Tracing sustainability in the long run: Genuine Savings estimates 1850 - 2018*

Eoin McLaughlin†, Cristián Ducoing‡, and Les Oxley§

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Abstract

We introduce a new database of historical Genuine Savings (GS), an indicator of sustainable development promoted by the World Bank and widely used in contemporary economic research. GS derives from the theoretical work on wealth accounting, and addresses shortcomings in conventional metrics of economic development by incorporating broader measures of saving and investment, including human capital (education), and natural resource depletion. Its value as an indicator is determined by its ability to be used to predict future well-being. This article provides consistent historical estimates of GS since 1850 for 25 countries to enhance, complement, and contextualise the work of the World Bank and others.

Keywords: Genuine Savings, Sustainable Development, historical national accounts, Natural Resources

JEL Codes: Q01, Q32, Q56, N50, N10

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†Department of Economics, University of Cork, Eire. eoin.mclaughlin@ucc.ie

‡Department of Economic History, Lund University, Sweden & Department of Economics, Public University of Navarre, Spain. cristian.ducoing@ekh.lu.se

§Department of Economics, The University of Waikato. New Zealand loxley@waikato.ac.nz

1 Introduction

To maintain and augment the [Capital] stock that may be reserved for immediate consumption, is the sole end and purpose both of the fixed and circulating capitals. It is this stock which feeds, cloaths, and lodges the people. Their riches or poverty depends upon the abundant or sparing supplies which those two capitals can afford to the stock reserved for immediate consumption. (Smith, 1776, Book II, chapter I)

There exists considerable interest from international organisations and policymakers as to how the management of natural resources affects human wellbeing (e.g., Clark and Harley (2020)). For example, the 2021 *Dasgupta Review* argues that 'in order to judge whether the path of economic development we choose to follow is sustainable, nations need to adopt a system of economic accounts that records an inclusive measure of their wealth'. The concept of *Inclusive* (or *Comprehensive*) wealth measures the value of produced, natural, and human capital in a country and this approach has been adopted by both the World Bank (World Bank, 2006, 2011, 2018, 2021) and the UN Environmental Programme (UNU-IHDP., 2012, 2014, 2018).[1]. Wealth includes all assets from which people can obtain well-being, either directly or indirectly. Changes in wealth per capita, whether positive or negative, are indicators of sustainable or unsustainable development (Hanley et al., 2015).

Polasky et al. (2019) call for a greater integration of both economic and sustainable development concepts and ideas. We echo this call. However, we also call more specifically for greater integration of economic history and sustainability science. Due to the work of the late Angus Maddison and colleagues, we are able to utilise GDP estimates as far back as the Middle Ages for some countries. (Bolt and van Zanden, 2014; Broadberry et al., 2015). While this has provided invaluable material for studying the sources of economic growth, the economic history community has shown little engagement with sustainable development research and the the measurement of wealth in particular. Seeing wealth as the foundation of future income and hence welfare, means that changes in wealth (saving/investment) provide an indication of the feasibility of future, sustainable, development paths (Dasgupta, 2001). The work presented here is the first step towards producing such long-run comprehensive welfare indicators, focusing more on stocks (e.g., wealth), including natural capital, which provide future generations with the capabilities to increase their well-being, rather than on flows (e.g., income), conventionally measured by GDP, which simply measures

[1] In August 2022 the US government announced a new national strategy for monitoring natural assets.

annual outcomes without recourse to their long term implications. If wealth-based methods are to inform sustainable social, economic, and environmental futures, they should, as a minimum, be able to explain the past. We will therefore analyse whether historical experiences can explain variations in past and current levels of comprehensive/inclusive wealth within and across countries and what future sustainable development prospects might look like. If the wealth accounting concept is to complement or replace other indicators, it requires evidence which includes long run estimates for a wide range of countries and a standardized empirical methodology (Hanley et al., 2015). The goal of this work is both to illustrate how the concept can be applied to economic history and also to inspire future scholars to expand on this work and develop new estimates to help inform modern debates.

This article introduces a new historical database of Genuine Savings (GS),[2] a widely used modern economic indicator of sustainable development. The database is the first attempt to collect and collate existing estimates by several scholars to create a consistent database with a wide range of geographic coverage. It builds on work by researchers that has been primarily been published in the field of environmental economics (Rubio, 2004; Lindmark and Acar, 2013; Greasley et al., 2014; Hanley et al., 2015; Greasley et al., 2017). This work is complementary to existing collaborative research programmes in economic history, namely the Maddison Project (Bolt and van Zanden, 2014), by providing sustainability contexualisation to historic income growth. The project also relates to recent work on historical estimates of the Human Development Index (HDI) (Prados de La Escosura, 2021), but with a greater emphasis on environmental degradation. Through the creation of a new database we hope to give important historical context to current debates on sustainability. Therefore our estimates of the change in wealth will complement and nuance these research agendas.

The historical focus is necessary to provide evidence as to whether past policies, choices and resultant outcomes, guided by GDP as a welfare enhancing measure, have maximized (or even increased) well-being, sustainably. Historical data and outcomes provide important measures to test the robustness of the GS approach. Furthermore, historical data enhance current metrics and provide a deeper understanding of natural capital, human capital, technological change, and environmental degradation in the long run, to guide policy for the future.[3] Much of the current work on environmental economics considers uncertain, unknown futures, (scenarios or predictions),

[2] Interchangeably known as 'Comprehensive Investment' and 'Adjusted Net Savings'.

[3] Recent studies are going in the same direction, such as the *Dasgupta Review* and the inclusion of Natural Capital in UN accounting

which may simply never exist.[4] However, insights and data from the past can test alternative modelling approaches to inform policy making in the present and the future. Fenichel et al. (2016) argue that a better understanding of how past changes influence present sustainability outcomes, can be used to forecast the impact of future changes in sustainability.

2 Economics of Sustainable Development

By the early 1990s, the phrase 'Sustainable Development' had become 'pervasive' and was 'the watchword for international aid agencies, the jargon of development planners, the theme of conferences and learned papers, and the slogan of developmental and environmental activists' (Lélé, 1991). However, a clear definition of the phrase was elusive as there were (and are) several, sometimes contradictory, definitions (Pezzey, 1992; Dietz and Neumayer, 2007).[5] The 1987 *Brundtland Report*, one of the most widely cited interpretations of Sustainable Development (SD) as a concept (Schubert and Láng, 2005), defined it as, 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs. ' (World Commission on Environment and Development, 1987, p.43).

The *Brundtland Report* definition therefore has inter- and intra- generational equity considerations and has been the starting point of economists engaging with the concept of SD. For example, Asheim (1994) sees SD as an inter-generational equity issue and defines SD, following the lines of Hartwick (1977), 'as a requirement of our generation to manage the resource base such that the average quality of life that we ensure ourselves can potentially be shared by all future generations'. Whereas Pezzey (1992) defined SD as 'non-declining utility of a representative member of society for millenia into the future'. The former definition has become interpreted as a 'capabilities-based' and the latter as an 'outcome-based' definitions of SD (Hanley et al., 2015). The capabilities-based approach views a SD path of an economy as one where the (per capita) real values of changes in capital stocks are non-negative (i.e. constant or increasing). Whereas the means-based approach views a SD path as one where utility or consumption per capita is non-declining. Dasgupta (2001) illustrates the relationship between both approaches and shows how comprehensive wealth, in particular the change in wealth, equates to future well-being.[6] The latter approach to sustainability links future well-being with changes in capital stocks (Pearce and Atkinson, 1993; Pearce, 2002).

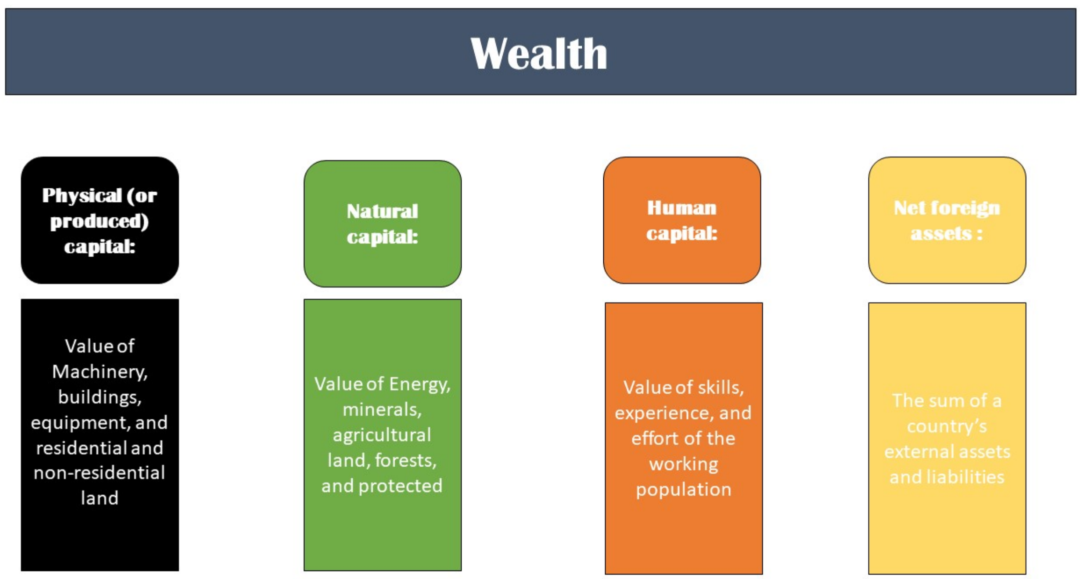
[4]climate change uncertainty has received increasing attention since the 2000s (Tol, 2003)

[5]SD is inherently interdisciplinary and, as Qasim (2017) shows, this leads to a wide engagement with the concepts and and development of metrics to assess it.

[6]This is also elucidated in Arrow et al. (2012).

Wealth is seen as the foundation of future income and hence welfare (Weitzman, 2003, 2017), as changes in wealth (saving/ investment) provide an indication of the feasibility of future, sustainable, development paths. The intuition here is that wealth underpins future well-being within an economy, as wealth (capital) broadly defined is required to generate future income streams (i.e., GDP) (Arrow et al., 2004, 2012) - e.g. see Figure 1. This approach has been the hallmark of recent efforts by the World Bank and the UN (e.g., see (World Bank, 2006, 2011, 2018, 2021; UNU-IHDP., 2012, 2014, 2018).

Figure 1: Components of Wealth



Dasgupta (2001) defines (*comprehensive*) wealth in terms of manufactured capital, human capital, natural capital, and knowledge. There is a further distinction within this literature in terms of how one perceives aggregate capital. One approach being that SD requires non-declining total wealth (weak sustainability) and another where SD requires non-declining natural capital (strong sustainability). The first approach, effectively uses extensions of the Solow (1956) neoclassical growth model to incorporate exhaustible resources (Solow, 1974; Dasgupta and Heal, 1974; Stiglitz, 1974), and assumes perfect substitutability between different types of capital and the monetisation of natural capital.[7] Whereas the latter approach deems that a decrease in a physical unit of natural capital can not be replaced by increase the quantity of other forms of capital (Costanza and Daly, 1992).[8] Fenichel and Zhao (2015) show how technological advances can enhance the array of

[7]So a $1 decrease in the value of natural capital can be compensated by a $1 increase in human capital for instance.
[8]Costanza and Daly (1992) refer to total natural capital which is renewable plus nonrenewable natural capital.

substitution possibilities, however the extent of substitutability is difficult to determine empirically (e.g. (Markandya and Pedroso-Galinato, 2007; Cohen et al., 2019), therefore how one chooses to approach sustainable development, from a weak or strong perspective, is a matter of preference. However, if a country fails a weak sustainability test, such as negative genuine savings, it will in all likelihood also fail a strong test as well (Hamilton and Clemens, 1999).

The GS approach to sustainability rests firmly on the so-called Hartwick (1977) rule, which shows how consumption can be constant over time by re-investing rents from natural resource extraction into other forms of capital (i.e. person-made or human). One of the attractions of GS is that, under certain assumptions, it can be used to assess both the capabilities-based and the outcome-based approaches to SD (Hanley et al., 2015). Another attraction is that it is firmly grounded in the system of national accounts (SNA) framework and can be used to measure and compare countries in a consistent manner. At the most basic level, the economics of SD is more welfare orientated and focuses on changes in wellbeing (proxied by per capita consumption) than GDP growth, as it focuses on net savings(investment), and places greater emphasis on natural resource stocks (Ferreira et al., 2008). The GS approach therefore relates to both the idea of wealth accounting, as it is an indicator of how a nation's total wealth changes year-on-year (i.e. a flow) (Hamilton and Hepburn, 2017; World Bank, 2018), and income accounting (i.e. GDP), as it is built upon the foundations of the SNAs (Hanley et al., 2015). In accounting terms, while both GS and GDP are flows, the distinction between them is clear: GS is a measure of the change in the stock of wealth, whereas GDP is a measure of income that is derived from the stock of wealth (Weitzman, 2003).

2.1 Existing GS estimates

Over the past 25 years, starting with Pearce and Atkinson (1993) and Hamilton and Clemens (1999), there have been a series of Genuine Savings estimates for a range of countries. The time period covered by most estimates range from the 1970s to the present.

Studies have tended to trade-off scale and scope, with studies focusing on individual countries being richer in data quality but not directly comparable across countries. Definitions of metrics have also varied with 'green' and 'genuine' savings measures commonly constructed and used interchangeably (see Hanley et al. (2015) for a review of the empirical literature). There are several

Ecosystems are the example given for renewable (or active) natural resources as they can yield a service when harvested (timber) or when left in place (e.g. erosion control). Whereas nonrenewables are passive in that they yield no service until they are harvested.

studies that have calculated GS for shorter time periods. Some have explicitly compared estimates of GS with measures of Green National Product (Pezzey et al., 2006; Mota et al., 2010). Others have focused on expanding measures of GS to incorporate additional pollutants (Pezzey et al., 2006; Mota and Domingos, 2013; Ferreira and Vincent, 2005; Pezzey and Burke, 2014).[9] At the most extreme, McGrath et al. (2021) incorporate damage costs for local pollutants and find that this changes genuine savings signals (from positive to negative) for several European countries over the period 1990 to 2018.

There have been several estimates of historical GS, the pioneering work was by Rubio (2004) who estimated GS for Mexico and Venezuela from the 1920s to the 1990s. Later work looked at the experience of developed countries over more than a hundred years, with a focus on Sweden, the UK, Germany, the US, and Australia (Lindmark and Acar, 2013; Greasley et al., 2014; Hanley et al., 2015; Greasley et al., 2017). More recent work has analysed GS for countries in the twentieth century (Qasim et al., 2020; McGrath et al., 2021). The innovative contribution of Greasley et al. (2014) was to test the predictive power of GS as a forward looking indicator of sustainable development using the historical experience of the UK, where GS performs best over long horizons and when TFP was incorporated. These findings were corroborated for the US, Germany, and Australia (Hanley et al., 2015; Greasley et al., 2017) although not in the case of Sweden (Lindmark et al., 2018).

Pezzey and Burke (2014) argue that the scale that GS should be analysed is at a global level. Their contribution is to aggregate national level estimates of GS and incorporate differences in carbon pricing at a global level. The global scale approach was extended by Blum et al. (2017) who incorporated historical estimates of the above mentioned developed countries with estimates for several Latin American countries. Our database expands on this work by extending the range of countries included in the database.

3 Methodology

GS, also known as adjusted net saving (ANS), measures the “true” (or “genuine”) rate of saving (investment) in an economy after taking into account depreciation of fixed capital, investment in human capital, depletion of natural resources, and damages caused by pollution. Genuine savings, the name used in this article, is an indicator that aims to assess an economy’s sustainability based on the concepts of Environmental Economic Accounting (SEEA, 1993, 2003, 2014). In effect, GS is

[9] For example Ferreira and Moro (2011) estimate GS for Ireland from 1995-2005, McGrath et al. (2019) build on this work by incorporating additional pollutants and estimate GS for Ireland from 1990-2016.

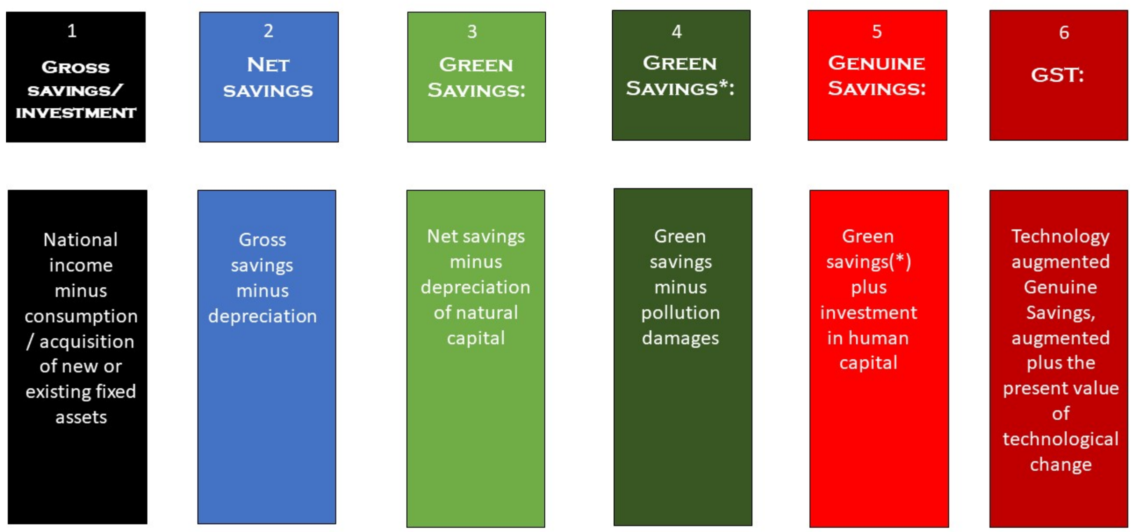
tracking the *change* in wealth.

The main formula for calculating GS is as follows:

$$GS = I - \delta K - n - \sigma(e) + m \tag{1}$$

Where I is investment, δK is traditional depreciation of fixed capital, n are resource rents, σ is the damage cost from pollution[10], and m is human capital. We construct several indicators, as illustrated in figure 2, to display and distinguish several aspects of sustainability.

Figure 2: Genuine Savings Calculations



We have largely followed Hamilton and Clemens (1999) and the World Bank (2006, 2011) methodology[11] for calculating GS by estimating a range of increasingly-comprehensive measures of year-on-year changes in total wealth over time.[12]

3.1 Net National Savings and Investment

The starting point for World Bank (2011) in calculating GS is to estimate National Savings as a residual from GDP minus total (private & government) consumption. Then estimates of depreciation

[10]Emissions minus dissipation

[11]This is outlined in Bolt et al. (2002)

[12]Recent work of the World Bank (2018, 2021) has focused primarily on wealth estimates and calculate the change in wealth as a predictor of sustainability. There is only one study which attempted to do this using historic data but viewed GS as a more reliable indicator of sustainability (McLaughlin et al., 2014).

are subtracted from this to calculate net savings rates.

Maddison (1992) was a pioneer in the comparative study of historical savings rates, calculating historical savings rates for 11 countries from the 1870s through to the 1980s. However, these are gross savings rates and there is no allowance for depreciation.

For our study we deviate from the Hamilton and Clemens (1999) approach and incorporate net *investment* as an alternative to net *savings*. Here net investment, including overseas investment, reflects changes in a country's physical assets. Estimates of net investment are readily available for various countries, but for some of them we have estimated net investment using gross investment and consumption of fixed capital, or simply annual depreciation of assets (see appendix for a detailed list of sources used).

3.2 Natural Capital

To account for the depletion of natural (renewable and non-renewable) resources we subtracted the rent from the depletion of natural resources, using gross revenues minus average costs of depletion, from net investment.[13] For many European countries (e.g. Great Britain), the bulk of rents from resource extraction originate from fossil fuels (coal, oil, and natural gas). We also considered other resources (metals and mineral ores), but the quantities by and large are negligible compared with the accumulation of other assets. For the US and Australia, two resource abundant developed nations, we included data on coal, oil and gas as well as metal and mineral ores. For Latin American countries, resources considered include metal and mineral ores and fossil fuels. Important sources of natural capital depletion are petroleum (Argentina, Colombia, Mexico), gold (Brazil, Colombia), silver (Colombia), coal (Brazil) and copper (Chile).

In terms of renewable resources, we include changes in forestry. Hamilton and Clemens (1999) do not include net natural growth of living resources and only include forestry that are commercially exploited and acknowledge that this methodological decision biases against sustainability. Here we include net growth to reduce this bias, while the forest stock appreciates it also has biodiversity benefits that would be overlooked if this is omitted. As we do not fully value ecosystems or

[13] We used the market value of extracted renewables and non-renewable resources as well as the extracted quantities to compute the gross revenues. The average extraction costs were estimated using labour requirement and the average wage of labourers. Similarly, estimates of the value of the change in timber stocks by country was based on changes in area covered with forests, the average quantity of timber per m^3 and the market value of timber. For more recent periods the FAO (2010) provides estimates on the cubic quantities of timber on a given surface area; it is likely that applying this methodology on historical periods overestimates historical forest stocks since we implicitly assume than the high modern tree planting density has existed throughout the period under observation.

biodiversity, excluding net forest growth would bias against sustainability even further. However, we are aware that forest growth cannot be readily translated straightforwardly into *Biodiversity*.

3.3 Human capital

It is possible to measure human capital created by investment in education and skills (Dasgupta, 2001), however within existing national accounting frameworks expenditure on children's education (via teacher salaries) is considered to be consumption, while some element of capital spending on school building is included in capital formation this is a small share of annual education expenditure (Hamilton and Clemens, 1999). To address this we use education expenditure to proxy the accumulation of human capital to obtain a more inclusive measure of a country's assets.

Admittedly there are limitations to this approach as it is known that education does not perfectly equate with human capital, however, alternatives measurements of human capital stocks, such as discounted life-time earnings, are not available for all countries over the whole of our sample. Furthermore, an additional limitation of this approach is that education expenditure as a proxy for human capital accumulation makes no allowances for appreciation of (e.g. on-the-job training & experience) and depreciation (aging & mortality) of human capital. Moreover, this approach does not account for international migration whereby migrant recipients benefit from the human-capital embodied in immigrants and developing countries may experience losses in human capital through emigration.

Besides data availability and evident flaws and limitations of the expenditure approach, it must be understood that we are measuring the "savings to produce further increases in well-being". Under this framework, the re-investment of resource rents are a valid indicator of *societies' effort* to compensate future generations (Hartwick, 1977).

3.4 Technological progress and the value of time

Technological change has been an important concept in the theoretical literature (Weitzman, 1997, 1999; Arrow et al., 2004, 2012), but there are a number of challenges incorporating a measure of technology into empirical studies.[14] Weitzman (1997) suggests that this adjustment may be in the region of 40 per cent of Net National Product. Thus, omitting a technological progress measure would mis-state the degree of sustainability of an economy. In relation to technological progress, although many of the general purpose technologies were invented in the late nineteenth century

[14]For example, such as how to measure technology, i.e. R&D, patents, energy intensity, total factor productivity.

(telephones, electricity, combustion engine), it was not until the twentieth century that they were adopted en-masse and in many cases this meant the use of new natural resources that had been overlooked in the past (oil and natural gas for example) but in turn this lead to more efficient use of resources (e.g. improvements in fuel efficiency, e.g. see Gordon (2016)).

Several studies have used changes in TFP as an indicator of technological progress and incorporated this into the genuine savings framework through the net present value of TFP's contribution to future GDP growth (Pezzey et al., 2006; Mota and Domingos, 2013; Greasley et al., 2014). We follow this approach and incorporate the effects of exogenous technological progress into our measure of GS by including the present value of TFP growth. Following Pezzey et al. (2006) and Greasley et al. (2014) we calculate the present value of future changes in trend TFP over a 20 year time horizon. This is done to capture the uncertainty over the duration of the value of technological progress.[15]

TFP is a central piece of the puzzle to assess sustainable development; this metric, however, is somewhat in conflict with other components of GS. TFP is related to innovativeness, intangible assets, institutions and social capital, and as a consequence the incorporation of TFP brings the risk of 'double-counting' the effects equally associated with technology and human capital.

Baier et al. (2006) find that incorporating a measure of human capital reduces the size of the residual; Similarly, Manuelli and Seshadri (2014) argue that better measurements of human capital quantity and quality can further reduce TFP. Moveover, as Bakker et al. (2019) note, 'TFP growth is not a synonym for technological change' and TFP growth may in fact be an over/under estimate of the contribution of technological change to labour productivity growth owing to a misspecified production function.

This gives us reason to believe that the overlap between human capital accumulation and the value of technology accumulation leads to a slight overestimation of total capital formation. Data limitations and availability prevent us from fully disentangling human capital and technology. We therefore opt to incorporate an unadjusted TFP series in our estimates, however, in the results section we illustrate the effect of TFP appended to Green investment to avoid the possibility of double counting as education expenditure is included in GS.

[15] Arrow et al. (2012, table 3) incorporate a measure of TFP but does so by adding the current TFP growth rate to the per capita growth rate of Total (Comprehensive) Wealth. However, this approach only adds 1 year and does not take account of the value of time as an uncontrolled capital stock. The choice of 20 years follows Pezzey et al. (2006) and Greasley et al. (2014). Using the case of Argentina as an example, where the present value of TFP is 10.12 per cent over 20 years, if a shorter horizon (10 years) is used this is reduced to 8.45 per cent of GDP and if a longer horizon (30 years) is used this increases to 15.87 per cent of GDP. Therefore, by choosing a 20-year horizon we err on the side of underestimation of the value of technological progress.

3.5 Social Costs of Carbon

Carbon dioxide (CO_2) is a greenhouse gas (GHG) with a lifetime of up to 200 years in the atmosphere and accounts for 75 per cent of global warming potential (Stern, 2007, table 8.1). The Social Cost of Carbon (SCC) represents "future damage" from of an additional tonne of CO_2 (Rennert et al., 2021). We incorporate a range of prices, related to the damage from CO_2 emissions, in our global estimates.

The crucial factor is that CO_2 is a stock pollutant in that the annual emissions add to the existing concentration in the atmosphere and each unit of emissions increases the marginal damage cost of the pollutant in the future (Kunnas et al., 2014). To account for CO_2 in our sustainability indicator we used the total amount of carbon dioxide emitted and estimates of the social costs of carbon derived from the wider literature.

There are a range of price estimates that we have incorporated, such as the constant $20 tonne carbon cost of the World Bank metric, $29 t/c from Tol (2012), $110 t/c from the Stern Review (Stern, 2007). In this paper we have incorporated the last estimates to show the impact of emissions under different scenarios.[16] and warn against choosing a singular price because of the wide range of estimates.

Table 1: Selected SCC estimations, different sources and methods

Source (Year)	**SCC, price per ton (Interval)**	**Discount rate**
World Bank/Fankhauser	US$20,3 (20 - 30, after 2010)	n/a
Tol (2008)	US$25	2%
US Interim SCC	US$51 (14 to 260)	3%
Stern (2022 and 2007)	US$110 (77 to 124)	2%
Pezzey & Burke Control (2014)	US$131	2-3 %
Pezzey & Burke Non Control (2014)	US$1455	2-3 %
Rennert et al. (2022)	US$185 (44 to 413)	2%

Sources: Fankhauser (1994), Tol (2012), Stern (2022, 2007), Rennert et al. (2022) and Pezzey and Burke (2014)

The current predominant view in the academic literature seems to be that the underlying DICE models are biased downwards (Stern, 2022). A recent review by Hänsel et al. (2020) argues for a higher cost of $ 208 in 2020. The results presented below utilise two estimates of the social cost

[16] There are a range of 300 estimates published in journals and reports(Tol, 2011). Kaufman et al. (2020) reported SCCs between US$0 and US$2000

of carbon by Pezzey and Burke (2014) .[17] The first price, \$131 t/c, estimated from a DICE model recalibrated to assume that it is economically optimal to control emissions such that warming may be limited to an agreed target of 2°C and a significantly higher price of \$1455 t/c which assumes that no controls of CO_2 emissions are implemented. We also incorporate a lower bound estimate of \$51 from Government (2021). Support from these prices can be found in the most recent estimates of SCC based on a new integrated model assessment, and it has resulted in a SCC of US\$ 185 (with a lower bound of US\$44 and an upper bound of \$413 per CO_2 ton) (Rennert et al., 2022). A summary of the main SSC estimates are presented in table 1.

We choose to highlight these contrasting prices as our study shares similarities with Pezzey and Burke (2014) and Pezzey (2022) in that we also attempt to determine if the world is on a "global" sustainability path. These prices are discounted over time as suggested by Tol (2012) and as illustrated by Kunnas et al. (2014).[18]

Using the US as an example, Figure 3 illustrates our approach to SSC. The left panel discounts \$51 SCC while the right panel discounts the \$ 110 (converted to 1990 prices) using different discount rates, from 1.5 % to 7 %.

In turn, discounting the same SCC by different discount rates has a dramatic effect on the estimate of the damage cost of US carbon emissions, see Figure 4. The results below are thus sensitive to both the discount rate as well as the chosen SCC.

Several questions arise from the estimated SCC used in these calculations. The most relevant relates to the discount rate used. In our historical GS the SSC is linearly discounted over time, while there are arguments for using different discount factors or different SSCs at different points in time. In order to address this concern, we have estimated a price variation based on the previous accumulated CO_2 emissions. The difference with the linearly discounted SSC is marginal (between 0.3 % and 0.5 %).[19]

3.6 International dollars

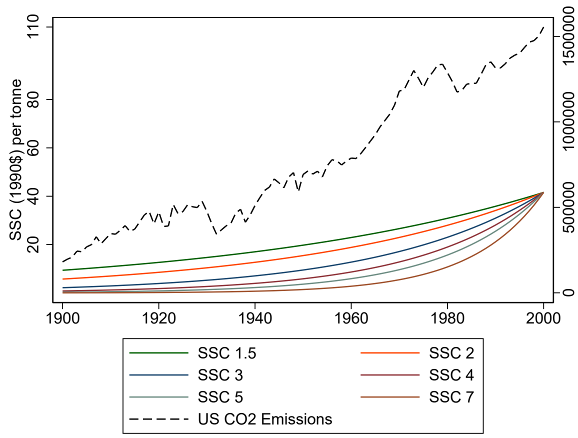
Until recently, the World Bank (2006) made comparisons of wealth between countries using market exchange rates. While noting the variance in wealth per capita between developed and developing

[17] Although Pezzey (2019) himself warns that '*SCCs attract more attention globally from academics than from policymakers.*'

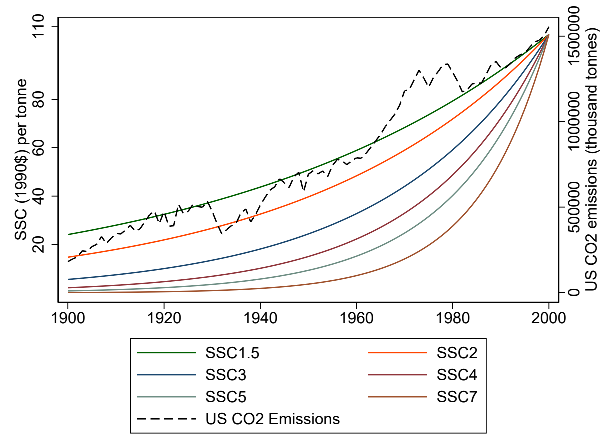
[18] For a more comprehensive overview of data sources used, see the data appendix as well as Blum et al. (2013), Camacho (2014), Greasley et al. (2014), Greasley et al. (2017); Höfeler (2014), Klenk (2013) and Mennig (2015). "Experts Clash over Cost of Carbon" Accessed the 20th of September, 2022 https://www.scientificamerican.com/article/experts-clash-over-cost-of-carbon/text

[19] The results of this exercise included in the appendix

Figure 3: SSC example using different discount rates

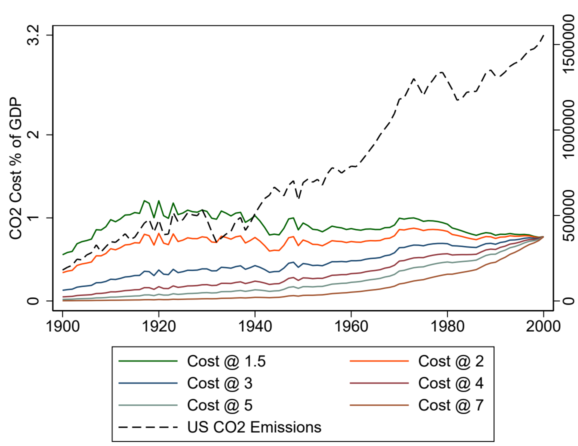


(a) $51 SCC

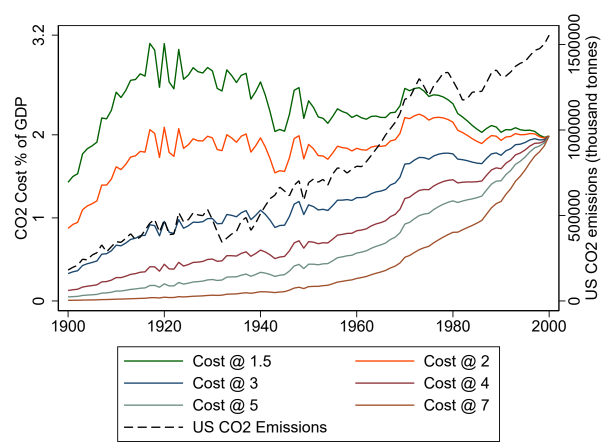


(b) $ 110 SCC

Figure 4: SSC example using the US with $51 and $110



(a) $ 51 SCC Cost (% of GDP)



(b) $ 110 SCC Cost (% of GDP)

countries, some of this was attributed to the use of nominal exchange rates (World Bank, 2006, p.17). The most recent World Bank (2021) attempts to address this issue by adopting Purchasing Power Parities, derived from the International Comparison Programme (Deaton and Heston, 2010). The issue here is that the prices collected are not necessarily related to the capital stocks that are being measured in wealth accounting and were originally intended to be used in comparing income across countries. Although it is acknowledged that various theoretical and empirical considerations, such as issues are whether using PPP is appropriate in a wealth accounting context, what level of PPP should be used, and how to construct a constant value series based on PPPs, were not addressed in the application of PPPs in a wealth accounting context (World Bank, 2021, p. 83).

While we share the reservations about applying PPPs that are derived for another purpose, using a PPP based series enables comparability across space and time. All units have been deflated using national GDP deflators and have been converted into purchasing power adjusted international dollars following Maddison (2001) and Bolt and van Zanden (2014), expressed as Geary-Khamis dollars ($) in the figures below. Such PPP adjusted estimates are similar to Hanley et al. (2015) and Greasley et al. (2017).

3.7 Limitations

A limitation of the construction of GS as outlined above is that it only covers quantifiable indicators that can be approximately expressed in monetary units. Thus GS overlooks non-market environmental goods and services. As a result the GS metric excludes developments in fisheries, biodiversity, and ecosystem services. It also underestimates pollution damages as it does not incorporate some major pollutants, such SO_2 and NOx, that were more local in impact.

While historical estimates of biodiversity are available, these indicators are difficult to incorporate in an augmented long-run GS metric until a compromise estimate of their economic value over time is obtained.

Losses in biodiversity are largely the result of changes in land use; the increasing demand for grazing and cropland has encouraged deforestation which in turn has resulted in losses in biodiversity. Estimates of the development of biodiversity suggests that Latin America and the US, and the majority of the world's countries, experienced losses in biodiversity whereas some countries in Western Europe saw stagnating or even increases in biodiversity.[20] Any future evaluation of the

[20]Stock valuations of global ecosystem services are most notable at the end of our period of study, such as Costanza et al. (1997), who estimated the global value of the entire biosphere to be between $16-54 trillion, and **?**, who updated the Costanza et al. (1997) figures from 1997-2011. However, these stock valuations do not enable us to value changes

costs of biodiversity loss and SO_2 emissions will lower any sustainability indicator (see Goldewijk (2014) for an overview). Therefore our estimates can be seen as a lower bound estimate of natural capital.

Similarly, there are estimates of SO_2 pollution. The global output of SO_2 increased throughout the twentieth century, with the major share of SO_2 being emitted in North America, followed by Western Europe. Total global SO_2 emissions rapidly rose after World War Two, and peaked around 1980. During the late twentieth century, mainly environmental regulation combined with fuel-saving technologies and a transition away from fuels with a high-sulphur content, helped to lower global SO_2 output (Stern and Kaufmann, 1996). The challenge with SO_2 pollution is placing a damage cost on emissions. Unlike CO_2 pollution which is global, SO_2 damages are time and context specific which would require country level estimates SO_2 pollution at various points in time. For example, EEA (2014) estimates of SO_2 damage costs per tonne are based on health damage caused by SO_2. These estimates vary enormously by country.[21] Although both approaches effectively measure health costs through loss in lifetime earnings, the dramatic increase in life expectancy over time raises challenges to this conventional approach.[22]

The absence of monetary evaluations of these phenomena, however, cannot hide the fact that economic growth seems to adversely affect biodiversity and levels of pollution (Dasgupta, 2021).

4 Historical estimates of Genuine Savings. The new dataset

As with the majority of economic history research or historical data in the long run, the main group of countries studied have been the developed ones. If we classified these countries by the length of the period already estimated, United Kingdom has the longest series of GS thanks to the work of Greasley et al. (2014), whose foundation rests on the classic work of UK capital stock estimates (Feinstein, 1972, 1978; Feinstein and Pollard, 1988). With further estimates of GS available from a number of published studies for several developed countries: USA, Germany, Australia, France, Switzerland, New Zealand and Spain (Hanley et al., 2015; Blum et al., 2019; Greasley et al., 2017;

in ecosystem services in the years preceding 1997. Furthermore, there have been increasing use of revealed and stated preference methods to value changes in environmental goods and services. However, these studies have not been applied consistently over time and benefit transfers may not be applicable spatially or temporally for all countries in our study.

[21] For example, estimates range from €1,052 in Cyprus to €38,778 in Norway based on value of a life year or from €2,270 in Cyprus to €90,337 in Switzerland based on value of a statistical life.

[22] In real terms, the marginal value of an additional year of life when life expectancy is 43 (as it was in 1900), is significantly different to the marginal value of an additional year of life when life expectancy is 79 (as in 2019).

Blum et al., 2017; Qasim et al., 2020; Iriarte, 2021).

One issue with estimates of GS is the lack of long run data for developing countries. A previous study of Latin American 'Green' investment over the period 1973-1986 lamented the quality of conventional measures of reproducible capital in Latin American countries (Vincent, 2001). In order to overcome this concern, we make use of capital stock estimates for Latin American (Tafunell and Ducoing, 2016) and the investment series produced by Tafunell (2013). We also note the availability of the pioneering work of Rubio (2004) who was the first to estimate GS for several Latin American Countries, including Mexico and Venezuela, in the twentieth century. Blum et al. (2017) extended these estimates, as well as incorporating four additional Latin American countries (Argentina, Brazil, Chile and Colombia). Most recently Labat et al. (2019) estimated a long run series for Uruguay (1875 - 2020).

In this paper we include GS for an additional four countries: Japan, Norway, Portugal, and Denmark.[23] Moreover, the Argentinean and Chilean data have extended a further 20 years back in time from the former estimation mentioned above (Blum et al., 2017).

A summary of the countries presented in this article and the time spans that cover each of the estimates is presented in table 2. One of the important contributions of this present paper is the inclusion of long run data-based estimates of GS for more developing countries, which was previously a major issue for comparative economic history and economic development research.

4.1 Preliminary analysis of the new database

Firstly does the measurement of GS provide us with, as Hamilton and Clemens (1999) calls it, 'useful new information'? To see if this is the case we compare conventional net national savings (NNS) rates with our measure of resource depletion, shown in figure 5. This is effectively a first approximation to the so-called Hartwick (1977) rule, 'the investment of current exhaustible resource returns in reproducible capital implies per capita consumption is constant'. The 45° line labelled "marginal sustainability" highlights the difference between countries that are sustainable (savings rates > Resource depletion) and countries that are unsustainable (savings rates < Resource depletion). In contrast to Hamilton and Clemens (1999) we do not observe countries with negative net savings rates but we do identify countries that have higher resource depletion than net savings rates and are therefore deemed unsustainable.

The gap between NNS and GS has been called the "depletion rate" by Hamilton and Clemens

[23] The Denmark data has been estimated from a thesis written by Andrew Pierson.

Table 2: Data sources and period covered of Genuine Savings estimations

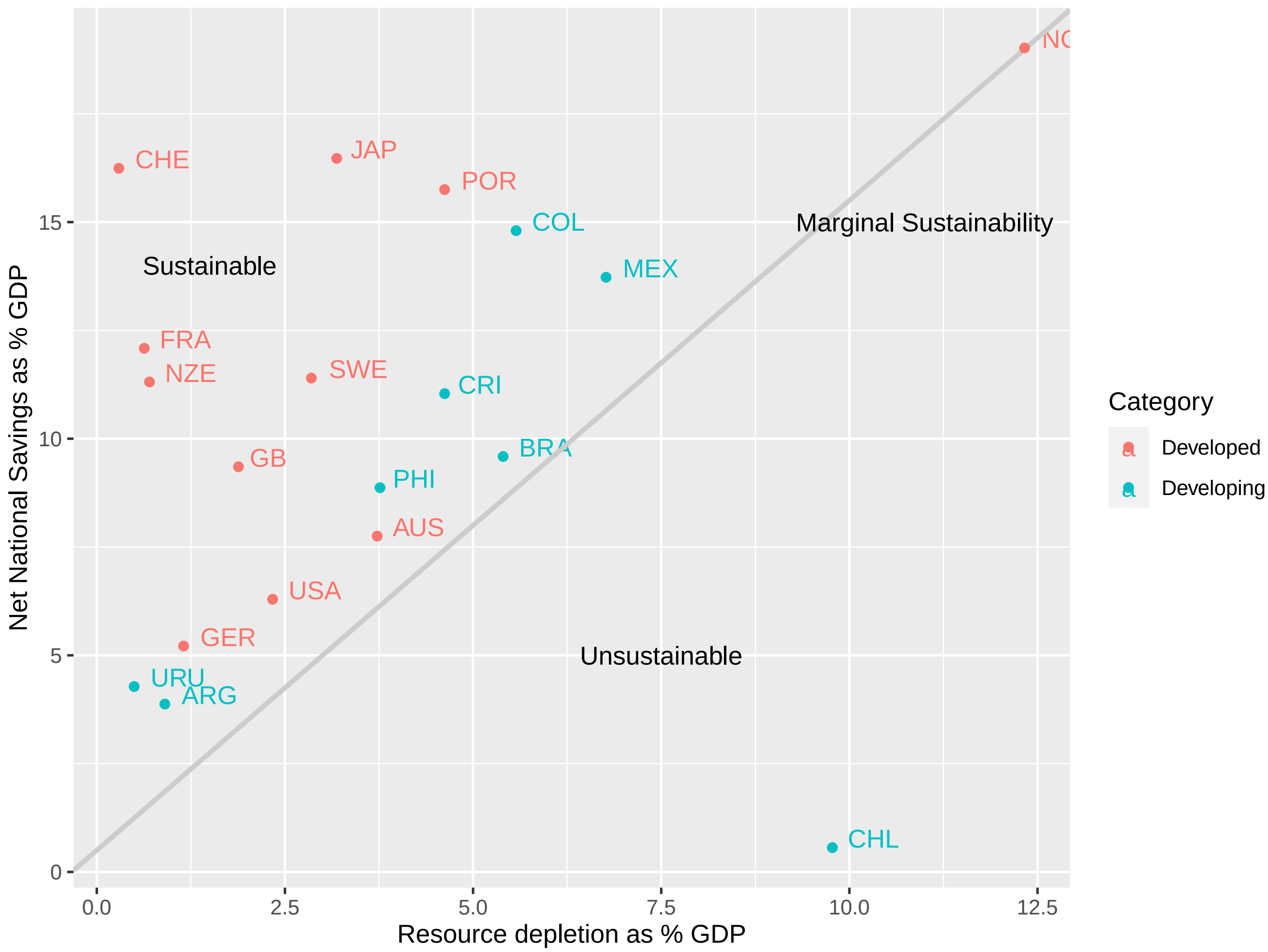
Country	**Period covered**	**Source**
Argentina	1900 - 2000	Blum et al. (2017)
Australia	1870 - 2018	Blum et al. (2017); Greasley et al. (2017)
Bolivia	1885 - 2015	This paper
Brazil	1880 - 2018	Blum et al. (2017)
Cambodia	1970 - 2010	Phillipsen + this paper
Chile	1880 - 2000	Blum et al. (2017) + this paper
Costa Rica	1902 - 2000	Pollack + this paper
Colombia	1900 - 2000	Blum et al. (2017)
Germany	1850 - 2010	Blum et al. (2013)
Great Britain	1850 - 2010	Greasley et al. (2014)
France	1900 - 2000	Blum et al. (2017)
Mexico	1900 - 2000	Blum et al. (2017)
New Zealand	1950 - 2000	Qasim et al. (2020)
Norway	1870 - 2000	Fink and Ducoing (2021)
Portugal	1900 - 2000	This paper
Spain	1950 - 2010	Iriarte (2021)
Sweden	1850 - 2010	Lindmark and Acar (2013)
Switzerland	1900 - 2000	Blum et al. (2017)
Japan	1880 - 2010	This paper
Venezuela	1935 - 1985	Rubio (2004)
Uruguay	1875 - 2015	Labat et al. (2019)
United Kingdom	1765 - 2000	Greasley et al. (2014)
United States of America	1870 - 2015	Hanley et al. (2015)

(1999). If we compare New Zealand with Argentina, two countries with a reasonably well developed agro-sector, savings rates are mainly positive, but there is a noticeable difference in levels between both countries, see Figure 6. The case of Chile (bottom left panel in Figure 6) is a representative example of development in Latin America. Between 1950 and 1990 the average GS per capita was negative, meaning that the extraction of natural resources, mainly copper, was not *re-invested* in either human capital nor fixed investment. The experience of Australia stands in contrast to that of Chile. Australia, despite its large mining sector, saw little difference between NNS and GS as resource rents were reinvested to maintain positive genuine savings.

Considering GS alone, Figure 7 shows all countries using the same scale. Clear trends emerge of savings rates that average 7.8% of GDP, ranging between 69% & -68% of GDP, in their extreme values.[24] Some countries experience periods of negative GS, such as Brazil, Australia, France, Germany, Britain, US, Uruguay, which tended to coincide with well known macro shocks such as

[24]See table 3 for summary statistics for each country.

Figure 5: Scatter plot of Resource Depletion and Net Savings rates, 1950-2000



wars and the Great Depression. Others, such as Sweden & Mexico, start the period experiencing negative GS and transition to positive GS. Of the countries two were notable outliers, Chile & Uruguay; the former for persistent negative GS, the latter for its high initial rates of GS and the volatility of the measure. Of the countries in the sample, only New Zealand & Spain do not show signs of negative GS.

The picture is changed when our measure of technological change is incorporated. Figure 8 compares GS rates and GSTFP rates for the countries in our database. While countries may have episodes of negative GS, this is overcome by positive GSTFP rates. While there are a few exceptions to this, in earlier periods countries had negative GS and low rates of TFP growth meant that technological progress was unable to compensate for negative GS. On the whole when a measure of technological progress is incorporated it shows a pattern of positive genuine savings indicating

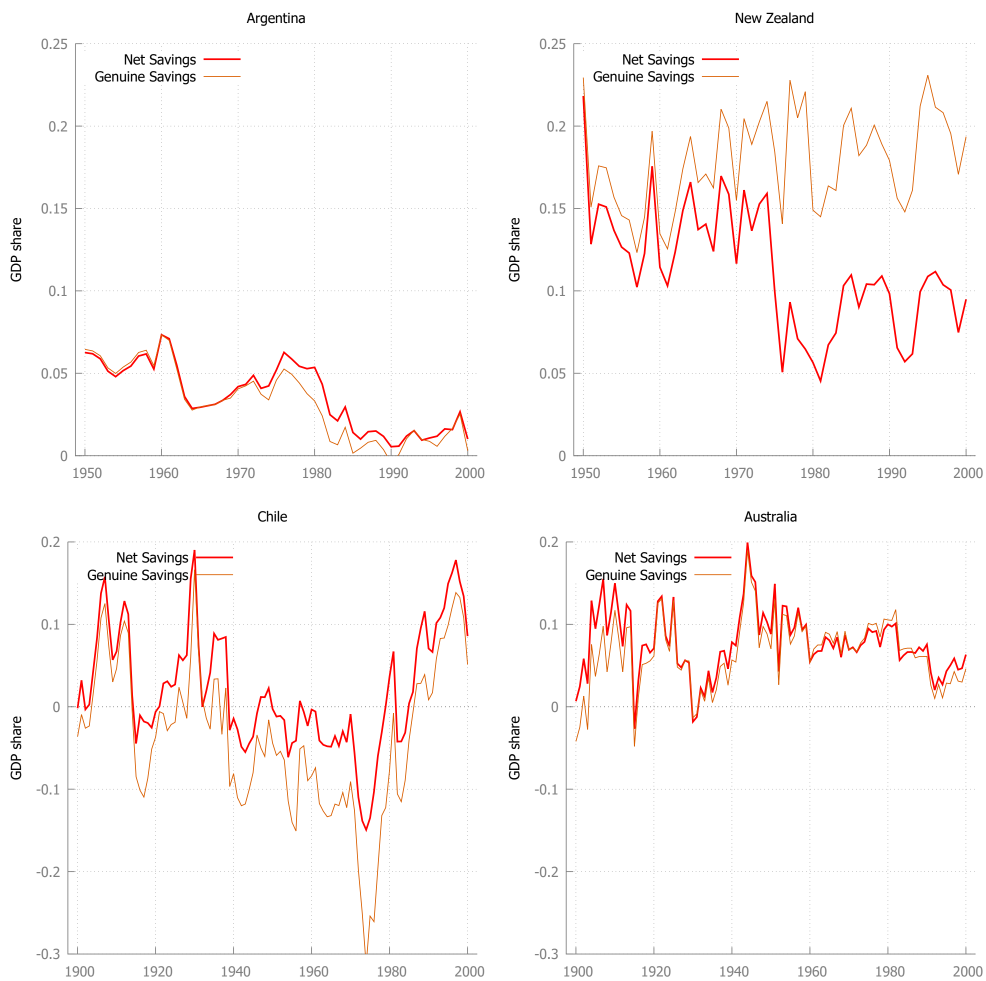


Figure 6: Net National Savings and Genuine Savings in Argentina, New Zealand, Chile and Australia. 1900 - 2000

that technological progress can not be omitted in studies sustainable development. This finding is in line with Ferreira and Vincent (2005) who argue that measures of GS are incomplete when sources of economic growth go beyond conventional capital accumulation.

Dasgupta (2009) makes the case that the empirical literature on the sources of economic growth may actually 'misdirect' and instead of focusing on GDP growth as an outcome variable, the outcome variable should be the change in wellbeing. Another aspect to this is that the literature on growth finds conventional investment to be a key driver in growth, but what of comprehensive investment, how do the figures presented here compare to standard narratives surrounding economic growth? Figure 11 plots GS (as a % of GDP) & GDP% growth over different time periods.[25]

[25]There are two outliers. In 1870-1914 Uruguay has very high GS rates (46.49% and 1946-1973 Cambodia with 97.89% of GDP, these are excluded from this figure) in the period 1870-1913 but growth is modest.

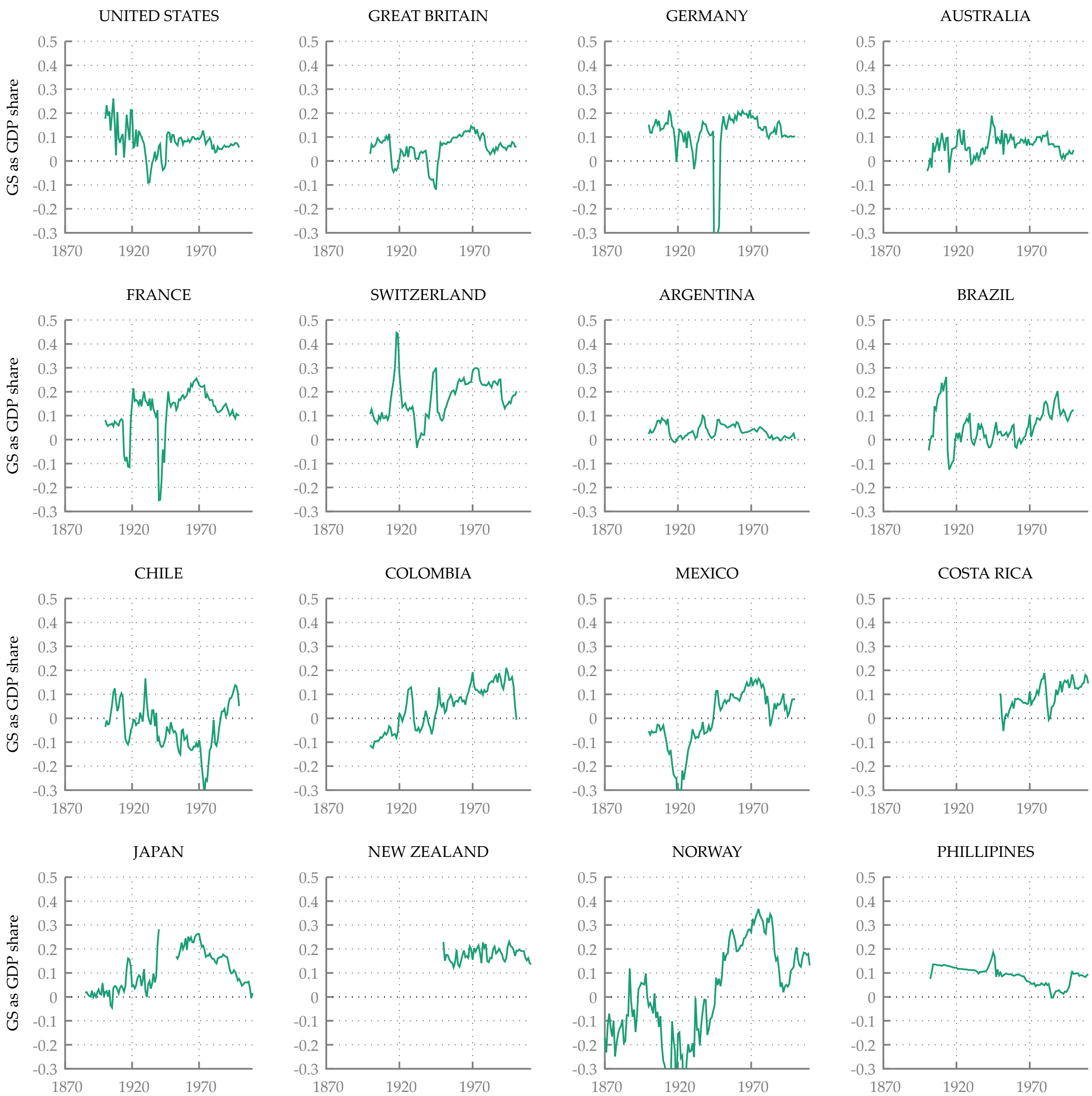
For three of the sub-periods there is a positive association between GS rates and GDP growth. However, this relationship breaks down during the interwar period. Several countries experience negative GS rates during the first period, but the number of countries that experienced negative GS declined in each sub-period. Of the countries included in the sample, only Chile and Venezuela persistently displayed negative GS in consecutive periods, this is driven by the resource intensity of their respective economies. On the whole, most countries only experienced short spells of negative GS and reverted to positive growth rates thereafter, the major exception here was Venezuela in the final period 1974-2000. Thus overall, we do find evidence to support the view that countries can experience GDP growth at the expense of growth in (comprehensive) wealth (UNU-IHDP., 2018; Yamaguchi et al., 2019), this also becomes evident when using the modern database of the World Bank (see Figure 10).

The theoretical literature on genuine savings stresses a link between GS and well-being, although in practice this has tended to be defined in monetary units. An exception is Gnégé (2009) who explores the relationship between GS and other measures of well-being such as changes in infant mortality and the Human Development Index, finding a weak positive relationship between the two.[26] Here we focus on the relationship between the GS indicator and the new augmented HDI series (Prados de La Escosura, 2021). The initial findings here suggest a weak correlation between GS and HDI initially but that the relationship strenghtened significantly over time.

Finally, what are the effects of global pollutants on GS? Figure 12 illustrates the effect of including 4 different SSCs, this is analogous to our GS* above. The SCC represent a range from the distribution in the literature (see discussion above). We include a "price" of \$ 0, which is effectively our benchmark global GS estimate. A \$ 51 SSC shows a slight decrease in the level of GS per capita, doubling the SSC to \$ 131 sees a further decrease in the level of the GS indicator but it is not negative barring the Great Depression and the Second World War. A substantial divergence in the GS metric is noted when the \$51 SSC effectively sees a thirty fold increase (\$ 1455), the price advocated by Pezzey and Burke (2014). Clearly the GS* metric is sensitive to the price of carbon, but this highlights the challenge of estimating a practical SSC to give policymakers a more realistic impression of likely future damage costs from carbon-intensive economic activity (Kaufman et al., 2020).

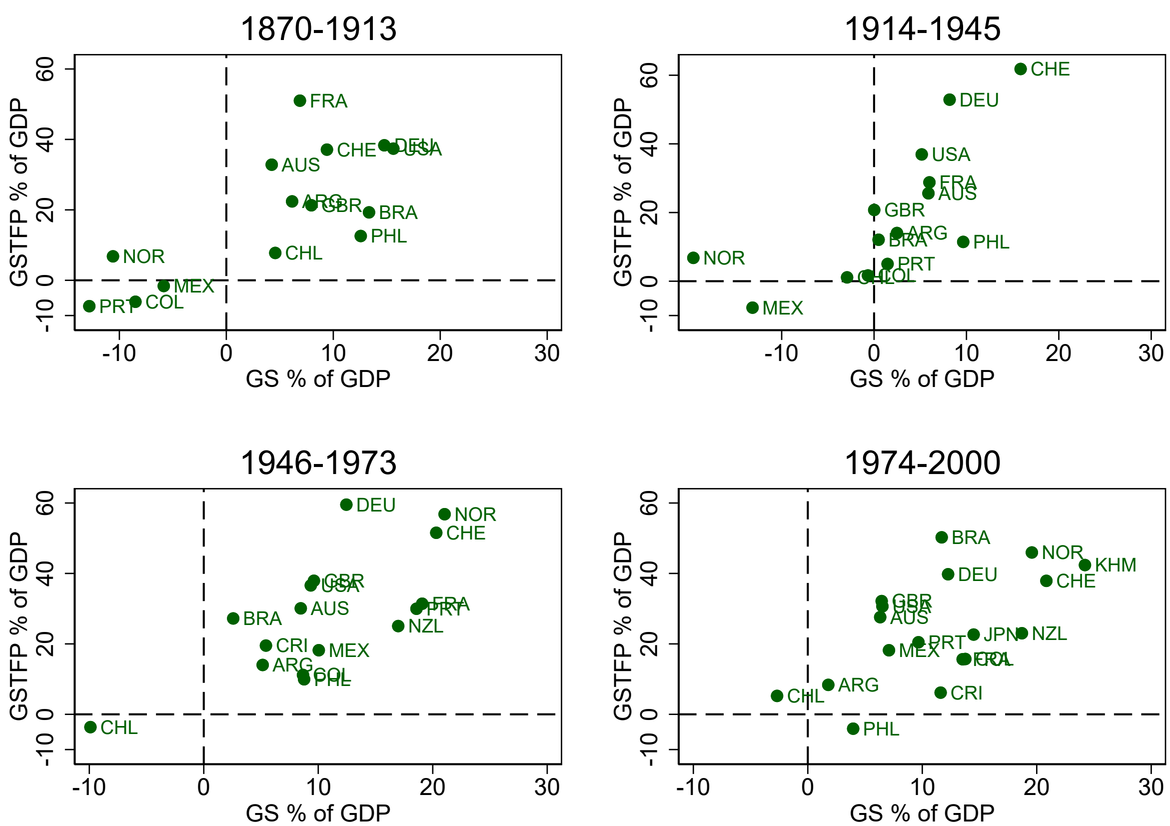
[26]Similarly, Blum et al. (2019) explore non-monetary indicators of well-being and find a positive correlation.

Figure 7: Genuine Savings as share of GDP. Selected countries, 1850 - 2020



Source: See table 2

Figure 8: Genuine Savings incorporating technological change, 1870 - 2020



Source: See table 2

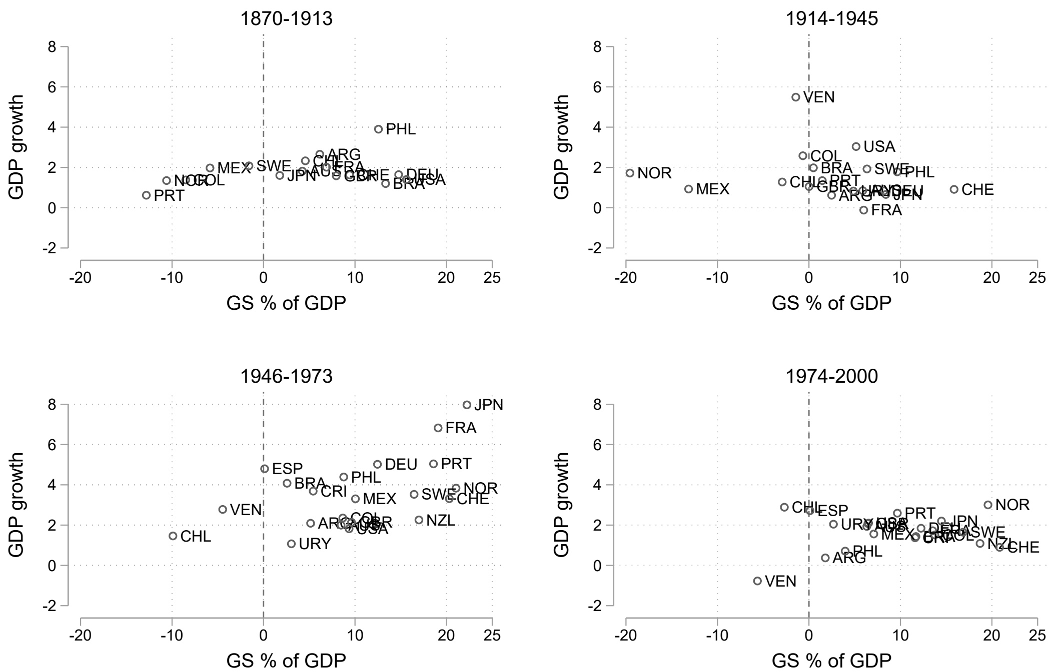


Figure 9: GDP growth and savings rates. 1870 - 2000

Source: See table 2 and Maddison database

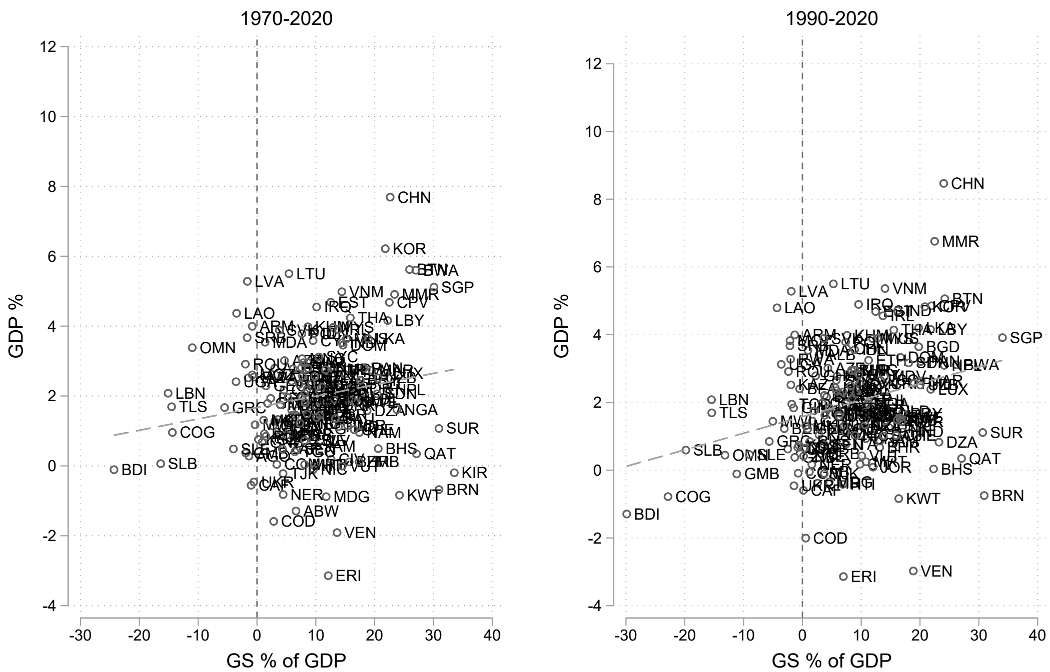


Figure 10: GS (% of GDP) and GDP per capita growth

Source:World Development Indicators

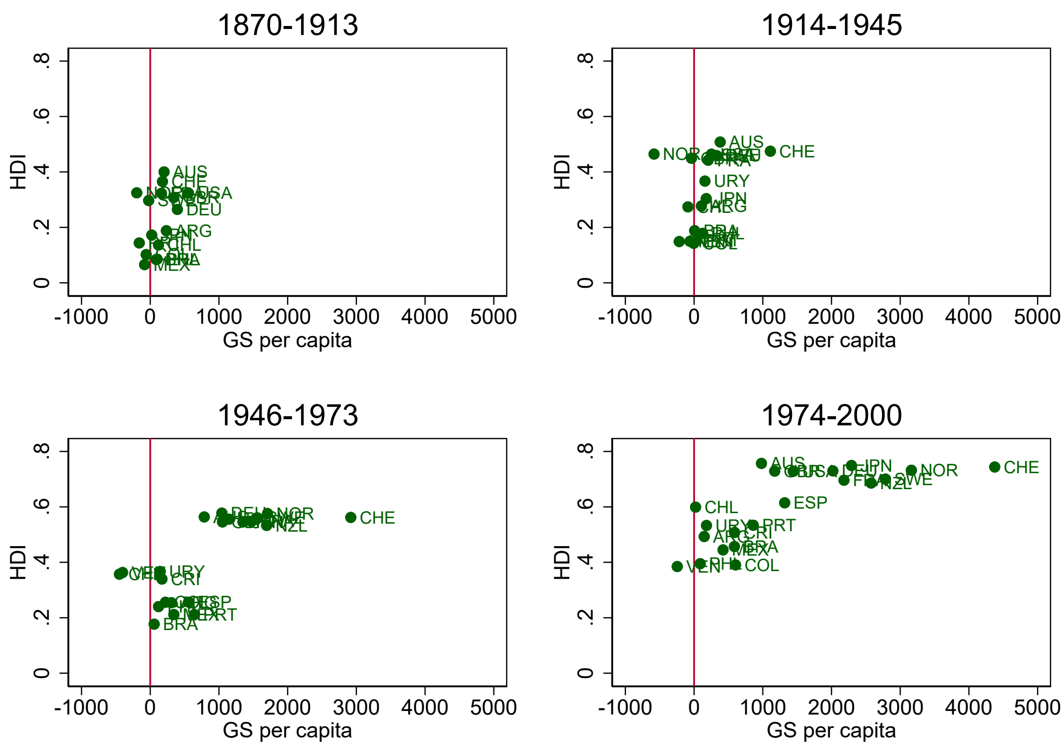
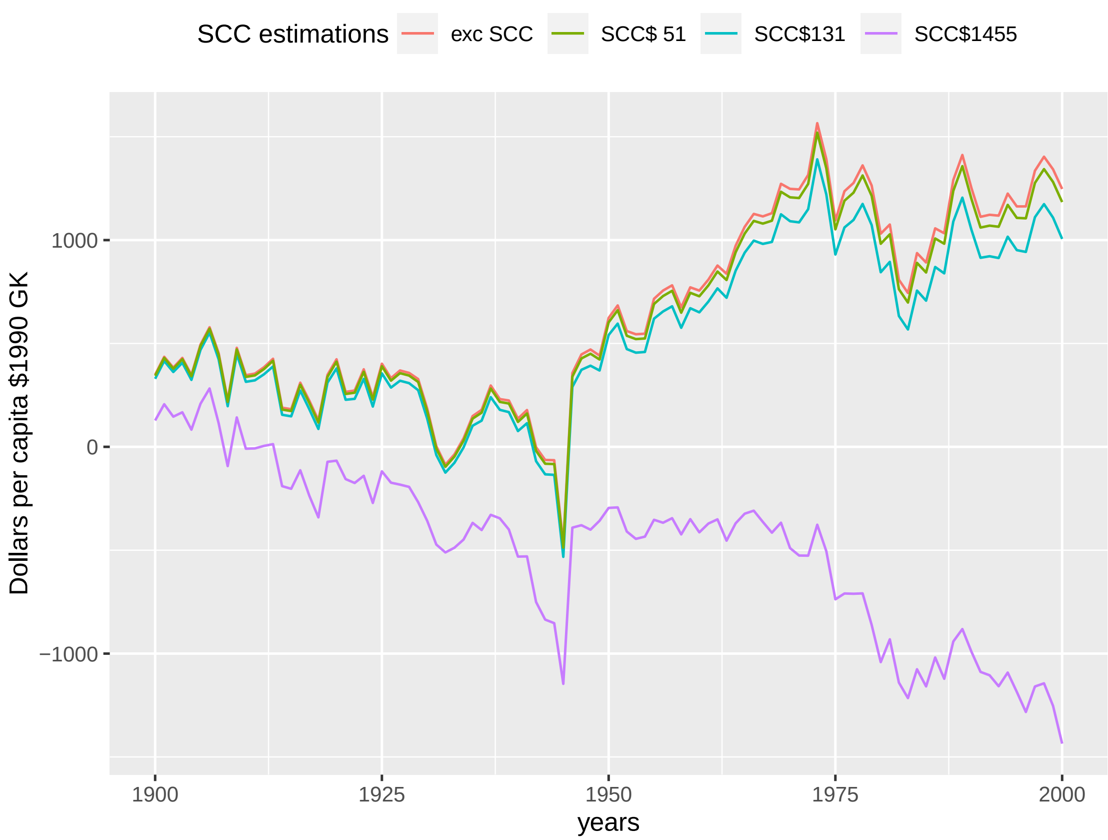


Figure 11: HDI and savings rates. 1870 - 2000

Source: See table 2 and Prados de la Escosura database

Figure 12: Global GS estimations with four different CO_2 cost prices



Source: See table 2

5 Conclusion

This is the first major compilation of data on historical sustainability trends for a significant sample of countries. Through a standardized methodology, the authors have provided future researchers and the general public a starting point to compare sustainable development from the nineteenth century to the present day.

Historical estimates of GS help us to trace the main trends in long run sustainability and present new information for policy makers. One powerful and concerning message is the destiny of natural resources rents (and environmental degradation). As we can see in fig. 6, Latin American countries, whom have based their economic development on the exploitation of their natural wealth, have been incapable of maintaining a constant rate of savings, hampering their future well-being.

Another extremely relevant finding is that the treatment of CO_2 and how it is priced has an enormous impact on the sustainability signal (Pezzey and Burke (2014). The prices shown, namely the high 'business as usual' and the lower 'control', highlight the messages embodied in their assumptions: if there are no attempts to control emissions into the future, the last one hundred and fifty years were built on unsustainable practices; if, however, the damaging potential of uncontrolled emissions are accepted and these emissions are optimally 'controlled', then the development seen in the last century can be determined to have been on a sustainable path. However, current climate events are closer to the former price.

The preliminary results presented in this article have strong implications for the present and future economic development of the countries considered in this study. A number of studies argue that consumption is a function of (previous) capital accumulation, since the productive basis, i.e. labour, physical and intangible capital, are the productive forces used to generate income. The lessons from these studies are straightforward: current investment in physical capital, intangible assets such as human capital and technology may result in higher consumption, wages and well-being in the future. Likewise, erosion of the productive base due to depreciation of assets, pollution and depletion of natural resources may limit, or even reduce, future well-being. The implications of this perspective for the 'global' economy are clear; in order to ensure future sustainability, the Hartwick Rule should be followed and technological progress, i.e. an increasingly intelligent use of existing assets, can play an significant role in future sustainability. However, in order to use GS in a applied policy framework, further studies and tests must be implemented. The data presented in the article are a crucial input to informed debate.

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Data Appendix

Summary statistics of "GS as a share of GDP" are shown in Table 3. We are aware of the GDP differences between these countries, but this variable is a good proxy of the *saving effort* of each country.

Table 3: Summary Statistics: Genuine Savings as share of GDP 1870–2019

Country	Mean	Median	Standard Deviation	Min	Max
USA	0.0811	0.0805	0.0615	−0.0916	0.261
Great Britain	0.0549	0.0603	0.0541	−0.120	0.145
Germany	0.113	0.131	0.113	−0.595	0.212
Australia	0.0655	0.0694	0.0417	−0.0480	0.190
France	0.118	0.138	0.0980	−0.254	0.256
Switzerland	0.175	0.175	0.0874	−0.0341	0.447
Argentina	0.0354	0.0324	0.0268	−0.0117	0.100
Brazil	0.0577	0.0439	0.0761	−0.125	0.262
Chile	−0.0375	−0.0362	0.0931	−0.314	0.166
Colombia	0.0469	0.0629	0.0898	−0.124	0.211
Mexico	−0.00298	0.0334	0.123	−0.437	0.171
Costa Rica	0.102	0.110	0.0563	−0.0526	0.189
Japan	0.0981	0.0666	0.0823	−0.0448	0.282
New Zealand	0.175	0.174	0.0286	0.123	0.231
Norway	0.0207	0.0448	0.207	−0.684	0.368
The Phillipines	0.0897	0.0937	0.0367	−0.00327	0.186
Portugal	0.0684	0.0768	0.112	−0.311	0.250
Sweden	0.0800	0.0892	0.0861	−0.0669	0.223
Uruguay	0.154	0.0967	0.155	−0.105	0.691

Total Factor Productivity

We calculate TFP assuming a standard Cobb-Douglas production function with capital and labour measured in person-hours.

$\mathrm{Y} = \mathrm{AL}^{(\alpha)}\ \mathrm{K}^{1-\alpha}$

Where Y equals income, L is labour (measured in person hours) and K is the capital stock. A denotes TFP which is estimated as a residual from this calculation. Trend TFP was used to estimate the value of exogenous technological progress.

Trend TFP is estimated using a Kalman filter.

Social Cost of Carbon under price variation

As we discuss in section 3, our SCC estimates are based on a linear discount rate, using the lastest models that have measured the potential damage of further CO_2 emissions (see table 1).

As the accumulated carbon in the atmosphere is lower in the first half of the twentieth century, we initially use a lower constant SCC for this period. As the emissions increase in the latter twentieth century, the accumulated carbon in the atmosphere and the decreased capacity of the atmosphere to absorb excess carbon emission, lead us utilise a higher SCC in line with the literature, as discussed above.

As we highlight in the main text, the difference between the estimates based on a discount rate of 2% are marginal. This is due to the fact that the amount of CO_2 emissions in the first half of the twentieth century are lower compared to the latter twentieth century, as shown in figure 13. To formalize our visual analysis, we performed a structural break test on CO_2 emissions (the data from in figure 13). The results identify a clear break point in 1954. As a result of this, we do not believe that there is a reason (or noticeable difference) to estimate distinct SSCs for different time periods. Rather we use a linearly discounted SCC which gives a lower SSC for the earlier years of the twentieth century.

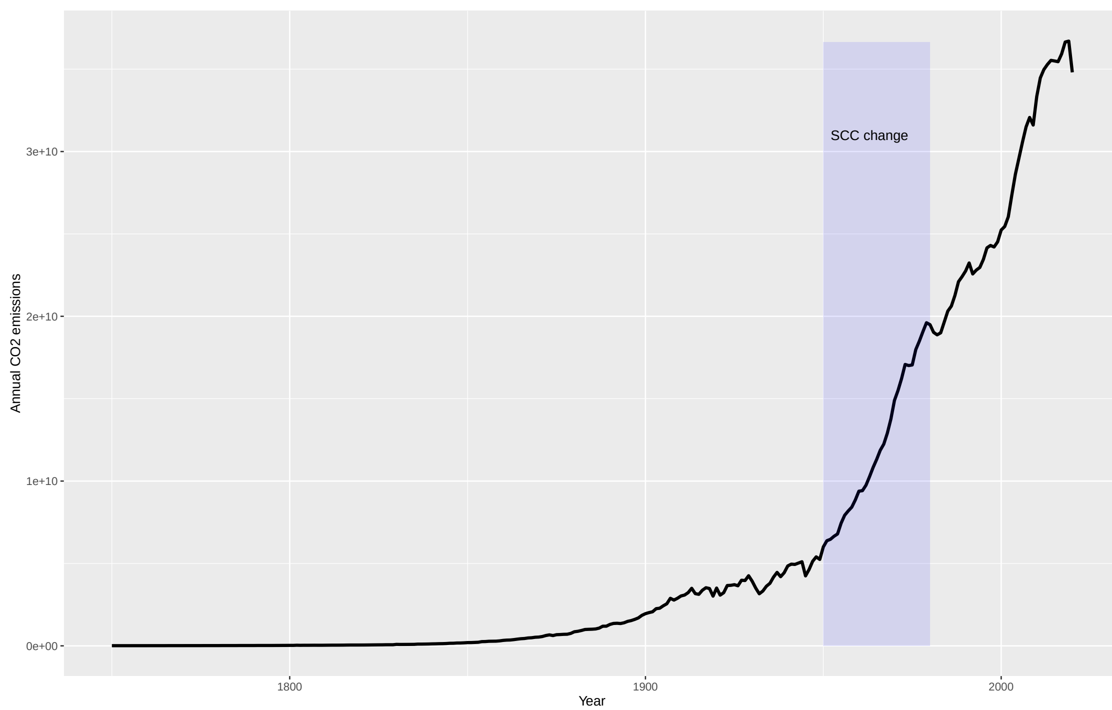

Figure 13: CO2 historical emissions

Data availability

The data can be downloaded from the following link:
https://www.genuinesavings.org/data. They are available in several formats (Stata, Gretl, Excel, csv and R) and the reference should be this paper if there are more than 5 countries used in the study. If the number of countries in your study is fewer to five, please use the list of references for each country available in the data set.

The code to reproduce the graphics and some of the estimations is available at further request: cristian.ducoing@ekh.lu.se

Sources

Australia

The GS estimations for Australia are from Greasley et al. (2017)

Great Britain and United States

The GS estimations of Great Britain and United States are from Greasley et al. (2014); Hanley et al. (2015)

France

Please note that all statistics used for this study refer to 'European France', excluding Algeria and other (former) colonies. GDP and GDP deflator: Pre-1982 data on French GDP are available from Toutain (1987) and Flora et al. (1983). GDP levels for later periods are taken from the official Statistical Yearbooks of the French National Institute of Statistics and Economic Studies (INSEE). Data for the period between 1914 and 1920 can be found in Hautcoeur (2005). For the period 1939 to 1945 data on French GDP are taken from Occhino, Oosterlinck and White (2006). A GDP deflator was constructed using data from Mitchell (2007), Lévy-Leboyer and Bourguignon (1985) and the INSEE. Net investment: net fixed capital formation and changes in inventories for the 19th and the beginning of the 20th century are provided by Lévy-Leboyer and Bourguignon (1985). The gap between 1914 and 1945 was estimated using Markovitch (1966) who reports investment and destructions during the wars as well as investment in the inter-war period and Carré, Dubois and Malinvaud (1972). For the period 1945 to 2000 data on inventory changes and net fixed capital formation were taken from the INSEE, the World Bank (2014) and the United Nations UNSD (2014) investment statistics. Data on net overseas investment is provided by Banque de France (2014), who provide a section with historical time series back to the 18th century. Private consumption was taken from Flora et al. (1983), the INSEE, Baudrillard (1996), Beaupré (2004) and Asselain (1984). Forestry: For the second half of the 19th century a complete time series of French forest stocks and the French timber market was not available. In France, forestry management only developed to a high standard at the end of the 19th century. Therefore, linear interpolation was used for the construction of the time series between 1850 and 1890 as there was only data available in five year intervals. Information on French forestry stocks was taken from Zon (1910) and Zon and Sparhawk (1923), Cinotti (1996), Koerner et al. (2000) and from the statistical database of the FAO (2014). Non-renewable resources: Detailed data on French mining activities, including the number of employees in the mining sector, extraction quantities and market prices, can be found in the yearly publications of the French mining sector entitled Les Annales des Mines, where the first issue was published in 1794. Additional information are provided by the statistical yearbooks of the INSEE, especially by the Annuaires Rétrospectifs, which include data back to the 18th century, and by Mitchell (2007). To assess the costs of depletion, the number of employees in the mining sector and their average wage were used. Data on the labour force is provided by Les Annales des Mines and the INSEE. Wages of mining workers are reported by the INSEE, Simiand (1907), Marchand and Thélot (1997) and Diebolt and Jaoul-Grammare (2008). Education expenditure is provided by Diebolt (1995, 2000). For the post-1994 period World Bank (2014) data on education expenditure were used. Carbon emissions were taken from Andres et al. (1999) and Boden, Marland and Andres (1995). This data is available online on the website of the Carbon Dioxide Information Analysis Center, an organization within the United States Department of Energy, under http://cdiac.ornl.gov/CO2_Emission/timeseries/national. Total Factor Productivity: labour hours worked and real GDP is taken from Greasley and Madsen (2006). Information on capital stock can be found in Guerrero (2013). Factor shares used were from Greasley and Madsen (2006), capital share is 0.60 and labour 0.40. A Kalman filter of the TFP growth rate was estimated and this was forecast using an ARIMA (2,1). Discount rates: Data on historical interest rates and government bond yields were taken from Homer and Sylla (2005) and Banque de France (2014).

Germany

GDP and GDP deflator: Pre-1975 data on German national product is available from Flora et al. (1983) and Hoffmann et al. (1965). GDP levels for later periods are taken from German Statistical Yearbooks (1999, 2008). Missing periods 1914-1924 and 1940-1949 were estimated using Ritschl and Spoerer's (1997) GNP series. A GDP deflator was constructed using data from Hoffman et al (1965), Mitchell (2007) and the United Nations Statistical Division (2013). Net investment: Net investment from 1850-1959 is provided by Hoffmann et al. (1965). We estimated the gap during 1914-1924 using Kirner (1968) who reports investment in buildings, construction, and equipment by sector for the war and inter-war periods. The period 1939 to 1949 was estimated by using data on net capital stock provided by Krengel (1958). To estimate investment during 1960 to 1975 we used Flora et al.'s (1983) data on net capital formation. For the period 1976 to 2000 we use official World Bank (2010) and United Nations (2013) investment statistics to complete the series. Data on the change in overseas capital stock and advances is provided by Hoffmann et al. (1965). Gaps during war and inter-war periods were estimated using information on the balance of payments provided by the German central bank (Deutsche Bundesbank, 1998, 2005). Remaining missing values were estimated using trade balances as a proxy for capital flows (Deutsche Bundesbank, 1976; Flora et al., 1983; Hardach, 1973). Private Consumption is taken from Flora et al. (1983), German Statistical Office, downloadable under www.gesis.oreg/histat, Ritschl (2005), Abelshauser (1998), and Harrison (1988). Forestry: Zon (1910), Zon et al. (1923), Hoffmann et al. (1965), and Endres (1922). Non-renewable resources: Fischer (1989) and Fischer and Fehrenbach (1995) provide detailed data on German mining activities including the number of employees in mining, covering the period until the 1970s. Information on quantities and market prices by commodity on an annual basis are available. Additional information was collected from Mitchell (2007). Data provided by Fischer (1989) and Fischer and Fehrenbach (1995) are also available by German state, which allows subtracting contemporary contributions of the mining sector of Alsace-Lorraine between 1871 and 1918. Moreover, the statistical offices of the German Empire and the Federal Republic of Germany provide information on the 1914 to 1923 as well as the post-1962 periods, respectively (Bundesamt, 2013; Germany. Statistisches Reichsamt., 1925). To assess the costs of depletion the number of employees in mining and their average wage were used. Data on the labour force in mining is provided by Fischer (1989), Fischer and Fehrenbach (1995), and the German Statistical Office (2013). Wages of mining workers are reported by Hoffmann et al. (1965), Kuczynski (1947), Mitchell (2007), and official contemporary statistics (Germany. Statistisches Reichsamt., 1925). Expenditure on schooling: Data on education expenditure is provided by Hoffmann et al. (1965) and Diebolt (1997, 2000). For the post-1990 period we use World Bank data on education expenditure. Missing values for the periods 1922-24 and 1938-48 have to be estimated. For the former period, we assume that expenditures between 1921 and 1925 developed gradually and apply linear interpolation. For the latter period we use Flora (1983, p. 585) who reports that the number of pupils and students in Germany dropped by 16.3 per cent between 1936 and 1950 – this occurred most likely due to population losses after WWII. The corresponding drop in education expenditure was 16.5 per cent. We assume that the 1939 expenditure level was maintained until 1945, when the number of students plummeted. Therefore, we assume that the expenditure level between 1946 and 1948 was equal to the 1949 figure. Carbon emissions were taken from Andres et al. (1999) and Boden et al. (1995). TFP: Data on labour hours worked and real GDP is taken from Greasley and Madsen (2006). Information on capital stock for the period 1850 through 2000 is provided by Metz (2005). Missing values during and after WWII have been estimated on the basis of Krengel (1958). Factor shares used were from Greasley and Madsen (2006), capital share is 0.60 and labour 0.40. A Kalman filter of the TFP growth rate was estimated. Discount rates were taken from Homer and Sylla (2005) and Deutsche Bundesbank (2013)[2].

Switzerland

GDP: Halbeisen et al (2012), Wirtschaftsgeschichte der Schweiz im 20. Jahrhundert. Basel: Schwabe; HSSO: Historische Statistik der Schweiz Online (Historical Statistics of Switzerland online), Kammerer Patrick et al. (Hg.), www.fsw.uzh.ch/histstat/main.php.; Capital: Halbeisen et al. (2012); BFS Online: Swiss Statistics, Swiss Federal Statistical Office (BFS), www.bfs.admin.ch/; Kehoe and Ruhl (2003); Goldsmith (1981); Siegenthaler and Ritzmann-Blickenstorfer (1996); Education expenditure: BFS Online: Swiss Statistics, Swiss Federal Statistical Office (BFS), www.bfs.admin.ch/; HSSO: Historische Statistik der Schweiz Online (Historical Statistics of Switzerland online), Kammerer Patrick et al. (Hg.), www.fsw.uzh.ch/histstat/main.php; Forest: HSSO: Historische Statistik der Schweiz Online (Historical Statistics of Switzerland online), Kammerer Patrick et al. (Hg.), www.fsw.uzh.ch/histstat/main.php; Siegenthaler and Ritzmann-Blickenstorfer (1996); BFS Online: Swiss Statistics, Swiss Federal Statistical Office (BFS), www.bfs.admin.ch/; LFI Online: National forest inventory Switzerland LFI, http://www.lfi.ch/resultate/suche.php; Rieger (2007); Costs of production: BAFU (2010). Biodiversität und Holznutzung – Synergien und Grenzen. Federal Office for the Environments Switzerland (BAFU), April 2010; BAFU (2011). Jahrbuch Wald und Holz - Annuaire La forêt et le bois – Federal Office for the Environments Switzerland (BAFU); Strawe (1994); HSSO: Historische Statistik der Schweiz Online (Historical Statistics of Switzerland online), Kammerer Patrick et al. (Hg.), www.fsw.uzh.ch/histstat/main.php.; Degen (2012); BFS Online: Swiss Statistics, Swiss Federal Statistical Office (BFS), www.bfs.admin.ch/; Studer (2008); Fossil fuel: Marek (2008); Marek (1994); (Gisler, 2011); Gebhardt (1957); Bellwald (2013); BFS Online: Swiss Statistics, Swiss Federal Statistical Office (BFS), www.bfs.admin.ch/ Iron ore: Fehlmann H. & Durrer R. (1932); HSSO: Historische Statistik der Schweiz Online (Historical Statistics of Switzerland online), Kammerer Patrick et al. (Hg.), www.fsw.uzh.ch/histstat/main.php.; IEA online: International Energy Agency (IEA), http://www.iea.org/countries/membercountries/switzerland/; BFS Online: Swiss Statistics, Swiss Federal Statistical Office (BFS), www.bfs.admin.ch/; Kündig and Leuenberger (1997); Bärtschi, 2011; Gesis online, Historische Statistiken, Historical statistics (Histat): http://www.gesis.org/histat/; Population: BFS Online: Swiss Statistics, Swiss Federal Statistical Office (BFS), www.bfs.admin.ch/; HSSO: Historische Statistik der Schweiz Online (Historical Statistics of Switzerland online), Kammerer Patrick et al. (Hg.), www.fsw.uzh.ch/histstat/main.php.; Discount rates: BFS Online: Swiss Statistics, Swiss Federal Statistical Office (BFS), www.bfs.admin.ch/; TFP: Halbeisen et al, (2012).

Latin America

5.1 Latin America

5.1.1 Argentina

GDP and GDP deflator: Argentina – From 1900-2000 the nominal GDP was derived from Della Paolera and Taylor (2003). GDP deflator is based on data from MoxLAD (2014) from 1900-1960 and on data from World Bank (2014b) for years thereafter.

5.1.2 Brazil

Brazil – Nominal GDP and GDP deflator were derived from the historical series from IBGE (2014).

5.1.3 Chile

Chile – From 1900-1940 the nominal GDP in USD was calculated using Hofman (2000). From 1940-1995 the nominal GDP was taken from Braun-Llona et al. (2000) and from 1995-2010 from Banco Central de Chile (2014). The GDP deflator was derived from World Bank (2014b) from 1960-2010. Braun-Llona et al. (2000) reports a real GDP series from 1900-1995 in prices from 1995.

5.1.4 Colombia

5.1.5 Mexico

5.1.6 Uruguay

Labat et al. (2019)

5.1.7 Venezuela

Colombia – The nominal GDP was taken from GRECO (1999b) from 1905-1997 and from 1998-2010 from World Bank (2014b). For the years before 1905 the GDP was calculated using the growth rate reported by Hofman (2000). From 1900-1960 the GDP deflator was derived by using the variations given by GRECO (1999b), after 1960 is it taken from World Bank (2014b). Mexico – From 1900-1970 the nominal GDP was taken from INEGI (2009), following years are derived from World Bank (2014b). The GDP deflator was calculated using the GDP deflator reported by MoxLAD (2014). Consumer price index and inflation: Argentina, Brazil, Mexico – data were taken from Clio infra (2014). Chile – 1900-1995 from Braun-Llona et al. (2000); from 1995 and thereafter from Clio infra (2014). Colombia – 1900-1905 from Braun-Llona et al. (2000) and from 1905 to 1996 data is from GRECO (1999b). For the last years it was taken from World Bank (2014b). Exchange rates and changes in local currency units (LCU): Argentina – data from Della Paolera and Taylor (2003). The exchange rate from Nuevos Pesos to USD from 1916 until 1999 was taken from Della Paolera and Taylor (2003) and for later years from Clio infra (2014). Brazil – Changes in LCU were derived from MoxLAD (2014); the exchange rate from LCU to USD from IBGE (2014). Chile – Changes in LCU are reported by MoxLAD (2014). From 1900-1995 the exchange rate to USD is reported by Braun-Llona et al. (2000), while later years were taken from Banco Central de Chile (2014). Colombia – exchange rate from Pesos to USD was taken from GRECO (1999b) from 1905-1997; for the following years it is from CEPAL (2014). Mexico – Changes in LCU were taken from MoxLAD (2014); the exchange rate to USD was derived from INEGI (2009) until 2009, while later years are from CEPAL (2014). Investment and gross fixed capital formation (GFCF) – All countries – The series for GFCF after 1950 was taken from CEPAL (2009) and CEPAL (2014). These data was converted to real prices of 2010 and calculated for the years from 1900-1950 using the index reported by Tafunell (2011). Tafunell (2013) explains the method to build the GFCF data on non-residential construction and machinery and equipment. The article by Tafunell and Ducoing (2015) is an extension of the latter. Consumption of fixed capital – All countries – World Bank (2014b) reports information starting in 1970. For previous years data was estimated using the methodology reported by the World Bank in Bolt et al. (2002). Overseas investment – All countries – From 1900-1949 data is based on Taylor (1998). Argentina, Colombia, Mexico: From 1950-1969 data was taken from CEPAL (2009) and for later years from World Bank (2014b). Brazil, Chile: Data is taken from CEPAL (2014) from 1950-1974 and later from World Bank (2014b). Natural resources: Forestry – All countries – Annual change of forest area for the period of 1900-1985 was taken from Houghton et al. (1991). Forest area after 1990 was taken from the World Bank (2014b). Minerals & Energy - Argentina – Gold, silver: 1921-1944: Imperial Mineral Resources Bureau (various years); 1949-1954: Colonial Geological Surveys (various years); 1955-1969: Institute of Geological Sciences (various years-a); 1970-1980: Institute of Geological Sciences (various years-b); 1981-1991: British Geological Survey (various years); 1992-2010: British Geological Survey (2014); Rothwell (1898) reports data for 1895-1897. Copper: 1913-1944: Imperial Mineral Resources Bureau (various years); 1960-1969: Institute of Geological Sciences (various years-a); 1970-1973: Institute of Geological Sciences (various years-b); 1974-2008: CEPAL (2014); 2009-2010: British Geological Survey (2014). Missing years were linearly interpolated. Coal: 1939-2002: Mitchell (1998); 2003-2008: CEPAL (2014); 2009-2010 were assumed to be constant as 2008. Iron ore: 1937-1989 Mitchell (1998), 1990-2010 World Steel Association (2014). Natural gas: 1929-1966: Mitchell (1998); 1970-1980: Institute of Geological Sciences (various years-b); 1981-1991: British Geological Survey (various years); 1992-2010: British Geological Survey (2014). Crude petroleum: 1915-2002 Mitchell (1998); 2003-2010: British

Geological Survey (2014). Lead: 1920-2000: Mitchell (1998); 2001-2010: British Geological Survey (2014). Tin: 1923-1944: Imperial Mineral Resources Bureau (various years); 1944-54: Colonial Geological Surveys (various years); 1955-1970: Institute of Geological Sciences (various years-a); 1974-1995 CEPAL (2014), from 1996-2010 production was assumed to be constant as value of 1995. Zinc: 1939-1944: Imperial Mineral Resources Bureau (various years), 1945-1955: Institute of Geological Sciences (various years-a); 1956-2003: Mitchell (1998); 2004-2008: CEPAL (2014); 2009-2010: British Geological Survey (2014). Brazil – Gold: 1913-1944: Imperial Mineral Resources Bureau (various years), 1949-1954: Colonial Geological Surveys (various years); 1955-1969: Institute of Geological Sciences (various years-a); 1970-80: Institute of Geological Sciences (various years-b); 1981-91: British Geological Survey (various years); 1992-2010: British Geological Survey (2014); Rothwell (1898) reports data for 1895-1897. Silver: 1913-44: Imperial Mineral Resources Bureau (various years), 1949-54: Colonial Geological Surveys (various years); 1955-1969: Institute of Geological Sciences (various years-a); 1970-80: Institute of Geological Sciences (various years-b); 1981-91: British Geological Survey (various years); 1992-2010: British Geological Survey (2014). Copper: 1955-1960: Institute of Geological Sciences (various years-a); 1965: Instituto Brasileiro de Mineração (2013), 1974-2008 CEPAL (2014); 2009-2010: British Geological Survey (2014). Coal: 1913-2002: Mitchell (1998); 2003-2008: CEPAL (2014); 2009-2010 was assumed to be constant as value in 2008. Iron ore: 1923-1935: Imperial Mineral Resources Bureau (various years); 1936-92: Mitchell (1998), 1993-2008: CEPAL (2014); 2009-2010: British Geological Survey (2014). Natural gas: 1942-1966: Mitchell (1998), 1972-1980: Institute of Geological Sciences (various years-b); 1981-1991: British Geological Survey (various years); 1992-2010: British Geological Survey (2014). Crude petroleum: 1942-2002: Mitchell (1998); 2003-2010: British Geological Survey (2014). Lead: 1921-1944: Imperial Mineral Resources Bureau (various years); 1945-2003: Mitchell (1998); 2004-2010: British Geological Survey (2014). Tin: 1943-2002: Mitchell (1998); 2003-2008: CEPAL (2014); 2009-2010: British Geological Survey (2014). Zinc: 1965-2003: Mitchell (1998); 2003-2008: CEPAL (2014); 2009-2010: British Geological Survey (2014). Aluminium/ bauxite: 1953-1991: Mitchell (1998); 1992-2010: British Geological Survey (2014). Chile – Gold, silver: 1900-1995: Braun-Llona et al. (2000), 1996-2010: British Geological Survey (2014). Copper: 1900-1995: Braun-Llona et al. (2000); 1996-2008: CEPAL (2014); 2009-2010: British Geological Survey (2014). Coal: 1900-1990: Braun-Llona et al. (2000); 1991-2008: CEPAL (2014); 2009-2010 the production volume of 2008 was assumed. Iron ore: 1911-1998: Mitchell (1998); 1990-2007: CEPAL (2014); 2009-2010: British Geological Survey (2014). Natural gas: 1952-1966: Mitchell (1998); 1970-1980: Institute of Geological Sciences (various years-b); 1981-1991: British Geological Survey (various years); 1992-2010: British Geological Survey (2014). Crude petroleum: 1949-2002: Mitchell (1998); 2003-2010: British Geological Survey (2014). Lead: 1920-1944: Imperial Mineral Resources Bureau (various years), 1945-1954: Colonial Geological Surveys (various years); 1955-1969: Institute of Geological Sciences (various years-a); 1970-1980: Institute of Geological Sciences (various years-b); 1981-1991: British Geological Survey (various years); 1992-2010: British Geological Survey (2014). Zinc: 1926-33: Imperial Mineral Resources Bureau (various years); 1953-54: Colonial Geological Surveys (various years); 1955-1970: Institute of Geological Sciences (various years-a) missing years were assumed to be zero as production is already very low in the years before; 1974-2008: CEPAL (2014); 2009-2010: British Geological Survey (2014). Colombia - Gold, silver: 1913-1929: Imperial Mineral Resources Bureau (various years). 1931-2010: UMPME (2014). Copper: 1951-2010: UMPME (2014). Coal: 1926-32: Imperial Mineral Resources Bureau (various years); 1933-1949: Mitchell (1998); 1950-2010: Mineral Agency of Colombia. Iron ore: 1960-1998: Mitchell (1998); 1999-2010: British Geological Survey (2014). Natural gas: 1952-1966: Mitchell (1998); 1970-1980: Institute of Geological Sciences (various years-b); 1981-1991: British Geological Survey (various years): 1992-2010: British Geological Survey (2014). Crude petroleum: 1922-2005: Mitchell (1998); 2003-2010: British Geological Survey (2014). Lead: 1960-1985: Mitchell (1998); 1990-2010: Mosquera and Bautista (2005). Zinc: 1960-1970: Institute of Geological Sciences (various years-a). Mexico - Gold, silver: 1900-2008: INEGI (2009); 2009-2010: British Geological Survey (2014). Copper: 1900-1975: INEGI (2009); 1976-2003: Mitchell (1998); 2004-2007: CEPAL (2014); 2008-2010: British Geological Survey (2014). Coal: 1900-2008: INEGI (2009). Iron ore: 1900-2008: INEGI (2009); 2009-2010: British Geological Survey (2014). Natural gas: 1932-1966: Mitchell (1998); 1970-1980: Institute of Geological Sciences (various years-b); 1981-1991: British Geological Survey (various years); 1992-2010: British Geological Survey (2014). Crude petroleum: 1901-2007: INEGI (2009). Lead: 1900-2008: INEGI (2009); 2009-2010: British Geological Survey (2014). Tin: 1903-2008: INEGI (2009). Zinc: 1900-2008: INEGI (2009); 2009-2010: British Geological Survey (2014). Resource prices: Coal: 1900-1971: U.S. Bureau of Mines (2014); 1972-2010: U. S. Energy Information Administration (2012). Crude petroleum, lead, copper, silver, tin, zinc: 1900-2010: The price index was taken from MoxLAD (2014). Natural gas: 1922-2010: U.S. Energy Information Administration (2014). Iron ore: 1900-2010: U.S. Geological Survey (2014). Gold: 1908-2000: GRECO (1999a); 2001-2010: World Bank (2014a). Bauxite: 1900-2010: U.S. Geological Survey (2014). Labor costs were calculated by multiplying the economically active populations (EAP) in the extractive industry with the average real wage. Argentina - 1914-1990: EAP of the extractive industry was taken from Mitchell (1998), who reports data for the years 1914, 1947, 1960, 1970 and 1980. For 1980 and 1985 data from CEPAL (2014) and from 1990-2010 data from World Bank (2014b) was available for the total workforce. Brazil - From IBGE (1990) information about the EAP in extractive industry from 1900-1989 are available. From 1990-2010 data from the World Bank (2014b) about the total workforce was available. From 1990 to 1995 the percentage of occupied population in the extractive industry from the whole labor force was calculated. Chile - Braun-Llona et al. (2000) gives the number of people working in mining as well as percentages of people working in mining from the whole labor force from 1900-1995. From 1996 the total EAP was available from World Bank (2014b). Colombia - Mitchell (1998) reports the EAP in the extractive sector for 1938, 1951, 1964, 1973, 1992 and 2004. Data about the general workforce is available from GRECO (1999b) between 1925 and 1996 as well as between 1997 and 2010 from World Bank (2014b). Mexico - INEGI (2009) reports the EAP in the extractive and petroleum industry from 1900-1997 and from 1998-2004 the EAP in the extractive and petroleum sector. The discount rate for calculating the PV of future changes in real wages is based on each country's geometrical average of real GDP growth rate. Population: Argentina – From 1900-1996 the population was taken from Braun-Llona et al. (2000) and thereafter from INDEC (2014). Brazil - The whole series was taken from IBGE (2014). Chile – From 1900-1995 data was derived from Braun-Llona et al. (2000) and for years after 1996 from Banco Central de Chile (2014). Colombia – From 1905-1997 data was derived from GRECO (1999b), the following years were from DANE (2014). The first five years were calculated using the average growth rate between 1905 and 1915. Mexico – The whole series until 1995 was taken from Braun-Llona et al. (2000), the following years from World Bank (2014b). Education expenditure: Argentina – World Bank (2014b) and MoxLAD (2014). Brazil – From 1930-2004 data was calculated with information on education expenditure which is given as a percentage of GDP by Rodrigues M. (2007). From 2004-2010 data is reported by World Bank (2014b). Chile - Braun-Llona et al. (2000) report data for the period between 1900 to 1996. The data series was completed with World Bank (2014b). Colombia – Data from Helg (2001), DANE (1985), World Bank (2014b) and MoxLAD (2014). Mexico – From 1900-1966 data is derived from INEGI (2009) and from 1997-2014 from INEGI (2014). Carbon emissions: All countries – Data on emissions are reported by Boden et al. (2014). The prices for CO2 were calculated using the methodology presented by Tol (2012) who estimated a CO2 price of 29 USD per ton in 2015. The prices for other years are calculated by discounting it with a rate of 1.99 %. TFP: LA ASTORGA, P., BERGÉS, A. R., & FITZGERALD, V. (2011). PRODUCTIVITY GROWTH IN LATIN AMERICA OVER THE LONG RUN. Review of Income and Wealth, 57(2), 203–223. http://doi.org/10.1111/j.1475-4991.2011.00447.x Argentina – From 1900-1993 TFP growth is reported by Elias (1996) and from 1993-2010 from data estimated by Feenstra et al. (2013). Brazil, Chile – From 1900-1950 data was derived from Elias (1996). These growth rates were assumed to be constant for every decade. From 1950-2010 growth was calculated from the series estimated by Feenstra et al. (2013). Colombia – From 1900-1950 growth rates are reported by Astorga et al. (2003); thereafter we used a series provided by Feenstra et al. (2013). Mexico – From 1900-1950 growth rates are derived from Baier et al. (2006). From 1950-2010 the growth was calculated from the series estimated by Feenstra et al. (2013). The value of technology in the economy was calculated using the methodology in Pezzey et al. (2006).