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Stirling Economics Discussion Paper 2013-06

April 2013

Online at

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## **Comprehensive investment and future well-being in the USA, 1869-2000**

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We thank the Leverhulme Trust for funding this work. We also thank comments from participants at the the Edinburgh FRESH meeting November 2013 and participants in a seminar on long-run indicators of sustainable development and wellbeing at University of Edinburgh, October 2011, especially Kirk Hamilton and Giles Atkinson.

**Abstract:**

This paper reports long-run tests of how comprehensive investment (CI) predicts future well-being in the USA. Theory suggests that a country with a positive level of CI should experience non-declining future utility. Despite the widespread uptake of CI, previous tests of its predictive power are for short time intervals. We assemble data for increasingly-comprehensive measures of US capital back to 1869 which are used to predict future consumption per capita. Our results show that with the inclusion of natural and human capital, CI can predict changes in future well-being reasonably well over 20 years into the future. Extending CI, to include measures of intangible or social capital, yield results that closely predict consumption over 20-50 years horizons.

*Keywords:* sustainable development, natural resources, intangible capital, comprehensive investment, future well-being, US economic growth.

JEL codes: E01, E21, N11, O11, O44, Q01

## 1. Introduction

According to a number of authors, a country can sustain future consumption by maintaining its capital stock per capita, broadly defined (Arrow *et al*, 2012). Precisely, they mean that maintaining capital, when defined to include all assets which are important for the flow of well-being to a population and the functioning of the economic-environmental system, will, under certain conditions, result in non-declining consumption over time (Hamilton and Withagen, 2007). Pemberton and Ulph (2001, p. 28) provide a modified version of this result, showing that an economy is acting in a sustainable manner at “....a particular moment of time if the value obtained from the vector of capital stocks it passes on to the future is the same as the value...it inherited”.

This idea of achieving non-declining consumption through time by investing enough in all forms of capital to offset depletion and depreciation has been referred to as maintaining “comprehensive wealth”, defined as the value of all capital stocks in the economy at any point in time given certain shadow prices for aggregating these stocks. The year-on-year change in comprehensive wealth is variously referred to as comprehensive investment, adjusted net savings and genuine savings (Arrow *et al*, 2012; World Bank, 2006; Heal, 2012). If change in the comprehensive wealth measure is positive in any year, then enough is being invested in capital, broadly defined, to meet the Pemberton and Ulph condition. More generally, the World Bank has interpreted what we will now term comprehensive investment as a meaningful indicator of the sustainability of economic development for a country (World Bank, 2011).

In this paper we construct a number of increasingly-comprehensive measures of investment for the USA over the period 1869-2000, and test whether these measures are significantly related to future changes in consumption in the way which sustainability theory predicts. We define comprehensive wealth as the aggregate value of all capital stocks which contribute to the generation of consumption goods and thus to well-being, where consumption here is broadly defined to include both market-valued and non-market goods and services. Comprehensive wealth is thus composed of a number of capital stocks: produced capital (roads, machinery, telecommunications networks), natural capital (all gifts of nature, including ecosystems and their functions, and renewable and non-renewable resources), human capital, and social or intangible capital (institutions or organizations) (Knack and Keefer, 1997). If technological progress is viewed as being entirely exogenous, then it may also be treated as a type of capital, or “value of time” (Pemberton and Ulph, 2001). Arrow et al (2012) also include a stock of health capital in their model, and include exogenous terms-of-trade changes in the value of time. Pezzey et al (2006) argue that changes in net foreign assets should be included in a comprehensive investment calculation.

As Arrow et al (2012) show, the year-on-year change in comprehensive wealth, termed comprehensive investment (CI), when evaluated at appropriate shadow prices, is an indicator of the future path of well-being, such that a positive value of CI implies a rise in inter-generational well-being, where intergenerational well-being is the sum of discounted utility values across the population over infinite time. The appropriate shadow prices show the marginal change in intergenerational well-being for a one unit change in the particular capital stock. A comparable claim is that in Hamilton and Withagen (2007) who show that a

positive value of CI implies rising consumption over time, again under certain conditions. Pezzey (2004), however, finds that CI is only a one-sided indicator of sustainability, in that a negative value results in a decline in future well-being, but that no symmetric result can be obtained for a positive value.

There is thus a body of literature in the economics of sustainable development that holds that changes in wealth today are an indicator of changes in future well-being and that CI can serve as an instantaneous indicator of the sustainability of future economic activity. In this paper, we assemble data for US CI over the period 1869-2000 to test this claim empirically. Our measure of CI includes: produced and net foreign capital; human capital; and natural capital. Two variants of natural capital, one comprising mineral and energy resources, forests and farmland, and the second measure further augmented with carbon costs, are utilized. This latter variant is considered since the World Bank's calculations of CI include as disinvestment an estimate of the costs of an annual change in the stock of CO<sub>2</sub> in the atmosphere due to greenhouse gas emissions from human activity. We also report estimates of value for changes in the "stock" of exogenous technology, using changes in total factor productivity following the method set out in Pezzey et al (2006) and the work of Weitzman (1997). Finally we explore the effects of including social or intangible capital in CI via a measure of residual productivity.

## **2. Empirical tests of comprehensive investment and future well-being.**

Whilst the theoretical underpinnings of CI are well-established (if much debated), empirical tests of the extent to which a positive CI in a particular year is a good indicator of improving

(or at least of non-declining) well-being over time remain very limited. Three pioneering studies are Ferreira and Vincent (2005), World Bank (2006) and Ferreira, Hamilton and Vincent (2008). However, these tests utilize CI estimate for short time spans, typically for the years 1970-82, and link CI to consumption over the next 20 years, 1983-2003. The 30 years of data adopted by these studies could be viewed as being inadequate for examining the claimed long-run relationship between CI and well-being.

Greasley et al (2012) survey these earlier tests and here we employ the same basic approach as previous authors but within a time series framework to consider how well CI predicts changes in future consumption per capita in the USA over a long time frame since 1869. Consequently we are able to explore how well CI predicts future changes in consumption for periods up to 50 years, with spans of CI data over at least 90 years. Based on Ferreira, Hamilton and Vincent (2008), we use increasingly - comprehensive measures of investment to test three hypotheses of the long-run predicted relationship between comprehensive investment and future well-being:

$$PV\Delta FC_t = \beta_0 + \beta_1 S_t + \varepsilon \quad (1)$$

where  $S$  is a measure of comprehensive investment, and  $PV\Delta FC_t$  is the present value of changes in future consumption over some defined time period as evaluated at period  $t$  (equation (7) in FHV)<sup>1</sup>. The strongest test of the theory is:

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

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<sup>1</sup> Note that via this specification, if  $PV\Delta FC$  and  $S$  are expressed in per-capita terms, it assumes a constant rate of population growth over the period under examination – see FHV (2008) and Dasgupta (2001). FHV highlight, and in some specifications adjust for the possibility of wealth dilution arising from faster population growth in less developed countries.

Hypothesis 1 implies that all that matters for changes in future well-being is the size of the comprehensive investment term  $S$ . Weaker hypotheses are that:

H2:  $\beta_1 = 1$ , and

H3:  $\beta_1 > 0$  where  $\beta_1 \rightarrow 1$  as  $S$  become more inclusive.

Hypothesis 2 implies that each \$ increase in comprehensive investment brings about a \$ increase in the present value of future consumption flows. Hypothesis 3, the weakest hypothesis, simply postulates a positive relationship between future consumption and investment which progressively approaches unity as omitted components of  $S$  are reduced.

The empirical strategy followed here is to test H1, H2 and H3 for three different measures of  $PV\Delta FC$  as at year  $t$  for  $(t+20)$ ,  $(t+30)$  and  $(t+50)$ ; and for alternative, increasingly comprehensive measures of investment, 1-6, defined as:

1. NETPINV: annual changes in net produced capital and net overseas assets
2. NETPNRINV: NETPINV plus changes in elements of the stock of natural capital
3. GREENINV: NETPNRINV adjusted for the cost of carbon emissions
4. CI: GREENINV plus changes in human capital
5. CITFP: CI plus the value of changes in exogenous technological progress
6. GREENTFP: GREENINV plus changes in elements of human and social capital



Our expectation is that as the measure of  $S_t$  in Eq. 1 is made increasingly comprehensive, in terms of how many aspects of changes in the value the USA's capital stock it measures, then  $\beta_1$  will approach 1.

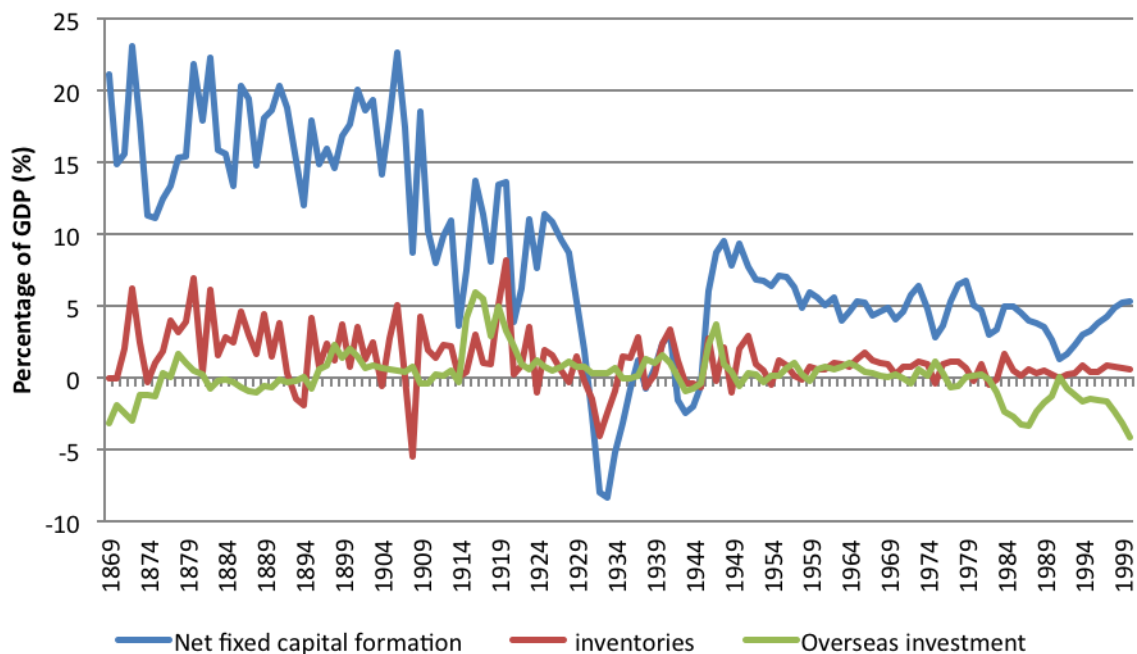
### 3. Data

In this section, each component 1-6 of an increasingly comprehensive measure of annual investment in the total capital stock of the USA, 1869-2000 is outlined. Full details of data construction can be found in the Data Appendix.

#### 3.1 Changes in produced and net overseas capital (NETPINV)

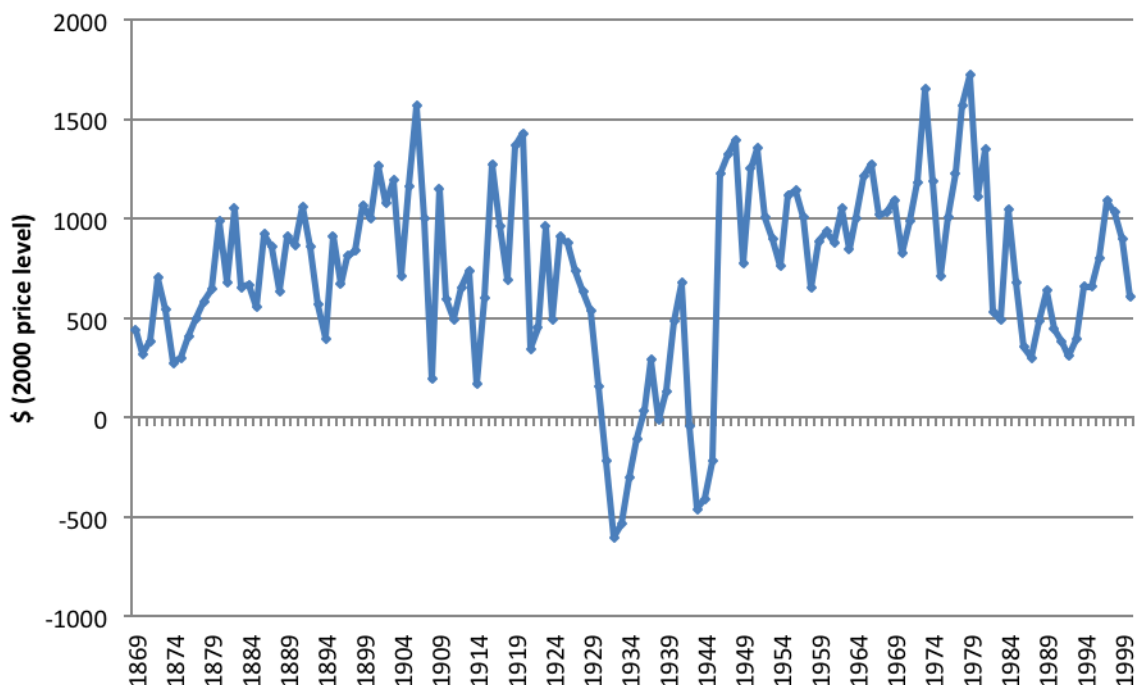
US net produced investment comprises gross investment minus capital consumption, changes in inventories and net overseas investment, see Figure 1 where these data are shown relative to GDP.

**Figure 1: US net fixed capital formation, inventories and net overseas investments.**



Produced capital formation experienced a long downward trend from around 15-20% of GDP 1870-1900, to around 5% at the start of the 21<sup>st</sup> century. A sharp down step in the produced investment ratio occurred in the 1920s, and the USA experienced a long period of negative investment, which spanned the Great Depression of the 1930s and World War 2. The subsequent upturn after 1945 never regained the investment-GDP ratio of 1925. Net overseas investment was generally positive from the 1890s to the 1970s, while inventory changes gradually diminished relative to GDP. In per capita terms, overall net investment in produced capital falls from around 1929, is negative over much of the time until 1945, but regains the levels of the early 20<sup>th</sup> century in the 1970s, see Figure 2.

**Figure 2: Overall net produced investment per capita (\$ 2000)**



### 3.2 Adding changes in elements of natural capital (NETPNRINV)

The elements of natural capital included here are forestry, mining (metals and minerals) and agricultural land. We include annual output from non-renewables as a loss of natural capital; the net annual change in forest stocks enters as either a positive (net gain) or negative (net loss) term. The area of forest land fell to the 1920s, but rose over the next half

**Table1: The value of US forest stocks**

	Area	Volume per hectare	Standing volume	Change in Standing volume	Price - cost	Value of change in volume	Value of change in volume /GDP
	Million hectares	M <sup>3</sup> per hectare	Million M <sup>3</sup>	Million M <sup>3</sup>	\$ M <sup>3</sup>	\$ million	%
1861-1870	256.06	94.86	24289.05	-97.00	0.43	-40.76	-0.52
1871-1880	237.14	94.86	22494.33	-243.59	0.37	-89.83	-1.06
1881-1890	220.44	94.86	20909.75	-92.13	0.33	-30.69	-0.24
1891-1900	176.60	94.86	16751.08	-644.90	0.28	-181.23	-1.10
1901-1910	145.21	94.86	13773.59	-49.90	0.49	-24.21	-0.08
1911-1920	137.23	94.86	13016.88	-95.97	0.74	-71.45	-0.16
1921-1930	137.23	94.86	13016.88	-95.97	0.74	-71.45	-0.16
1931-1940	147.34	89.94	13251.84	-37.67	0.44	-24.15	-0.02
1941-1950	151.27	86.90	13139.04	167.66	0.88	232.23	0.08
1951-1960	201.09	86.35	17400.32	689.77	3.05	2043.01	0.45
1961-1970	239.80	92.87	22271.17	272.42	2.63	981.51	0.10
1971-1980	291.88	102.50	29941.73	724.68	12.64	5912.80	0.40
1981-1990	294.74	110.91	32691.59	231.54	14.19	2641.02	0.06
1991-2000	298.21	115.55	34458.02	119.52	29.33	3436.64	0.05

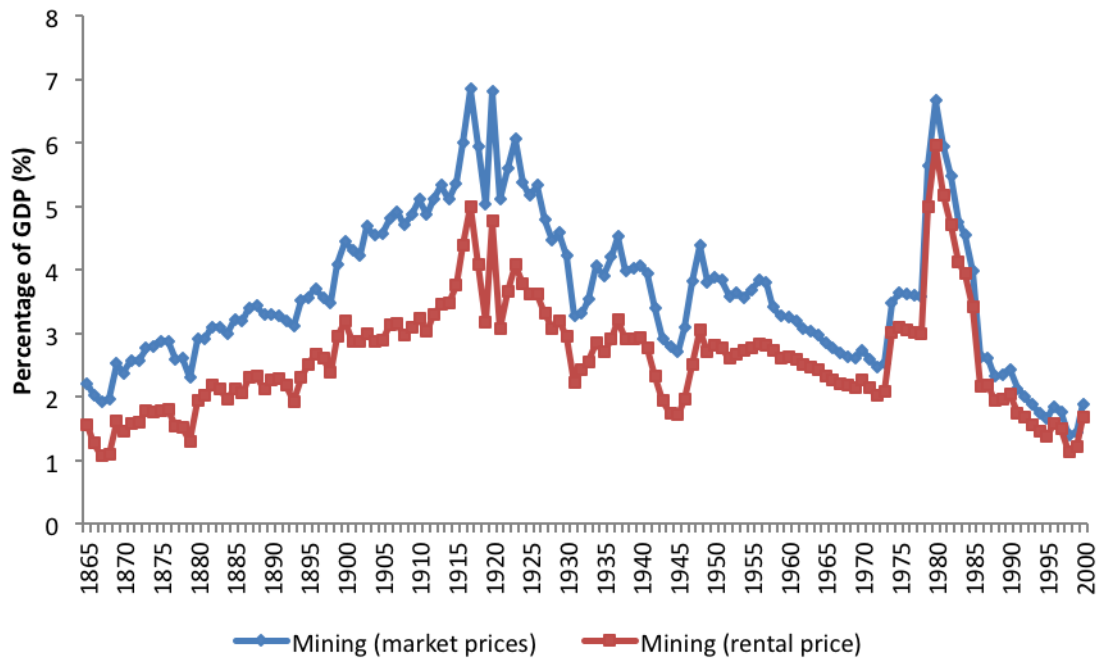
Sources: see Data Appendix

century to a peak of around 300 million hectares in the early 1970s. The standing value of the forest stock fell to the 1920s but rose thereafter, partly reflecting higher volumes per hectare after 1945. The rental value of forest depletion (valued using the difference

between harvest price and marginal cost) averaged around 1% of GDP each year in the period 1870-1900; whereas afforestation took place during the twentieth century (Table 1).

The value of mining at market prices and at rental prices is shown in Figure 3. Over the period since 1865 mining valued at market prices averaged 3.87% of GDP while the value of extracted mining rents, which deduct marginal extraction costs from prices, averaged 2.83% of GDP. Fuels, including coal, oil and gas account for most of the extracted rents. The market value of metals, including iron ore, copper, bauxite peaked relative to GDP during World War 1, and fell to below 1% thereafter. Other minerals, including, gypsum, stone and salt, had a market value over 1% of GDP in the 1920s, but this ratio fell thereafter. Overall, the extraction of mining rents rose above 5% of GDP during World War 1, and hit 6% around 1980. Extracted mineral rents never fell below 1% of GDP, and when the produced investment ratio collapsed during the 1930s, the depletion of minerals accentuated the marked fall in the US capital stock.

**Figure 3: Depletion of minerals.**



Increases in the area of farmland or its' per hectare value are treated as net additions to the natural capital stock. The farmland area of the USA more than doubled in size 1870-2000, despite a gradual decline from around 1950. Changes in the rental value of farmland generally augmented the US natural capital stock before 1950, although there was a brief decline during the rural financial crisis after the post-World War 1 boom, see Table 2. However, changes in the rental value of farmland were small relative to the aggregate capital stock and less than 0.5% of GDP in 1890, the year the frontier officially closed.

**Table 2: Changes in farmland rental value**

	Present value of rent per acre	Total farmland	Change in farmland	Change in rental value	Change in rents/GDP
	\$	Million acres	Million acres	\$ m	%
1861-1870	1.27	407.74	0.52	0.66	0.00
1871-1880	3.27	536.08	128.35	419.64	0.40
1881-1890	5.73	623.22	87.14	499.15	0.33
1891-1900	4.00	841.20	217.98	872.93	0.42
1901-1910	2.18	881.43	40.23	105.22	0.03
1911-1920	4.17	923.38	7.72	32.37	0.06
1921-1930	6.94	950.70	3.14	31.58	0.03
1931-1940	12.14	1044.65	7.50	81.38	0.12
1941-1950	35.57	1132.03	9.63	270.04	0.13
1951-1960	52.82	1144.49	-4.06	-198.25	-0.04
1961-1970	65.90	1091.85	-6.73	-468.95	-0.06
1971-1980	94.49	1019.34	-5.29	-492.57	-0.03
1981-1990	101.58	971.79	-4.76	-481.00	-0.01
1991-2000	111.40	936.03	-2.94	-326.91	0.00

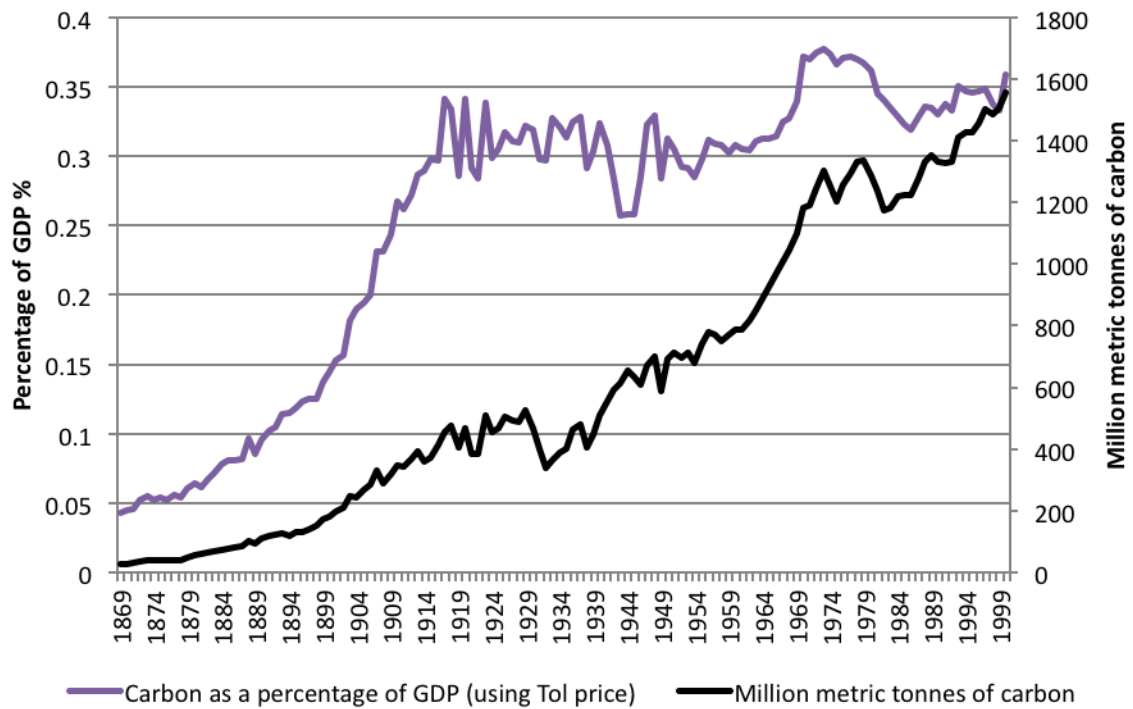
Sources: see Data Appendix

### 3.3 Adding carbon costs (GREENINV)

Here we consider the extent to which pollution depletes natural capital. Emissions of greenhouse gases add to the stock of greenhouse gases in the atmosphere, and many authors have included estimates of the shadow cost of carbon emissions in comprehensive investment-type calculations (World Bank, 2011; Pezzey and Burke, 2013). This value is a deduction from natural capital since it represents a using up of scarce global assimilative capacity. The estimates here suggest the disinvestment associated with carbon pollution

averaged around 0.33% of GDP during the 20<sup>th</sup> century, see Figure 4, but pollution costs rose sharply in the period to 1920 when energy-GDP ratios were also rising (Devine, 1983).

**Figure 4: Cost of carbon emissions**

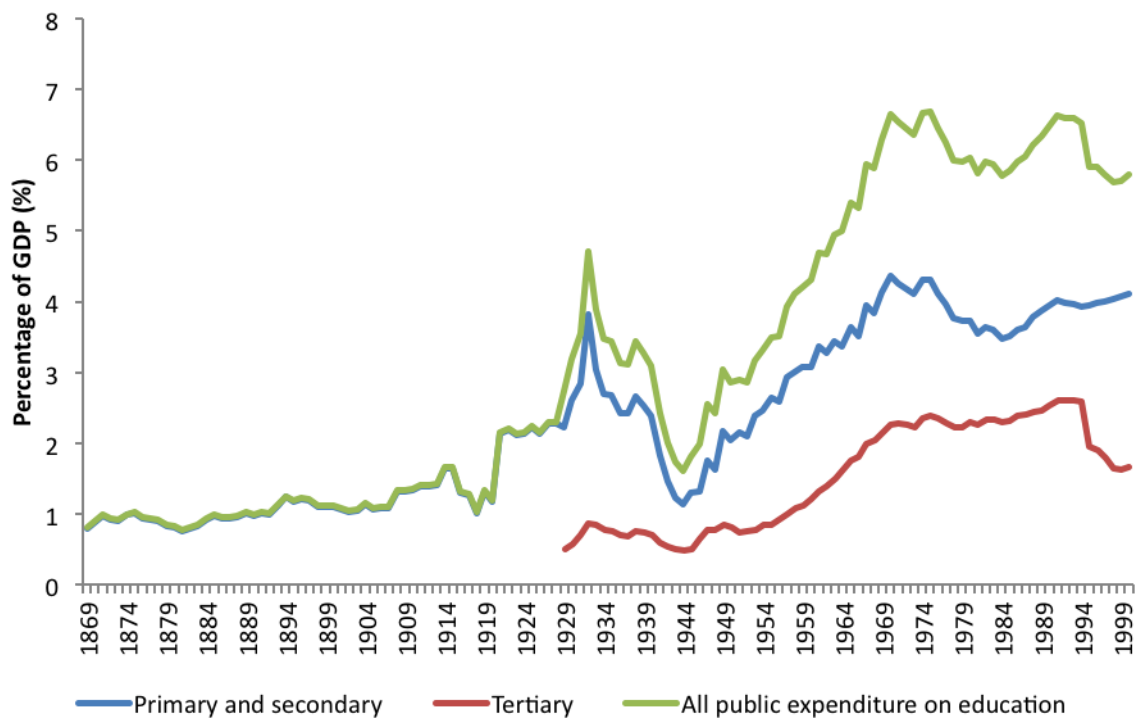


### 3.4 Adding changes in human capital (CI)

Like the World Bank (2006, 2011), we use annual investment in public education as a measure of the change in the stock of human capital. Whilst one could use an alternative approach, based on lifetime earnings and changes in worker productivity (Arrow et al, 2012), the expenditure approach fits naturally with measures of comprehensive investment. A measure of such expenditures would ideally include private spending on education and spending by firms on worker training, but consistent, continuous data are not available on either of these. Public education investment rose to around 6.5% of GDP by the 1960s, but the ratio levelled thereafter, see Figure 5. The earlier spike and trough in the ratio reflect

that education spending was maintained when GDP collapsed at the onset of the Great Depression and surged during World War 2.

**Figure 5: Public investment in education**

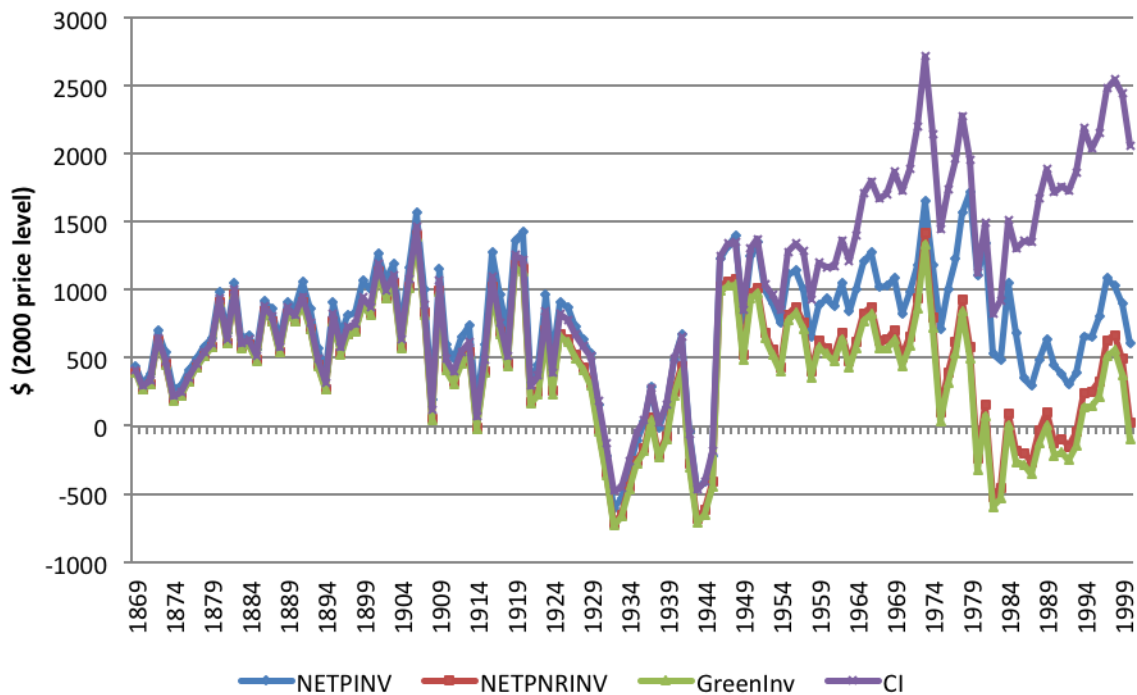


Putting together these individual changes in capital stocks for the USA, we see that real CI per capita rises by around four times 1869-2000, see Figure 6. Within these years CI per capita shows no discernible trend from around 1880-1925. Net produced investment was above CI during these years since public education investment was insufficient to offset the effects of natural resource depletion. From 1925-1945 the USA witnessed a major slump in CI associated with the Great Depression and World War 2, which included spells when the capital stocks included in CI fell. After 1945 net produced investment per capita was typically no higher than it had been before 1925. The major change after 1945 was that



higher public investment in education more than offsets natural capital depletion, hence CI per capita rises, and exceeds the earlier 1906 peak for the first time in 1965.

**Figure 6: Comprehensive investment per capita**



### 3.5 Adding changes in the value of exogenous technological progress (CITFP)

Weizman (1997) and Pemberton and Ulph (2001) advocate the inclusion of measures of exogenous technological progress in an assessment of the capital stocks of a country in terms of producing comprehensive investment measures which predict sustainability. Pezzey (2004) and Pezzey et al (2006) refer to such technological progress as part of a “value of time passing”, which increases the future consumption possibilities of an economy. We therefore use CI augmented with exogenous technological progress as a more inclusive investment measure. Trend TFP estimates underpin the measure of exogenous

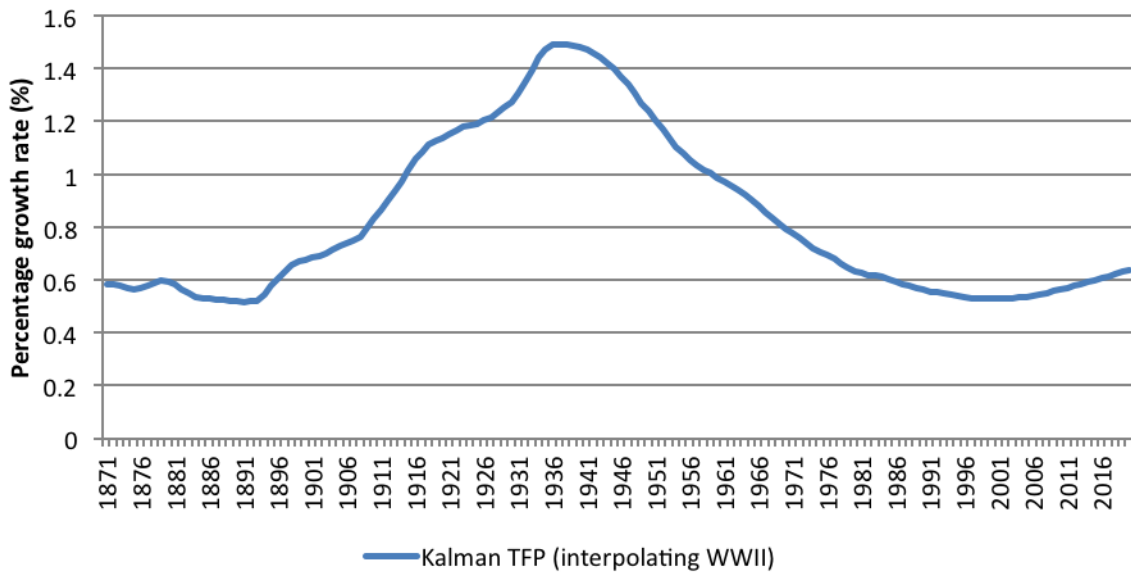
technological progress. Our approach, derived from Pezzey et al (2006), estimates exogenous technology's contribution to the future values of GDP by using trend TFP growth for 1870-2021 where TFP% is trend TFP:

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

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 2% discount, represents the value of technological progress to the economy [PV (GDP<sub>t+20</sub> - GDP<sub>t</sub>)]

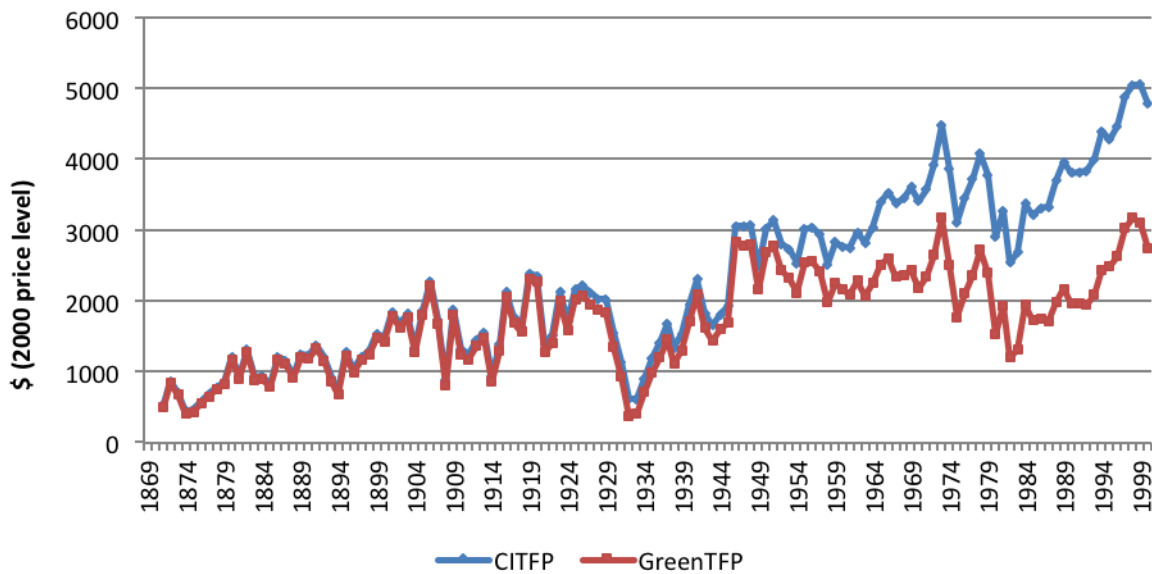
The estimates of trend TFP are illustrated as Figure 7. The results are similar to those reported by Field (2006) who argues that US productivity growth peaked in the 1930s. Adding the value of TFP to CI, see Figure 8, shows this more comprehensive measure CITFP per capita was always positive. In 2000 CITFP was around \$5000 per capita or around 50% higher than un-augmented CI. Treating technological progress as a separable part of the total stock of wealth which can be measured by TFP assumes that all technological progress is exogenous (Pemberton and Ulph, 2001). This is clearly not the case empirically, and part of the TFP might arise from, for example, R&D spending. Of particular concern for the CITFP measure is its inclusion of public education investment, which might be associated with endogenous technological change and higher TFP. Thus CITFP might overstate changes in comprehensive wealth with regard to those elements of technological change which are endogenous

**Figure 7: 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 8: CITFP and GREENTFP per capita**



### *3.6 Adjusting for changes in intangible capital (GREENTFP)*

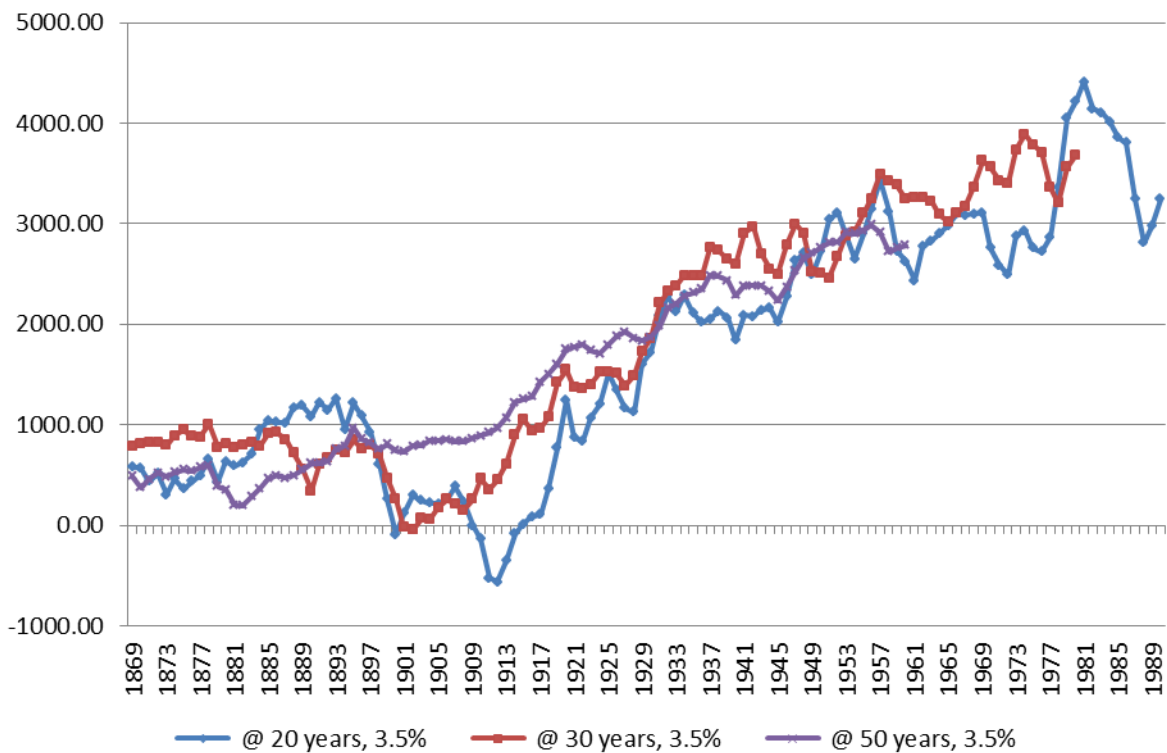
Our final adjustment recognizes that combining human capital formation and TFP within CITFP may double count elements of the capital stock, but that the exclusion of TFP would mean our measures of comprehensive investment would omit possibly important elements of social, institutional or intangible capital. Some direct measures of social capital have been proposed, including polity indexes, but they are difficult to value within a monetary accounting of comprehensive wealth over time and are not included here (Kaufmann et al (2005)).

An alternative to considering TFP as a measure of exogenous technological progress is to say that it captures the production effects of capital inputs, including human and social, not explicitly measured. Moreover, since our TFP construction does not adjust for the quality of labour or include intangible capital, the TFP index will reflect any quality changes, from say, more educated workers, as well as R&D investment, and the consequences of organizational and institutional changes. Abramovitz and David (2000) provide the fullest discussion of US TFP, and for its 20<sup>th</sup> century rise they highlight the contributions from various elements of intangible capital associated with organizational change and knowledge-based progress. Given GREENINV essentially relates to the tangible capital stock, adding the value of TFP as a measure of intangible capital value, provides an alternative comprehensive investment measure GREENTFP, which avoids the possible double counting issues associated with CITFP. GREENTFP per capita rises around three times 1869-2000, compared to the around five times rise in CITFP, see Figure 8, suggesting that including education investment and TFP within a single measure may overstate comprehensive wealth.

### 3.7 Measuring changes in future consumption.

Based on the approach in Ferreira, Hamilton and Vincent (2008), we use the present value of future changes in consumption per capita as a measure of changes in future well-being against which to compare current levels in comprehensive investment. These present values of changes in future consumption are calculated for 20 years, 30 years and 50 years into the future, relative to the corresponding estimate of comprehensive investment. Thus, in the case of the 20 year future horizon, the final CI data point is for 1990, given the consumer spending data end in 2011, whereas with the 50 year horizons the matching CI data are for 1869-1960. All three measure of changes in future consumption per capita, see Figure 9, rise over time. The 50 years horizon smooth the future changes in consumption per capita, whereas over 20 years the changes in future consumption are sometimes volatile.

**Figure 9: Present value of future changes in consumption per capita (\$ 2000)**



#### 4. Estimation and Results

The key results test whether the measures of comprehensive investment are significantly related to future changes in consumption in the way that the sustainability theories predict. These theories (Hamilton and Withagen, 2007; Pemberton and Ulph, 2001) are formulated in infinite time as long run steady-state properties and therefore empirical tests should ideally use very long time series of data. Given the reality of finite data, the very long series used here are complemented with the super consistency properties that arise in cointegrated systems. The estimation route we follow is Johansen (1995) where we test for the existence of a significant cointegrating relationship and utilize the estimates and standard errors from these methods in the specific tests of sustainability<sup>2</sup>. As such, estimation simply offers a route to test the theoretical implications of the models and not to find the “best fitting model that explains the dependent variable”.

Based upon Eq. (1), the strong-form test of the CI models of sustainability can be expressed as the joint hypothesis: H1:  $\beta_0 = 0$  and  $\beta_1 = 1$ ; where changes in future well-being solely depend on the size of the comprehensive investment term  $S$ . Like any joint hypothesis within a classical approach, rejection of the null can arise due to  $\beta_0 \neq 0$  and/or  $\beta_1 \neq 1$ . In this paper the joint hypothesis is tested using a Wald test. The weaker-form tests: H2:  $\beta_1 = 1$ ; and H3:  $\beta_1 > 0$  where  $\beta_1 \rightarrow 1$  as  $S$  become more inclusive are evaluated both via a White corrected- $t^3$  test and/or a Wald test. The theory, however, does not present a scenario where  $\beta_0 \neq 0$  which is something we will return to later in terms of the estimation methods.

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<sup>2</sup> Depending on the outcome of the tests(s) the existence of cointegration mitigates issues of potential spurious regression between the variables of interest.

<sup>3</sup> Potential problems of inference due to the Generated Regressors arising from the construction of both lhs and rhs variables do not arise in our case for two reasons i) the variables are all time  $t$  measures and ii) some variables are cointegrated, see Oxley and McAleer (1993).

The results in Table 3 are tests for hypothesis H1-H3 for four measures of investment NETPINV, NETPNRINV, GREENINV and CI as defined in section 2, where the present value of future changes consumption per capita is measured over 20, 30 or 50 years.

<b>Table 3: Tests of Sustainability Hypotheses without the inclusion of TFP</b>							
1	2	3	4	5	6	7	8
Sample	Dependent	Independent	$\beta_0$	$\beta_1$	$\beta_0=0$ ; & $\beta_1=1$	$\beta_1=1$	Cointegration
1869-1990	PV $\Delta$ FCONS20	NETPINV	1472.8*	0.336	83.6*	7.41*	N
1869-1980	PV $\Delta$ FCONS30		1634.7*	0.228	98.4*	10.4*	N
1869-1960	PV $\Delta$ FCONS50		1594.0*	-0.211	111.8*	38.1*	N
1869-1990	PV $\Delta$ FCONS20	NETPNRINV	2050.5*	-0.719*	184.4*	175.0*	Y
1869-1980	PV $\Delta$ FCONS30		2043.4*	-0.465*	166.2*	32.6*	Y
1869-1960	PV $\Delta$ FCONS50		1698.1*	-0.506*	174.6*	58.3*	N
1869-1960	PV $\Delta$ FCONS50	GREENINV	2078.2*	-0.834*	205.4*	62.5*	Y
1869-1980	PV $\Delta$ FCONS30		2093.5*	-0.591*	180.5*	39.1*	Y
1869-1960	PV $\Delta$ FCONS50		1712.3*	-0.554*	185.5*	63.4*	N
1869-1990	PV $\Delta$ FCONS20	CI	930.7*	0.928*	73.64*	0.18	Y
1869-1980	PV $\Delta$ FCONS30		1181.8*	0.771*	92.9*	1.76	N <sup>+</sup>
1869-1960	PV $\Delta$ FCONS50		1462.9*	-0.019	106.4*	25.1*	N

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  $\chi^2$  distribution. \* denotes rejects the relevant null at the 5% level. Column 8 indicates whether the estimated equation is cointegrated, Y = yes, N = no at the 5% level, using Johansen ML methods (restricted intercepts, no trends - a range of lags in the VAR used), additionally N<sup>+</sup> indicates the null of no cointegration is rejected at the 10% level

When investment is restricted to changes in produced capital and net foreign investment alone (NETPINV), both the strong H1 hypothesis and the weaker null hypothesis H2 that  $\beta_1 = 1$  are rejected at the 5% level. As indeed is the weakest hypothesis H3 since produced investment has no positive effect of future consumption per capita over 20-50 years horizons given  $\beta_1 = 0$  is not rejected.

Extending the measure of capital to include natural resources, NETPNRINV and then, additionally carbon costs, GREENINV produce test results that also reject the weakest hypothesis H3. Indeed, allowing for historic carbon dioxide emissions as negative changes to

overall capital produces very small changes in the estimates compared to those for NETPNRINV. Both natural resource augmented measures yield estimated coefficients that point to comprehensive investment reducing future consumption. The reason is simple enough, the US depleted part of its natural capital with the upshot that GREENINV per capita fell over the period 1869-2000, while future changes in consumption were mainly positive. Most of the depletion arose from minerals extraction; the costs of carbon emissions were relatively small. In all cases the estimates of  $\beta_1$  for NETPNRINV and GREENINV are significantly negative, suggesting natural resource depletion increased future consumption over the time periods considered. This finding runs counter to all three sustainability hypotheses, and it is scrutinized further in the Discussion section. Further extensions to the measure of capital to include human capital, CI reverse the finding of non-sustainability. Over 20 and 30 year horizons H2 and H3 are not rejected for CI. The results over 20 years are the more robust given the finding in favour of cointegration at the 5% level, and an estimate for  $\beta_1$  of 0.98. It would thus seem that, at least over relatively short 20 and perhaps 30 year horizons, education investment more than offsets the effects of natural resources on future changes in consumption.

Next we turn attention to knowledge and social capital measured by total factor productivity, TFP. Weizman (1997) and Pemberton and Ulph (2001) advocate the inclusion of measures of exogenous technological progress in comprehensive investment. Following Pezzey et al (2006), our estimate of exogenous technology's contribution to changes in knowledge capital are based upon trend TFP. CI augmented with exogenous technology, CITFP, yields estimates which are more favourable to the sustainability hypotheses H1-H3 than CI alone, see Table 4. The weaker hypothesis H2:  $\beta_1 = 1$  is not rejected over 20, 30 and



50 year horizons, and the strong form, H1:  $\beta_0 = 0$ ;  $\beta_1 = 1$ , is not rejected looking 30 years ahead. The CITFP results with the 50 year suggest that changes in knowledge capital have long-horizon implications for future consumption beyond those associated with human capital formation. A possible downside of the CITFP results is that TFP reflects more than exogenous technology, and to the extent that education investment produces knowledge there may be an element of double counting in the CITFP measure.

<b>Table 4: Tests of Sustainability Hypotheses with the inclusion of TFP</b>							
1	2	3	4	5	6	7	8
Sample	Dependent	Independent	$\beta_0$	$\beta_1$	$\beta_0=0$ ; & $\beta_1=1$	$\beta_1=1$	Cointegration
1869-1990	PV $\Delta$ FCONS20	CITFP	-185.1	0.926*	21.26*	0.99	Y
1869-1980	PV $\Delta$ FCONS30		-2.00	0.929*	0.876	4.49	Y
1869-1960	PV $\Delta$ FCONS50		37.4	0.880*	7.99*	1.85	Y
1869-1990	PV $\Delta$ FCONS20	GREENTFP	21.12	1.041*	0.953	0.078	Y
1869-1980	PV $\Delta$ FCONS30		24.25	1.098*	4.74	0.536	Y
1869-1960	PV $\Delta$ FCONS50		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  $\chi^2$  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).

The alternative approach postulates that TFP captures social and organizational capital, in addition to the effects of human capital formation. Thus adding the changes in the capitalized value of TFP to GREENINV, which essentially measures tangible capital formation, yields GREENTFP, an inclusive measure of both tangible and intangible investment. The estimated coefficients for GREENTFP provide results that are most

supportive of the strongest H1 sustainability hypothesis. The strong form, H1:  $\beta_0 = 0$ ;  $\beta_1 = 1$ , is not rejected over 20, 30 and 50 year horizons.

## **5. Discussion and Conclusions**

Our empirical tests of the sustainability hypotheses differ from those of previous authors by utilizing long runs of data and by focussing upon a single, now developed country, the USA. In their landmark paper Feirrera and Vincent (2005) find stronger support for more comprehensive investment measures predicting future consumption in non-OECD countries than in OECD countries. Indeed, for OECD countries they find against any measure of investment positively influencing future consumption, a result they attribute to their empirical models not including technological progress or TFP. For non-OECD countries the exclusion of technology was argued to matter less, and their comprehensive investment measures had some success in predicting future well-being, albeit over short time frames.

Even for non-OECD countries Feirrera and Vincent argue the benefits of broadening the measure of net investment extend only to green investment, not to more comprehensive measures including education investment, a finding they attribute to the shortcomings of the human capital formation indicator used by the World Bank. Hence the subsequent empirical studies of the World Bank (2006) and Ferreira, Hamilton and Vincent (2008) focussed on developing countries and excluded education investment. An element of the relative success of green measures of investment in predicting future consumption in non-OECD countries in previous studies may be due to their use of a sample period dating from the 1970s, when the rental values of extracted natural resource rents were high, whilst

subsequent consumption per capita growth over the next two decades was low and negative for many natural resource abundant economies. Over the twenty years from 1980 the present value of the change in future consumption is negative in 24 of the cases considered by the World Bank, but none of these are high income countries (World Bank, 2006, Figures 6.1 and 6.5)

Ferreira, Hamilton and Vincent have thus provided an explanation of the weak consumption performance during the 1980s and 1990s of many non-OECD countries which rests on resource depletion rather than the resource curse proposed by Sachs and Warner (2001). Others, including Brunnschweiler and Bulte (2008) are also sceptical of the resource curse; they argue that the extraction of resource rents measures resource dependency, rather than resource abundance, which is associated with improved economic performance. However, the merits of the green investment model espoused by Ferreira, Hamilton and Vincent needs to be judged in the context of their 20 year forecast horizon. While the extraction of rents from non-renewable resources diminishes the possibility of future consumption, the timing of any reduction will depend on the pace of reserve depletion, which may be modest over the 20 years horizon.

The results reported here differ from those of previous studies, notably so in the benefits we find for future consumption from public education investment. In part the differences may reflect that the USA has some characteristics of a developing as well an OECD country over our long sample period. Predicting future well-being over long periods which include

structural transformations from rural to urban-industrial economies presents complex challenges for comprehensive investment models that are largely ignored in earlier studies. Our results, however, support Feirrer and Vincent (2005) in that conventional net produced investment has no predictive power for explaining changes in future consumption. In contrast, for the USA since 1869, adjusting for natural resource depletion produces green investment measures which fail even the weakest tests of sustainability; indeed our green measure predicts resource depletion increases future consumption. One possibility here is that for the USA there were positive productivity externalities associated with natural resource use, for example in the stimulus given to coal or oil using technology (Greasley and Madsen, 2010). Since our simple GREENINV measure excludes technology or residual productivity, its estimated negative coefficient possibly reflects missing elements of human and social capital or exogenous technology, which form part of comprehensive wealth.

Our results are supportive of World Bank-type, public investment in education measures, which, when included in comprehensive investment, predict year on year future changes in consumption per capita very well over 20 or 30 years horizons. The strongest version of the sustainability hypothesis  $H1: \beta_0 = 0; \beta_1 = 1$ ; however, does not receive support from the CI measure. There are several possible reasons why the test results for CI reject the strong hypothesis. Private education investment and workplace learning are excluded from the measure of human capital formation, in the absence of consistent long run data. Alternative human capital indicators, for example years of schooling and wage-based indicators have been proposed. These alternatives ascribe higher productivity (and wages) to schooling

and/or assume that wages measure productivity. Accordingly, the alternative human capital formation measures are not well-suited to our analysis which seeks to explain how well future consumption per capita, which correlates closely with average real wages, is explained by current comprehensive investment. However public education investment does not measure fully all elements of human capital formation and the rejection of the strong hypothesis needs to be judged in that context.

Additionally, the measure of CI excludes intangible elements of capital formation, which may also be important for future consumption. The World Bank (2006) explores the possible elements of intangible capital, which in effect includes anything not measured elsewhere. Elements of social capital, including trust, and institutional capital, including governance are part of intangible capital, but the World Bank (2006) also count human capital here, given its omission from their measure of adjusted net saving used in predicting future well-being. Others, for example Abramovitz and David (2000) emphasize the importance of business organization as a form of intangible capital. Drawing of the work of Kaufmann et al (2005) and using an indicator of the rule of law, the World Bank (2006) estimate the relative importance of schooling and institutions in residual (intangible capital) productivity, reporting the rule of law accounts for 60% and human capital for 35% of the intangible capital residual. The case for incorporating a measure of residual productivity in comprehensive investment thus appears strong, although there is no consensus how it should be done.

Our approach utilizes a measure of TFP in two ways. To the extent that TFP reflects exogenous technological progress, its value may simply be added to CI, producing a net

investment measure here denoted CITFP. This broader measure predicts future consumption better than CI over 30 and 50 year horizons; indeed over 30 years the strongest sustainability hypothesis is not rejected. The upshot appears clear enough, either public education investment does not fully capture human capital formation or that there are sources of productivity growth which are not explained by changes in human capital. The latter may, as Pezzey suggests, derive from exogenous technology. Certainly analysts who are sympathetic to endogenous interpretations of economic growth do not deny that important elements of technological progress may be exogenous (Crafts, 1995). The contrast in the CI and CITFP results points to a relatively short horizon of 20 years over which the benefits of education investment are realized, while the gains from exogenous technological shocks are longer lasting and may extend over 30-50 years.

The World Bank's (2006) interpretation of residual (intangible capital) productivity is rather different given they consider it embodies human and organizational capital, but they do not consider any explicit role for exogenous technology. Within the World Bank's framework our GREENTFP measure provides the appropriate broad indicator. Again GREENTFP predicts future consumption more satisfactorily over 30 or 50 year horizons than CI, and it does not reject the strong sustainability hypothesis over the 20-50 year horizons. Collectively the CI, CITFP and GREENTFP results favour the inclusion of education investment and social/institutional capital in comprehensive measures of wealth. The particular construction of TFP here probably makes GREENTFP our most plausible comprehensive measure, with the TFP element capturing human and intangible capital formation, where the latter includes exogenous technology as well as social/institutional capital. Refining measures of TFP where human and possibly institutional capital are defined as more clearly

specified inputs would help to shed further light on the key elements of comprehensive wealth. The results thus far highlight that the World Bank's indicator of sustainability is unlikely to be satisfactory over long horizons unless human and intangible measures of capital formation are included in comprehensive investment.

Finally, we note that including historic carbon emissions as negative changes in capital, which deplete the world's scarce assimilative capacity for greenhouse gases, resulted in very small changes in our estimate of comprehensive investment, and no qualitative change in the results of hypothesis testing. This may be explained by the very low value for past CO<sub>2</sub> emissions as a percentage of GDP. Looking forward from the present day, CO<sub>2</sub> emissions would involve a larger and growing adjustment to comprehensive investment, as the marginal cost of emissions rises over time (Pezzey and Burke, 2013).

## **Data Appendix**

**GDP, GDP deflator, population:** Our GDP series, GDP deflator series were derived from Johnston and Williamson (2013).

**Consumption:** Annual consumption data for 1869-2012 is from Rhode (2002) 1869-1900, Carter et al (2006) 1901-1962 and ERP (2012) 1963-2012. Consumption is deflated using US consumer price index from Johnston and Williamson (2013). Per capita real consumption was obtained by dividing real consumption by population. The present value of the change in consumption was calculated over three time horizons, 20,30 and 50 years using a 3.5% discount rate.

**Net Investment:** Net investment consists of produced capital and overseas investment. Gross fixed capital formation, inventories and net overseas investment from 1869-1909 were taken from Rhode (2002). Annual data for gross investment, inventories and net overseas investment for the years 1909-1929 was taken from the data appendix to Kuznets

(1961). From 1929 to 1992 the data is from Carter et al (2006) and from 1992-2000 data was taken from the (ERP 2011). Capital consumption was from Kuznets (1961) for 1869-1929, from ERP(1963;1995;2011) for 1929-2000.<sup>4</sup>

**Green Investment:** The Green investment consists of renewables (forestry and land) and non-renewables (mining operations, metals and minerals including fuel). Carbon emissions are also included in some measures. Natural resources were valued at international prices minus average cost of production. This cost method was similar to that utilised in McLaughlin et al (2012). US natural capital was primarily calculated from volume 4 of Carter et al (2006).

**Forestry:** Changes in forestry stock were obtained by estimating the area of forestry and the standing volume of timber (m<sup>3</sup>). The area of forests were obtained from Carter et al (2006, series CF101-118 and Cf135-144). Estimates of standing volume were obtained from (Zon (1910), Zon & Sparhawk (1923), Clawson (1979), Oswald *et al.* (2007), USDA (1997), Smith & Darr (2002), Smith, *et al.* (1997), USDA (1997), Carter et al (2006). The earliest estimate of standing volume was 94.59 cubic metres per hectare in 1920. It was assumed that this was constant from 1850-1920. The forest area was multiplied by this estimate. From 1920 to 2000 the area of forestry was multiplied by the standing stock of timber (m<sup>3</sup>) per hectare. The change in the standing volume of timber was valued at market prices minus average costs. Prices were US stumpage prices from 1905-2000 and for the period 1869-1904 it was assumed that forestry prices followed a trend similar to the US building materials index (Carter et al 2006). Employment estimates and annual lumbering were derived from the

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<sup>4</sup> The series 1929-1962 from the 1963 ERP, the 1995 ERP begins in 1959-1994 and the 2012 series begins in 1964 and ends in 2011. The level for 1959 in from the 1963 ERP was \$41 b but \$46b in the 1995 ERP, the 1963 ERP series was scaled by a factor of 1.09 (rounded) to create a consistent series. From 1963 onwards the 2012 ERP series is used.



Carter et al (2006) and Lebedys (2004), the wages used to calculate wage cost per m<sup>3</sup> were unskilled wages derived from Officer (2012) and David & Solar (1977).

**Land:** We have calculated the economic value of gains/losses in farmland using estimates of rents (i.e. profits) per acre discounted over time. In any year the value of appreciation or depreciation in the stock of farmland is given by the physical change in area (we cannot distinguish different types of crop land) valued using the present value of rents over a 30 year forward period. Land value data was obtained from Carter et al (2006). Data from Lindert (1988) indicated that the rental value of land was 15 per cent of the land value, a rental value of us farmland was estimated assuming that this rental value was a constant ratio of the value of agricultural land. Rents were as far as 2030 were forecasted using an ARIMA (5,1,1). Data on farmland is taken from the Carter et al (2006, series DA17).

**Non-renewables:** From 1880-2000 mining (fuel, metals and minerals) data is from US historical statistics (Carter et al 2006). Fuel is comprised of coal Bituminous, Coal Subbituminous, Coal Lignite, Coal Pennsylvania Anthracite, Crude Petroleum, Natural Gasoline and Cycle Products, and Liquefied Petroleum Gases, Natural Gas Marketed, Uranium Concentrate. Metals are comprised of Iron Ore, Copper, Zinc, Manganese Ore, Chromite, Tungsten Concentrates, Molybdenum Ores and Concentrates, Vanadium Ores and Concentrates, Nickel, Bauxite, Aluminum Primary, Magnesium Primary, Gold, and Silver. Minerals are comprised of Crude Gypsum Mined, Lime, Sand and Gravel, Stone, Sulfur Production from Frasch Mines, Pyrites Production, Salt, Potash Sold By Producers, and Phosphate Rock.

From 1869-1880 mining output was estimated using data from US historical statistics and (Herfindahl 1966) and (Gallman 1960), and valued at international prices. Commodities used were iron ore, copper, lead, zinc, gold, silver, coal and crude petroleum.

Mining wage cost per tonne was calculated from data on mining wages in coal and the annual relative productivity between coal mining and mining.<sup>5</sup> Coal output, employment and wage data from 1869-2000 were obtained from Carter et al (2006). Mining employment and output were also obtained from Carter et al (2006). Over the period 1855-2000 the mean relative productivity between coal and mining was 1.06.

**Carbon Emissions:** US carbon pollution estimates were taken from Andres et al(1999) and Boden et al(1995) and the price series from is derived from Tol (2012). This is the 2015 price of \$29 per tonne of carbon discounted by 1.99 per cent to 1869.

**TFP:** We computed a time series of total factor productivity over time for the US, and then fitted a trend growth rate to this as a measure of technological progress. Data on labour hours worked and real capital stock is taken from Greasley & Madsen(2006), real GDP is taken from Johnston and Williamson (2013). Factor shares used were from Greasley & Madsen (2006). 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).

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<sup>5</sup> Including oil and gas.

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