealth dilution adjustment is thus defined as the product of a varying population growth rate and wealth per capita.

- What are the effects on genuine savings per capita?

- In contrast to the finding of FHV, our results show adjusting the various investment measures for wealth dilution has a considerable effect on the estimated parameters.
- This may be due in part to differences in the estimation of aggregate wealth since FHV use a direct but partial measure rather than the ‘top down’ World Bank approach of our study.
- Accounting for wealth dilution diminishes GS to negative values for long periods before 1945, although allowing for technical progress ameliorates the effect.



Also changes the results of the hypothesis tests for β1, although not the test for cointegration. We reject β1 = 1 more often.

Conclusions

- Across all countries and all time periods, a positive value for GS is associated with higher values of well-being. So it is a meaningful indicator of future welfare.
- On the whole, we find that the $\beta 1$ coefficient is often close to 1, especially when we include technological progress in the calculation.
- Once technological progress is included, we mainly find a cointegrating relationship between GS and changes in future well-being ➔ more evidence to support use of the indicator.

Caveats

- Whether we use future real wages or future consumption seems to matter
- Which time period we test over also matters
- Recall that we highly partial and rough measures of changes in Kn and Kh.
- Also, no accounting for changes in social capital.

Extensions

- Extending analysis to Australia (almost completed).
- Including Pollution – we have a working paper available (Kunnas et al, 2012) on valuing pollution over time (carbon dioxide and particulates).
- Alternative measures of well-being: height and infant mortality.
- Better ways of measuring technological progress.
- Testing fundamental assumption of modern growth theory???

papers available:

- Greasley et al *Journal of Environmental Economics and Management*, 2014
- McLoughlin et al, *Oxford Review of Economic Policy*, 2014 (forthcoming)
- Oxley et al, 2014, submitted to Environmental and Resource Economics

See www.stir.ac.uk. Economics Division working paper series.

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