Australia: a land of missed opportunities?

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Abstract:

Comprehensive Investment (CI) may provide an indicator of future changes in a country's per capita consumption. We explore the utility of the CI indicator for Australia by constructing CI data since 1861 and by estimating their relationship with changes in future consumption over periods of 50 years ahead. The CI measures include changes in natural, produced and human capital, and make allowance for exogenous technological progress. The results are used to consider how Australia's natural capital exploitation influenced the consumption of future generations. Further, we gauge if low CI relative to other leading OECD countries resulted in lower consumption levels in Australia over time than feasible, had it saved more.

Keywords: Australia, sustainable development, comprehensive investment, genuine savings, consumption, technological progress.

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1. Introduction: Comprehensive Investment as an indicator of sustainable development

The idea of using a nation's Comprehensive Investment (also referred to as Genuine Savings, Genuine Investment, Inclusive Investment and Adjusted Net Savings) as a forward-looking indicator of "weak" sustainability is well-established (Hamilton and Clemens, 1999, Arrow et al, 2003; Pezzey, 2004, Arrow et al, 2012). Weak sustainability assumes that all forms of capital – produced, natural, human and social capital - are perfectly substitutable, and can be measured and aggregated using a given numeraire. Pearce and Atkinson (1993) were the first to suggest that the change over time in a country's total capital stocks (the sum of produced, human, natural and social capital) indicates the sustainability of its consumption into the future. This value of a country's total capital stocks at some point in time has been variously referred to as Comprehensive Wealth, and Inclusive Wealth (UNU-IHDP and UNEP, 2014). The change in Comprehensive Wealth over an accounting period (typically one year) is the level of Comprehenisve Investment in that country. A negative value for this indicator at time *t* indicates that future well-being will be falling, since by implication re-investment in the total capital stock is insufficient to offset depreciation. So long as Comprehensive Investment is positive and not rising "too fast", then a theoretical prediction is that future well-being will be higher than present-day well-being (Hamilton and Withagen, 2007).

Sustainable development, as defined by Arrow et al (2012), postulates an economic path where intergenerational well-being does not declne over time. What aspects of inter-generational wellbeing are included in the consumption vector is not uniquely defined, but can include both market and non-market goods. The sign and value of Comprehensive Investment at time *t* reflects changes in the present value of flows of well-being in the future, since the shadow price of each asset included in Comprehensive Wealth is given by the marginal contribution of this asset to the present value of future flows of well-being (Arrow et al, 2003). These shadow prices used to calculate changes in comprehensive wealth thus reflect what one assumes about the inter-temporal social welfare function, since this defines well-being over time or at any instant in time. Comprehensive Investment (CI, from now on) estimates have been reported for virtually all of the world's economies, typically using World Bank datasets (World Bank, 2006, UNEP, 2012) for years after 1970, although several longer time series of CI for individual countries are also available (Lindmark and Acar, 2013, Greasley et al, 2014, Hanley et al 2016). Alternative indicators of weak sustainability to the wealth-based indicators discussed above include Green Net National Product (Pezzey, 2004): if Green Net National Product is falling, then this indicates future well-being will also be falling. Green Net National Product and CI are closely related to each other theoretically, as shown by Asheim and Weitzman (2001) – see also Pezzey et al, (2006).

For natural resource abundant economies, Hartwick (1977) developed 'a rule of thumb' for constant consumption over time, which required the re-investment of rents from natural resource extraction in capital stocks along a competitive path in a Cobb-Douglas economy. Hamilton, Ruta and Tajibaeva (2006), hereafter HRT, generalized this "Hartwick rule" and illustrated the possibility of unbounded and rising consumption if a CI rate of at least 5% of GDP was maintained over time. Since HRT's generalization of the Hartwick rule provides a policy yardstick for raising consumption over generations, it offers a relevant and possibly appealing prescription for resource-rich developed countries such as Australia.

This paper draws upon the theory of weak sustainability to investigate central issues in Australian political economy surrounding the utilization of natural resource rents and its comprehensive investment over time. Low rates of national savings have been mooted as characteristic of Australia's economy (McLean, 2013, Greasley, 2015). The establishment of nation-building wealth funds in 2008 to support investment in infrastructure, health and education illustrates the concern that consumption growth has rested on resource depletion and may be unsustainable (Australian Government Future Fund, 2014). In this paper, we extend the standard macro measure of saving to include accumulation of *all* forms of capital: produced, human, natural and social. Our purpose lies in gauging how Australia utilized its natural resource rents over time, and in particular whether higher consumption growth might have been sustained by Australia had it matched the CI of three “comparator” countries, namely Britain, Germany, and the USA. HRT, show, with post-1970 data, that consumption rather than investment of resource rents is common among resource-rich countries, to the detriment of future generations, but they do not consider Australia. Randall (2008), also using post-1970 World Bank data, describes Australia as “muddling along”, with adjusted net savings of around 5% of GDP, but he questions if its genuine savings are positive, once environmental factors, including water resource depletion are put into the accounts. Brown et al (2005) concur, and show that natural resource rich Queensland had a genuine savings rate of around half of the Australian average. However, neither HRT, Randall or Brown et al include a measure of technological change in their estimates of CI. In contrast, we include a proxy for technological progress in CI, based on the method suggested in Pezzey et al (2006), given the importance which other long-run analysis has shown of including such an adjustment (Greasley et al, 2014).

2. Australia as a case study

Australia attained world-leading incomes and consumption by the 1850s, but lost its exceptional position during the 20th century (Broadberry and Irwin, 2007, Madsen, 2015). At issue is whether or not a depletion of natural assets uncompensated by investment in other elements of the capital stock and a comparatively low CI contributed to this “lost exceptionalism”. Australia’s economy has long extracted natural resource rents (Cashin, 2002, Battelino, 2010). These rents have chiefly been gained from exploiting non-renewable minerals or finite pastoral land resources, against a backcloth of fast population growth.

As noted above, HRT emphasise the "missed opportunities" of natural resource abundant countries post-1970. Their counterfactuals show how the produced capital stocks of 70 resource-rich countries might have grown 1970-2000 had they adopted variants of the Hartwick rule. Most resource-rich developing countries did not attain their 'generalized' Hartwick rule of 5% genuine savings, and by implication actual produced capital stocks for most countries were lower than in the counterfactual world, creating a wedge between potential and actual consumption. However, Australia differs from many developing countries with regard to non-renewable resources. The rise and fall of public investment and swings in international borrowing have been distinctive elements of Australian produced capital formation (Maddock, 2015). Moreover, human and technological capital now form a large part of Australia's wealth. Randall (2008) reports that intangible capital (calculated as a residual) comprised nearly 80% of Australia's total wealth in 2000. Thus, HRT's method of constructing counterfactuals, which simply consider the re-investment of resource rents in produced capital, are too restricted for Australia.

Further, simply re-investing resource rents, or, indeed attaining a 5% CI/GDP ratio, does not provide a sensible 'rule of thumb' for Australia, which experienced world-leading incomes and consumption for much of the post-1861 period. This is because leading economies have often attained savings ratios of above 5%. The counterfactual CI ratio used in our paper therefore uses the savings rates (rates of comprehensive investment) attained by other leading OECD countries over the past 150 years (Hanley et al, 2016) to calibrate what Australia might have saved and invested, and thus how much higher its present day wealth (future consumption possibilities) might have been today.

The analysis has the following sequence. Firstly, by constructing long series of CI for years since 1861 and by investigating their correlation with the present value of consumption changes over horizons of 50 years into the future, the utility of CI as a consumption predictor for

Australia is gauged. Several variants of CI are considered, including indicators using total factor productivity to measure changes in technological capital. Our analysis of CI as a sustainability indicator also includes a variant which assumes that new minerals discoveries offset extraction over finite (50 years) time horizons. Secondly, having estimated the relationships between savings and future consumption, they are used to identify the appropriate savings counterfactual for gauging the feasible trajectory of Australia's consumption. Thirdly, by drawing on previously constructed estimates of CI for several OECD countries for year since 1870, we postulate how Australian consumption might have grown. The counterfactural exercise projects Australia's actual consumption per capita of 1870, by assuming it matched the higher savings rates of the OECD countries, to gauge whether or not Australia is indeed a land of missed opportunities. The utility of the counterfactual rests on showing that some variants of CI can predict future consumption over a fifty year horizon, for Australia and the comparator countries. To anticipate, augmenting CI with measures of technological progress is necessary to predict the future consumption of OECD countries, including Australia, over long horizons.

3. Comprehensive investment and future consumption

Ferreira, Hamilton and Vincent (2008), hereafter FHV, showed that with a constant population growth rate of γ, a population at time *t* of *N*, a consumption discount rate of ρ, and year-on-year change in produced capital *K,* denoted $\dot{K}$, that per capita CI, denoted g (for genuine savings) is given by:

$$g = \frac{\dot{K}}{N} - F_R\ r - \gamma\omega \qquad (1)$$

where $(F_R\ r)$ is the shadow value of per capita natural capital extraction and ω is per capita wealth, which is the sum of per capita natural and produced capital stocks W at time *t* divided by the population *N*. This shows CI per capita is determined by per capita net change in produced and natural capital (the first two terms on the right-hand side of equation (1) adjusted by a "wealth dilution effect" from population growth $-\gamma\omega$. Equation (1) thus shows the constituents of the CI indicator at any point in time.

Of equal interest is the theoretical literature which relates CI to changes in well-being into the future. For instance, Arrow et al (2012) show that intergenerational well-being is rising over future periods if CI is positive when evaluated at the correct shadow prices in the current period. Hamilton and Withagen (2007) show that if CI is positive and growing at a slower rate over time than the real discount rate, then consumption will rise over time. FHV (2008) show that in any period *t,* the value of g is equal to the discounted value of changes in per capita consumption from *t* to infinity if the consumption discount rate ρ is adjusted downwards by the (constant) population growth rate. If population grows at a varying rate, then the relationship between per capita CI and the present value of changes in future consumption is altered. From this, FHV derive a reduced-form relationship between CI and the present value of changes in future consumption (PVΔC) with constant population growth:

$$PV\Delta C_{it} = \beta_0 + \beta_1 g_{it} + \epsilon_{it} \qquad (2)$$

or with varying population growth:

$$PV\Delta C_{it} + PV(\Delta\gamma_{it}\omega_{it}) = \beta_0 + \beta_1 g_{it} + \epsilon_{it} \qquad (3)$$

Ferreira and Vincent (2005) was the first empirical test of CI as a forward-looking sustainability indicator. They used four alternative measures of changes in a country's capital: 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. A test of CI as a predictor of future changes in consumption is that $\beta_1 = 1$ They found that β_1 is always positive except for a sub sample of 22 OECD countries, a finding they attribute to the likely greater importance of technology or total factor productivity in developed countries. FHV (2008) estimated both (2) and (3) using data for 64 developing countries over the period 1970-2003. Their chief finding is that the hypothesis $\beta_1 > 0$ is supported only for green net savings and its varying population growth adjusted equivalent. However, their estimates of β_1 are "significantly below 1".

Greasley et al (2014) and Hanley et al (2016) extend tests of the CI by using longer spans of data, covering up to 250 years for Great Britain, Germany and the USA. They additionally investigate the effects of allowing for a "value of time passing"; treating time as an uncontrolled capital stock, that, through exogenous technological progress, expands the economy's production possibilities, following Pezzey (2004). Thus, in the terminology of (2) and (3), g can now include changes in both human capital and a value of technological progress as increments to the capital stock, as well as changes in produced and natural capital. The hypothesis of a one to one relation (β_1=1) between the more inclusive (value of technology-augmented) measures of net investment and future well-being over horizons of up to 100 years receives some support from their findings for Great Britain. Additionally, for a 3-country panel of Germany, the USA and Great Britain with post-1870 data for consumption per capita and CI measures augmented with the value of technology, these authors report estimates of β_1 = 1.12 and 1.16, for horizons of 50 years, depending on the inclusion or otherwise of fixed effects in the panel regressions.

3.1 Comprehensive Investment and Australia

Now we turn to formulating the CI measures used to indicate future changes in Australia's consumption for years since 1861. Several measures of Australia's CI per capita are used here to represent g in the empirical tests of Equations 2 and 3. The motivation of the tests is to establish how the alternative measure of CI indicate changes in the future consumption of Australia since 1861. The hypothesis β_1 = 1 provides the basis for gauging the utility of the CI measures as an indicator of changes in future consumption in Australia, assessed here over forward-looking horizons of up to 50 years.

An important consideration for the Australian CI estimates arises in the treatment of minerals in the natural capital stock measures, which form part of green net savings and varying population growth-adjusted green savings. Previous studies (e.g. Hamilton and Clemens, 1999; Hanley et al, 2016) simply treat mining as capital depletion, but new discoveries of economically viable resources are potentially an important increment to Australia's capital stocks. In recent decades, the discovery of new economically-viable reserves of many minerals have exceeded rates of extraction. In the absence of historical data on viable reserves, the alternative investment measures used here either count or omit mining as capital depletion, to gauge which approach best indicates future consumption changes. Moreover, technological progress has been a powerful long run force in raising incomes and consumption in developed countries (Abramovitz, 1956). Pemberton and Ulph (2001) and Pezzey et al. (2006) have highlighted the need to include changes in technology in measures of a nation's capital stocks. Weitzman (1997) suggested the incremental value of technological change for a nation's total capital could be as high as 40% of Net National Product. Since omitting a technological progress measure may understate changes in capital, especially for OECD countries, variants of CI augmented with a technology premium based on total factor productivity are also reported and utilized here.

Accordingly, the results in section 5 use eight alternative measures of g_t:

1. NP, which is net national investment in produced capital;

2. GreenI, which comprises NP plus changes in natural capital, where mineral extraction is equated to depletion;

3. CI, which comprises GreenI and education investment;

4. CIm, which is CI, augmented with the value of mineral extraction;

5. CITFP, which is CI augmented by a value for changes in exogenous technological progress;

6. CImTFP, which is CIm augmented by a value for changes in exogenous technological progress;

7. CITFPW, which comprises CITFP adjusted for the wealth dilution associated with a varying population growth; and

8. CImTFPW, which comprises CImTFP adjusted for the wealth dilution associated with a varying population growth.

These eight variables are described in the Data section 4 (using the sources detailed in the online Appendix), and used in tests of the hypothesis $\beta_1 = 1$, in the Results section 5. Having gauged the utility of the various savings measures as forward looking indicators of Australia's consumption, section 6 then reports a counterfactual experiment to show a trajectory of consumption in a world where Australia matches the investment of Germany, the USA and Britain over the period 1870-2011, rather than investing at observed historical rates.

4. Measuring Australia's Comprehensive Investment and Consumption

4.1 Consumption per capita

Australia's average consumption per capita was exceptionally high by the early 1870s, and was around 12% higher than that of the UK over the years 1870-4, when measured in (purchasing power adjusted), denoted \$GK. The disparity in 1870-4 with the USA and Germany was even greater, with Australian advantages of 35% and 68% respectively. Most analysts attribute this "Australian exceptionalism" to the high productivity of the pastoral and minerals economy (Broadberry and Irwin, 2007). However, compared to the most prosperous parts of the world

Australia has experienced consumption decline since the 1870s, most obviously relatively to the USA, as shown in Figure 1 (online appendix, herefter OA). British and Australian consumption per capita have aligned more closely since the 1870s, but the long phase of higher Australia levels post-1945 ended around 1990. Germany's relative position is impacted by the effects of the world wars, but, along with the UK, West Germany catches up with Australian consumption levels in the 1990s, although reunification hits average German consumption thereafter.

The PV of future changes in Australian consumption per capita in \$A, for horizons of between 20-50 years using alternative discount rates, are shown as Figure 2 (OA). The discount rate of 2.64%/year is the average long-run interest rate (Pope 1986, Homer & Sylla 2005, OECD) minus the CPI inflation rate from 1861-2011.[1] Thus, for example, the final data point for the 50 years' horizon is 1961, with consumption changes measured over 1961-2011. The series show that consumption per capita generally rises, especially in the 20th century, although over the shortest 20 years' horizon negative changes are experienced until the 1920s, with consumption per capita falling 1927-47. The central issue for us is whether or not this comparative decline in Australian consumption levels could have been avoided with higher savings.

4.2 Produced, Green and Education Investment

Estimates of Australia's net national produced investment, NP, are extant for years from 1861 (Butlin, 1962, ABS cat. no. 5206). The chief additional elements in GreenI are the increments in the rental value of land and the extracted value of mining rents. Pastoral land accounts for the bulk of farmland rents in Australia. Butlin's investment accounts reflect the importance of

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[1] Kozack (2005) considers possible criteria for choosing the discount rate. One alternative is to use a discount rate which will reflect the fundamentals of country's capacity to consume, for example exports or GDP. Australia's average growth rate of real GDP averaged 3.33%/year from 1861 to 2011. This higher discount rate is used as a sensitivity test in the Results section, and the data are also shown in Figure 2 (OA).

cattle and most especially sheep farming in Australia by incorporating livestock accumulation. His sequence of net domestic capital formation, plus livestock accumulation, less net overseas borrowing leads to a concept of net national capital accumulation (Butlin, 1962, p. 5). Livestock have been an important part of Australia's assets, and the changes in their stocks were large compared to net investment in produced capital in the 19th century. The annual gain from livestock accumulation averaged 1.05% of GDP 1861-90 (Butlin, 1962, pp. 62-7). The value of livestock's accumulation mirrors closely the changes in the rental value of pastoral land (Greasley, 2015, p. 163). Accordingly, the estimates of livestock accumulation are used here to approximate changes in pastoral rents since nomadic pastoralism, especially in the earlier years, makes measuring pasture in use problematical. The land area under cultivation each year can be measured directly. Rental values per hectare of agricultural land are higher than for pasture, but cultivated land rent's contribution to overall land rents is relatively modest (Greasley, 2015, p. 164).

The estimates of NP excluding livestock accumulation, shown in Figure 3 (OA), averaged 6.57% of GDP 1861-2011. NP was sometimes negative, most especially in the 1890s and the early 1930s. The highest rates of NP were achieved in the decade before World War One, and during World War Two and the 1950s. Australia's domestic produced investment (not shown) was sometime above NP, given the sometimes high level of overseas borrowing, for example during the 1870s and 1880s.

Australia has long extracted mineral rents, defined here as minerals production multiplied by price less wage costs per ton. Following the gold boom of the 1850s, there have been three periods when mining rents exceeded 5% of GDP: during the 1860s, around the turn of the twentieth century and since 1988. Over the long period mining rents averaged 3.53% of GDP. Debiting minerals extraction and adding changes in pastoral (approximated by livestock accumulation) and cultivated land rentals from and to NP yields the series GreenI in Figure 3

(OA). This measure of Australia's green investment averaged 3.29% of GDP 1861-2011, showing that Australia most likely surpassed the 'Hartwick Rule'. Some elements of natural capital, most especially the net loss of forests, are omitted from GreenI, simply because of a a lack of long run data. Randall (2008) and Brown at al (2005) argue that deforestation is modest after 1970. There are only conjectures of the likely forest area for earlier years, notably those of Gammage (2011) which argue that afforestation accompanied the decline of the aboriginal population.

There are, however, prolonged periods where GreenI is negative, including between 1991-2007, during the earlier mining booms of the 1860s, and around the turn of the twentieth century. For the years to World War Two, CI and GreenI align closely, given low education investment. Thus, Australia's CI was also negative for long periods before 1939; on several occasions by amounts in excess of 5% of GDP. In contrast, the higher rates of education investment after 1945 have been associated with consistently positive CI, contributing to an average CI/GDP ratio of 5.28% in the period 1861-2011.

The alternative measure CIm does not debit extracted mineral rents, postulating that minerals finds in Australia offset the resource depletion from mining. The CIm/GDP ratio averaged 8.81% between 1861-2011, showing Australia's savings in a more favourable light than the conventional CI measure. The historiography of Australia's mineral discoveries emphasizes that markets and institutions shaped exploration and the exploitation of minerals. Blainey (1970) charts the discoveries of the nineteenth century, arguing that searches intensified when other trades slackened, as the opportunity cost (chiefly of labour) diminished. Alluvial gold mining was labour intensive, but the capital intensity of mining rose, and mining investment reached 4% of GDP in 2009, around twice the ratio as during the early twentieth century mining boom. McLean (2013) attributes mining resurgence from the 1960s to Asian demand and shipping innovations, while Wright and Czelusta (2002) note the association of investment in mining education and the easing of export restrictions. The sustained rise in mineral prices from the 1970s further encouraged the rise in mining investment over the next forty years (Greasley, 2015).

4.3 Augmenting Comprehensive Investment with Technology.

Weitzman (1997) and Pemberton and Ulph (2011) advocated including exogenous technological progress in the capital stock assessments of a country. Arrow et al (2012) also included the value of technological progress as part of a country's capital stock. Pezzey (2004) refers to such technological progress as part of a "value of time passing", which increases the future consumption possibilities of an economy. The case for including exogenous technological progress within a more comprehensive investment measure appears strong for OECD countries where residual productivity plays a central role in income growth (Manuelli and Seshadri, 2014).

Trend growth TFP estimates underpin the valuation of exogenous technological progress. Treating time as an uncontrolled capital stock means TFP's contribution to the change in wealth in any year should be included in augmented measures of CI. Our approach to gauging how TFP contributes to changes in the value of wealth follows Pezzey et al (2006, Equation 14) and calculates the present value of future changes in TFP over a 20 year horizons, using a 2.64% per annum discount rate.[2]

The TFP index utilized here includes inputs of pastoral land, approximated by the stock of sheep and cattle, and hectares of cultivated land (Greasley and Madsen, 2016). Accordingly:

$$TFP = Y/K^{\alpha}T^{\beta}L^{1-\alpha-\beta}, \tag{5}$$

[2] Except where a 3.33%/year discount rate is used for consumption and then a 3.33%/year discount rate is also used for the value of TFP. Arrow et al (2012) adopt an alternative measure defined by the ratio of TFP/GDP.

where Y is real GDP, K is produced capital, T is pastoral and agricultural land, L is labor hours, and the exponents are the relevant output elasticity, measured by income shares.

The exclusion of mineral reserves as a factor input, needs to be explained. Over time the extraction of minerals will diminish the reserve, to the likely detriment of measured TFP (Syed, Grafton and Kalirajan, 2013). Alternatively, discoveries in Australia, most often of gold before 1914, but of a wider range of minerals from the 1960s, including iron ore and bauxite tempered depletion, to likely augment measured TFP. Thus the index of TFP, which shows actual average growth of 1.57% per annum 1842-90 and 0.79% per annum 1891-2009 is a residual which may reflect, inter alia, the vagaries of minerals discoveries.

The measures of savings including technological change used here (CITFP and CImTFP) incorporate estimates of trend TFP (extracted using a Kalman Filter) using data defined as Equation 5, and illustrated in Figure 4 (OA). TFP unadjusted for minerals reserves is adopted because TFP from any source will impinge upon future consumption. Moreover, the measures of TFP available for the comparator countries are also unadjusted for mineral reserves, thus the counterfactuals reported in section 6 are based on consistent data. The measure of trend TFP, therefore, is not strictly exogenous technological progress, the uncontrolled stock of technological capital associated with the 'passing of time', but rather reflects wider forces influencing residual productivity.

The present value of TFP summed over a 20 years' horizon and discounted at 2.64% per annum averaged around 20% of annual GDP since the1890s, and it was higher in earlier decades, see Figure 4 (OA). These data highlight the magnitude of TFP for changes in the comprehensive wealth of Australia. To illustrate, Figure 5 (OA) compares NP, GreenI, and CI with the TFP augmented measure, CITFP. Whereas CI averaged around 5% of GDP, the corresponding figure for CITFP is around 30%. These comparisons highlight the central influence of technological change and the other ingredients of residual productivity for rich countries like Australia, and temper the value of HRT-type 5% genuine savings prescriptions for OECD, and possibly for developing, countries.

Although the ratio of CITFP/GDP spiked in the 1870s and again after 1945, real CITFP per capita shows an upward movement though the 20th century, see Figure 6 (OA). While GreenI per capita is often negative, the values of CITFP per capita are consistently positive and generally rising. Intuitively at least, the positive changes in the PV of future consumption per capita shown in Figure 2 (OA) correspond generally with the upward shifts in CITFP per capita. The precise relationship is estimated in section 5.

4.4 Varying population growth and wealth-dilution.

With varying population growth FHV (2008) show that the relation between CI and the present value of future changes in consumption is altered by a wealth dilution effect (equation 3 above). The wealth dilution effect arises from the sharing of a given amount of capital between more people. So long as population growth is positive, wealth dilution reduces CI per capita, The measure of aggregate wealth used here to calculate the wealth dilution effect follows the World Bank's 'top-down' construction method. The World Bank measure identifies Total Wealth with the present value of an estimated stream of private and public consumption over 25 years. On this basis Australia's wealth per capita shows no appreciable gain from the 1860s to around the years of World War Two. Since then wealth per capita has grown by a factor of three.

5. Estimation and Results of hypothesis tests on β_1

The equations of interest are (2) and (3). These are not empirical models aiming to best represent the lhs variable, rather the equations are used test the implications of the CI model. Our focus lies in producing estimates of β_1 and their standard errors. These estimates may be effected by the proxies used for the relevant variables and by the estimation methods. Given the long time series for the alternative measures of g, used in the estimation of equations (2) and (3), the issue of possible non-stationarity of the data needs to be considered. Where the variables in (2) or (3) are stationary or integrated of order zero (denoted I(0)), the estimates will have classical properties[3] except where endogeneity issues might arise. Endogeneity is potentially a problem where population adjusted savings and wealth-dilution terms are included, as in (3), see FHV (2008). In such cases an instrumental variable estimator (2SLS) is adopted. A further issue arises if the relevant variables are non-stationary for example, integrated of order one (denoted I(1)). Here spurious correlation may arise unless the (two) variables in our test equations (2) or (3) are cointegrated, see Engle and Granger (1987).

Cointegration, should it exist, would have a property of producing 'super-consistent' estimates and the cointegrating relationship could be interpreted as representing a long run equilibrium (Greasley and Oxley, 2010). If the two variables in our test equations (2) or (3) are integrated of different orders, then a cointegrating relationship cannot exist; and if the two variables are both I(0), any linear combination of the variables (trivially) satisfies the properties of cointegration. Unit root tests of the variables of interest based upon the Augmented Dickey-Fuller test for (non) stationarity are reported as Table 1. Tests for the existence of cointegration use the 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.

Consider first the results for reported in Table 2, where the estimates of β_1 for NP, GreenI, CI and CIm fall in the range of 2.5 – 2.8. The proposition β_1=1 underpins the empirical tests of CI as an indicator of future consumption, as explained in Section 3. In all cases reported here the hypothesis β_1=1 is rejected for our data, so that the PV of future changes in real consumption per capita over a 50 years' horizon is higher than that indicated by the level of

[3] Neither (2) nor (3) include LDVs, as such any serial correlation will not induce bias or inefficiency. In all estimates presented serial correlation and heteroskedastic consistent standard errors are reported.

savings. Additionally, over the long run, the augmented measures GreenI, CI and CIm do not better indicate future changes in consumption than NP and all the measures *not* augmented with a value of technological progress greatly understate future consumption growth. Of course, these results need to be judged in the context of the ADF tests which do not reject the null of no-cointegration in the cases of NP, GreenI, CI and CIm.

What appears more relevant for Australia is the augmenting of the investment series with a technology premium. In this case, for CITFP and CImTFP (both of which are I(1), as is CONS50), the estimated β_1 parameter values are 1.34 and 1.31 respectively, and, in the latter case, the null of a one to one relationship between investment and future changes in consumption, looking forward fifty years, is not rejected. The results for CImTFP raise the possibilities that extracting minerals should not be counted as disinvestment and that Australia consumed exhaustible natural capital to support consumption, to the possible detriment of future generations. However, the longevity and the discovery of new mineral reserves in Australia casts some doubt of accounting conventions which simply equate extraction with disinvestment, and we return to this issue later. More certainly, technological change formed an important part of changes in Australia's wealth, and its value needs to be incorporated in interpretations of future consumption growth. However, once again, in the absence of cointegration, the estimated long run coefficients of β_1 in the cases of CITFP and CImTFP need to be treated with some caution.

A characteristic of Australia since 1870 has been its high population growth, which has exceeded the rates of Western Europe and the USA. Thus, the possibility of a significant wealth dilution effect (the spreading of capital among a larger population), may have particular resonance for Australia. There was also a secular decline in labour force participation in Australia from the high, 90% rates of the convict era to a low of around 40%, which was not reversed until the 1970s. Participation, thereafter, rose to around 50% by 2010, partly because of higher immigration. Australia's overseas born rose to 27% of its population in 2010, to temper the effects of an aging native population on labour participiation (Butlin et al, 2015).

The estimates, for the technology augmented measures in Table 3 are based on equation (3), which adjusts the savings-consumption relationship for possible wealth dilution. The form of the adjustment includes a wealth-related variable on both sides of the equation, hence we report OLS and 2SLS estimates, where the latter are deployed to counter any possible bias from endogeneity. As can be seen from Table 1, all of the relevant variables are I(0) making both OLS and 2SLS[4] feasible and appropriate. In all four cases the estimated β_1 value is not statistically significantly different from unity. These findings reinforce the argument for a technology premium to be included in the measure of savings, but also that wealth dilution associated with population growth was a drag on Australia's consumption growth. The robustness of these findings is strengthened by the rejection of no-cointegration.

The inclusion, or otherwise, of minerals extraction as disinvestment has very little effect on the estimated relationships. In the case of the 2SLS point estimates, β_1 is respectively 1.22 and 1.20 with and without the inclusion of mining as disinvestment. This does not mean that attempts to include natural capital within investment accounts are without merit. While GreenI here includes the rental value of farm land and mineral extraction, the accounting exercises of Brown et al (2005) and Randall (2008) further consider forest depletion, water quality and pollution. We are unable to measure these variables with pre-1970 data, and the effects of their exclusion are uncertain, so their omission might lead to an overstatement of rises in wealth. Yet the point estimates of β_1 all exceed unity. If anything, the wealth dilution-adjusted estimates suggest that our broadest measure of savings, CImTFPW understates changes in wealth, at least

[4] The instruments used in the 2SLS procedure were the dependent variable (-1); labour; capital; population; year; rate of interest (short).

in the context of understanding consumption changes over finite horizons of up to 50 years ahead.

There are other possibilities as to why the point estimates of β_1 in Table 3 all exceed unity. These include that the wealth dilution effects of population growth are overstated, or that the consumption discount rate is understated. Much of Australia's population growth since 1870 has been from immigration, and to the extent that the migrants embodied human capital not measured in the Australian national accounts, changes in its wealth might be understated in the accounting of CI. The consumption discount rate embedded in the estimates of Tables 2 and 3 is the *ex post* long run interest rate. To the extent that uncertainty surrounding the future might influence current consumption decisions this rate might understate the value of immediate consumption. The results in Table 4 incorporate a higher discount rate of 3.33%/year (less the population growth rate), which reflects Australia's long run capacity to consume, measured by real GDP growth. The effect is to reduce the point estimates of β_1 to values very close to unity. Another feature of the results in Table 4 is that the OLS and 2SLS estimated parameter values of β_1 are much closer than for the results in Table 3 with the lower discount rate. Again, the results which count or exclude mining output as capital depletion show little material difference.

6. Counterfactual Australia: comparisons with OECD countries

The statistical tests do not reject the hypothesis that CITFPW and CImTFPW exhibit a one to one relationship with the PV of future changes in Australia's consumption per capita for horizons of 50 years. We utilize this finding, along with earlier results for Britain, the USA and Germany, to explore what might have happened to the trajectory of Australia's consumption had Australia's savings matched that of the other countries. The chief elements in the savings ratios of the four countries are set out in Table 5. Australia, since 1946, has had the lowest CI ratio of the four. Its NP after 1946 exceeds that of Britain, but Australia's higher depletion of natural capital and slightly lower education investment accounts for its lower CI. The three comparator (using West German data) countries CI ratio averaged 9.91% between 1946-2000, which is 33% higher than Australia's ratio. The augmented ratio CITFP is also lower in Australia after 1946. The three country ratio averaged 38.4% between 1946-2000, which is around 32% higher than Australia's CITFP ratio of 29.11%. The implication is that, on both the simple measure (CI) and the technology adjusted measure (CITFP), Britain, Germany and the USA achieved savings rates averaging around one-third higher than those of Australia after 1946. The consequences for Australia's comparative consumption decline after 1946 appear to have been ameliorated (over a finite 50 years' horizons) by consuming natural capital, according to the CImTFP measure, since not debiting mineral use adds 4.04% to the saving rate 1946-20.

Over a longer period since 1870, Australia's CI ratio also aligned closely with that of Britain, but lagged well behind the US and German ratios, which averaged a 9.38% CI ratio between 1870-2000, some 60% above Australia's ratio. For the technology-augmented CITFP ratio the three country average over the longer period is 36.5%, or 31% above Australia's ratio. Together, the comparative data for the post-1946 and post-1870 periods highlight that Australia's savings have been persistently low compared to our comparator countries, and that all measures of savings (NP, CI and CITFP), contributed to the shortfalls. Again, the consumption of natural capital appears to have tempered the relative decline of Australia's consumption over the 50 years' horizon, with CImTFP showing a 3.1% higher savings rate than CITFP between 1861-2011.

Next we consider the possible extent of lost consumption arising from Australia's relatively low savings since 1870. Before doing so, we note that Australia savings rate was only low relative to the comparator countries used here. Compared to developing, natural resource rich countries, Australia's savings rates are deeply impressive. HRT's generalized 'Hartwick rule' postulates that a 5% genuine savings ratio may lead to unbounded consumption, and they highlight the failure of many natural resource rich countries to meet this rule post 1970. Our measure which corresponds most closely with HRT's genuine savings data is CI, and for Australia we estimate a CI/GDP ratio of 5.29% for the period 1861-2011. The CI ratio markedly understates the savings of Australia, since it excludes a value for technological progress's contribution to the stock of wealth. On the wider CITFP measure Australia's savings ratio averaged around 29% between 1861 and 2011. Concomitantly, the real value of Australia's consumption per capita grew around seven times over the same period, despite a wealth dilution effect due to the population growing by a factor of around 19. However, the other OECD countries attained CITFP ratios which averaged around 31% higher, despite their lower population growth, which again points to missed Australian consumption opportunities. Even if we postulate that Australia had greater capacity to support consumption over finite horizons by consuming natural capital, the CImTFP measure shows an 1861-2011 savings rate of around 32% which falls short of the average 36.5% CITFP of the comparator countries. At best, consuming natural capital only ameliorated the pace of Australia's relative consumption decline.

Had Australia, post-1870, matched the average CITFP of Britain, Germany and the USA, its consumption would at least have matched the average consumption growth of the comparators. We have shown elsewhere (Hanley et al, 2016) that CITFP provides a good, near one to one, indicator of future changes in consumption of the three comparator countries since 1870, over horizons of up to 50 years. The estimates of β_1 for Australian CITFP are also not statistically different from unity, once allowance is made for wealth dilution from population growth, and these results hold with the alternative measures of the discount rate. For Australia, CImTFP, where mining output is not debited in the savings measure, also provides a near one to one indicator of future consumption over a 50 year's horizon. Thus, Australia's consumption growth may have exceeded that of the other three countries had it simply matched their average CITFP, because of a greater capacity to consume natural capital.

A projection from Australia's actual consumption per capita in 1870, (Figure 7, OA) shows a counterfactual trajectory, assuming Australia did indeed match the average consumption growth of the OECD comparators. The counterfactual shows that Australia consumption per capita would have been around 28% higher by 2010 had its CI, and thus its consumption growth, been equal to that of the comparator countries. The counterfactual shows a potential for Australia's consumption to have sustained a distinct margin above that of the leading European economies, which was forgone because of Australia's relatively low savings. Thus, in 2010, counterfactual Australian consumption per capita is 26% above British, and 44% above West German levels. These are large losses by any standards.

The erosion of Australia's world leading consumption per capita levels of the early 1870s was not a smooth process. An illustration is provided by Figure 8 (OA), which show the discounted PV of consumption per capita changes over 50 year periods, for Australia and for the average of the comparator countries. In 1870, the (discounted) value of the change in Australia's consumption per capita over the next 50 years (PVΔC50) was $GK566, which, we have argued, reflects the value of CITFP or CImTFP in 1870. Thereafter, Australia's PVΔC50 fell sharply and was negative between 1879-1891. It was not until 1897 that Australia PVΔC50 shows levels above the comparator countries average PVΔC50. By implication, a long phase of relatively low Australian saving spanning the years 1870-1896 diminished relative Australian consumption growth over a period lasting until 1946. Unusually, Australia's PVΔC50 exceeds the three country average between 1897-1913. These were years of higher Australian savings, see Figures 5 and 6 (OA), with produced investment showing a sharp rise during the first decade of the twentieth century. This helped to moderate the gap between Australian and the comparator countries consumption growth through to the 1950s. However, Australia pre-1914 savings upturn was short lived, and it was choked-off, initially by World War One and by the interwar depression. Post-1945, CITFP growth was less strong in Australia, and the gaps between Australia's and the other countries PVΔC50 persist to present day.

7. Concluding remarks

Comprehensive Investment (Genuine Savings) has become the most widely-used economic indicator of sustainable development (World Bank, 2011; UNEP, 2014). This indicator focusses on how well a country maintains its asset base of all forms of capital over time, taking into account how the rents from natural resource exploitation are utilized as consumption or savings. The issues are important for Australia's political economy, given its high endowments of natural resources per capita. The standard World Bank savings indicators do not place Australia in favourable light, at least compared to other OECD countries. Moreover, others, including Brown et al (2005) and Randall (2008) have suggested that the World Bank indicators may overstate Australia's genuine savings, by understating its depletion of natural capital. The issues, however, are complex and Brown et al also note that new discoveries of minerals in Queensland have created reserves, of for example coal, which may last 600 years. Nevertheless, there is a growing concern that Australia's savings have been inadequate (McLean, 2013). The establishment of nation building wealth funds in 2008 to support investment in infrastructure, health and education illustrates one policy response to these widely-held concerns (Australian Government Future Fund, 2014).

This paper's principal contributions are fourfold. Firstly, estimates of Australia's comprehensive investment have been pushed back to 1870, and compared to the long run data for the USA, Britain and Germany. Secondly, these measure of savings have been extended to include a value of technological progress. Thirdly, the utility of comprehensive saving measures as predictors of future changes in consumption over a 50 year's horizons for Australia has been gauged. Fourthly, we have explored how the trajectory of Australia's consumption per capita would have grown after 1870, had it matched the savings of comparator OECD countries, to gauge Australia's "lost opportunities".

Australia's comprehensive investment as reported here has been positive in most years since 1870, even without allowing for a value of technological progress. A genuine savings ratio averaging around 5% of GDP, which is probably what Australia has attained since 1870, is sufficient to meet HRT's generalized 'Hartwick' rule for unbounded consumption over time. However, the growth of Australia's consumption after 1870 has, from the tests reported here, greatly exceeded what would follow from a 5% savings rate. Much of the discussion surrounding the utility of comprehensive investment as an indicator of weak sustainability surrounds the possibility that natural capital depletion is understated in the empirical estimates. Brown et al (2005) show, for example, that coral and water resource degradation may not be reflected in the accounts. Certainly, the historical data constructed here does not fully reflect all changes in natural capital. Yet, without allowing for a value of technological progress, the measures of comprehensive investment grossly understate future consumption, looking forward 50 years. However, when allowance is made for productivity advances, the technology augmented measure of savings indicate the future changes in consumption remarkably closely.

Now, this does not mean that incorporating changes in natural capital in measures of savings is unimportant. On the contrary, some forms of natural capital depletion may have implications for strong sustainability, and these ought to be measured. The impact at the local level of natural capital depletion, for tourism or agriculture, for example in Queensland or the Murray Darling Basin, might also be substantial. However, the results here show clearly that productivity improvements have been the chief driver of Australia's consumption growth since 1870. Thus, any attempts by policy makers to manage the natural capital stock, need also consider the implications for technological progress. In the case of minerals extraction, the World Bank's accounting methods would suggest a capital depletion averaging around 3% of GDP in Australia since 1861. In contrast, the results suggest a value of technological progress's contribution to wealth which averaged around 23% of GDP between 1861 and 1990. Within the context of weak sustainability, this technology premium clearly dominates natural capital depreciation, which has led to sustained and substantial growth of consumption, despite a rapid population growth.Weitzman's (1999) argument that worries surrounding natural capital depletion need also to reflect policy concenrns surrounding R&D effectiveness gains support from our Australian case study.

Within the assumptions of the weak sustainability model on which Comprehensive Investment is based, Australia can readily consume natural capital and maintain consumption growth, so long as sufficiently-rapid technological progress is maintained. Even in the context of strong sustainably, certain forms of natural capital depletion including minerals extraction, may have little economic relevance, given the remaining lifetimes of reserves at current extraction rates. The results here, however, reveal some real concerns about Australia's savings rate when compared to other OECD countries. In common with previous studies we also find that Australia's comprehensive investment has not matched that of other developed countries, a conclusion that applies to most years since 1870. The underpinnings of relatively low savings in Australia appear to be broadly based, and to span produced, human and technological capital. To an extent Australia's greater capacity to consume natural capital has probably ameliorated the pace of relative consumption decline. Even so, we show, on conservative assumptions, that Australia consumption per capita might have been 28% higher by 2010, had it matched the savings rates of leading OECD countries since 1870. Had this higher savings rate been realized, Australia would have maintained the per capita advantage in consumption which it had over western European countries more than 100 years ago.

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Tables

Table 1. Unit root tests

Variable	ADF	Order of integration
CONS50	-1.851	I(1)
NP	-2.957	I(1)
GreenI	-3.187	I(1)
CI	-3.218	I(1)
CIm	-2.476	I(1)
CITFP	-1.886	I(1)
CImTFP	-1.497	I(1)
CONSWP50	-4.218**	I(0)
CITFPW	-5.037**	I(0)
CImTFPW	-5.067**	I(0)

Notes: CONS50 is the dependent variable of Equation 2, the net present value of consumption per capita, measured over a 50 years horizon. The discount rate is 2.64%/year minus the population growth rate. CONSWP50 is the dependent variable of equation 3, $PV\,\Delta\,C_t + PV(\,\Delta\,\gamma_t\omega_t)$, which adjusts CONS50 for possible wealth dilution associated with population growth. The other variables are the 8 alternative measures of savings, g_t, defined on p. 9. The degree of augmentation in the ADF determined by the Hannan-Quinn criteria. **denotes significant at the 5% level.

Table 2: OLS Estimates of Equation 2 and Tests of β_1=1

1. Dependent	2. ndependent	3. β_0	4. β_1	5. β_1=1	6. ADF
CONS50	NP	711.5**	2.756**	26.24**	-2.40
		(242.5)	(0.343)	(0.00)	
CONS50	GreenI	1328.9**	2.544**	18.58**	-2.41
		(203.6)	(0.358)	(0.00)	
CONS50	CI	1098.1**	2.64**	24.83**	-2.75
		(207.5)	(0.328)	(0.00)	
CONS50	CIm	534.2**	2.60**	23.91**	-2.68
		(262.3)	(0.327)	(0.00)	
CONS50	CITFP	-820.3*	1.339**	3.07*	-1.52
		(468.4)	(0.193)	(0.08)	
CONS50	CImTFP	-1047.8**	1.310**	2.61	-1.48
		(506.2)	(0.191)	(0.11)	

Notes: CONS50 is the dependent variable of Equation 2, the net present value of consumption per capita, measured over a 50 years horizon. The discount rate is 2.64%/year minus the population growth rate. Figures in parentheses represent standard errors (columns 3 and 4) and p statistics (columns 5) where they are based upon Wald tests of the null hypothesis). ** and * denote significant at the 5 and 10% level respectively.

Table 3 OLS and 2SLS Estimates of Equation 3 and Tests of $\beta_1=1$

1. Dependent	2. Independent	3. β_0	4. β_1	5. $\beta_1=1$
OLS				
CONSWP50	CITFPW	5012.0**	1.096**	0.418
		(442.5)	(0.147)	(0.518)
2SLS				
CONSWP50	CITFPW	5324.1**	1.216**	1.36
		(445.8)	(0.151)	(0.18)
OLS				
CONSWP50	CImTFPW	4776.8**	1.101**	0.47
		(418.4)	(0.146)	(0.49)
2SLS				
CONSWP50	CImTFPW	5027.1**	1.201**	1.84
		(419.1)	(0.148)	(0.18)

CONSWP50 is the dependent variable of equation 3 = $PV\,\Delta\,C_t + PV(\,\Delta\,\gamma_t\omega_t)$, the net present value of consumption per capita, measured over a 50 years horizon, adjusted for possible wealth dilution associated with population growth. Discount rate = 2.64%/year minus population growth rate. Instruments used for 2SLS estimation are: dependent variable (-1); labour; capital; population; year; rate of interest (short). Figures in parentheses represent standard errors (columns 3 and 4) and p statistics (column 5) where they are based upon Wald tests of the null hypothesis). ** denote significant at the 5% level.

Table 4 OLS and 2SLS Estimates of Equation 3 and Tests of β_1=1 with alternative discount rate.

1. Dependent	2. Independent	3. β_0	4. β_1	5. β_1=1
OLS				
CONSWP50	CITFPW	4085.7**	1.029**	0.220
		(326.4)	(0.135)	(0.83)
2SLS				
CONSWP50	CITFPW	4441.0**	0.990**	0.01
		(334.4)	(0.118)	(0.93)
OLS				
CONSWP50	CImTFPW	4309.9**	1.026**	0.04
		(347.3)	(0.136)	(0.85)
2SLS				
CONSWP50	CImTFPW	362.4**	1.022**	2.62
		(32.1)	(0.013)	(0.11)

CONSWP50= $PV\Delta C_t + PV(\Delta\gamma_t\omega_t)$. Discount rate = 3.33%/year minus population growth rate. Instruments used for 2SLS estimation are: dependent variable (-1); labour; capital; population; year; rate of interest (short). Figures in parentheses represent standard errors (columns 3 and 4) and p statistics (columns 5) where they are based upon Wald tests of the null hypothesis). ** denote significant at the 5% level.

Table 5 Savings Ratios as a per cent of GDP, and population growth rates

	I	II	III	IV	V	VI	VII
	NP	*GreenI*	*CI*	*CITFP**	*CImTFP**	*PVTFP**	*Population*
	%	%	%	%	%	%	% per annum
	1870-2000						
Britain	5.40	3.53	5.71	25.62		19.94	0.62
Germany	10.00	8.78	11.59	45.40		33.81	0.64
W. Germany	10.00	9.27	12.19	46.00		33.81	0.81
US	9.81	7.12	10.26	37.62		27.36	1.52
Australia	6.89	3.93	5.81	27.85	30.78	21.99	1.93
Australia 1861-2011	6.57	3.28	5.29	29.12	32.22	23.78	2.00
	1946-2000						
Britain	6.29	4.43	8.07	35.77		27.35	0.33
Germany	9.35	8.16	12.36	49.83		37.47	0.53
W. Germany	9.35	9.35	13.46	50.94		37.48	0.63
US	5.37	2.97	8.20	32.41		24.21	1.28
Australia	7.75	4.11	7.42	29.26	32.27	21.69	1.75
Australia 1946-2011	7.52	3.44	6.97	29.26	32.27	22.14	1.70
	1870-1990						
Britain	5.50	3.63	5.68	25.57		19.90	0.54
Germany	10.32	9.00	11.70	46.22		34.52	0.35
W. Germany	10.32	9.54	12.38	46.90		34.52	0.83
US	10.44	7.65	10.55	40.16		29.61	1.39
Australia	7.10	4.43	6.06	27.85	30.78	21.79	1.72
Australia 1861-1990	6.74	3.92	5.52	29.12	32.22	23.55	2.11

* Present value of TFP is discounted over a 20 year horizon, the data in columns IV-VI are averages ending in the year 1991.