University of St. Andrews

Discussion Papers in Environmental Economics

Paper 2014-09

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November 2014

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Abstract

Genuine Savings has emerged as the leading economic indicator of sustainable economic development at the country level. It derives from the literatures on weak sustainability, wealth accounting and national income accounting. The paper is structured as follows: section 1 introduces the basic measure and the idea of weak sustainability. Section two provides an overview of the intellectual history of Genuine Savings (GS). This is followed by an outline of the basic theoretical structure underlying GS as well as extensions to this model. Section 4 provides an overview of empirical estimates of GS and section 5 looks at tests of the predictive power of GS. Section 6 concludes by assessing whether GS is in fact a sustainable and useful concept.

KEYWORDS: Sustainable development, Genuine Savings, Comprehensive Wealth, future well-being.

JEL CLASSIFICATION: E21, E22, Q00, Q01, Q20, Q30, Q50

1 Genuine Savings: Introduction to the basic measure

The purpose of this paper is to set out the theoretical and empirical under-pinning for a savings-based measure of the sustainability of economic development, known as *Genuine Savings*. Genuine Savings is also known as Adjusted Net Savings, Comprehensive Investment and as the change in "Inclusive Wealth" (all of these terms are explained below). We explain the underlying model of weak sustainability on which most economic analysis of sustainable development is based. The paper then explains how Genuine Savings is calculated in practice,

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and what kinds of results have been found in cross sectional, panel and time series analysis for a large number of countries. The final section of the paper is concerned with empirical testing of Genuine Savings as a predictor of changes in future well-being, and with setting out some ways in which the theory and practice of GS could be usefully improved.

Genuine Savings (GS) is a measure of how a nation's total capital stock changes year-on-year. It is thus firmly based in the idea of wealth accounting (Hamilton and Hepburn 2014). Total capital, also referred to as Comprehensive or Inclusive Wealth, includes all those assets from which people obtain well-being, either directly or indirectly. It thus comprises produced capital (machines, buildings, telecommunication networks), human capital, natural capital and social capital. Natural capital is all "gifts of nature": non-renewable and renewable resources such as oil reserves and forests; ecosystems, the functions of which generate flows of ecosystem services over time UKNEA (2011); and the global climate system. The values we obtain from natural capital are priced by the market in many cases (coal, timber) but not in others (nutrient cycles, landscape quality, biodiversity). Social capital is a measure of the quality of institutions and social networks. Since wealth is the basis of well-being, then changes in wealth (changes in capital stocks) have consequences for future well-being. It is these changes in wealth than GS seeks to quantify. According to Hamilton and Withagen (2007), a positive value for GS in time t implies rising consumption in periods $t+s$, into the future, so long as GS is not growing too fast: that is, as long as we are not saving "too much". A negative value for GS in time t implies that well-being is likely to decline in future time periods, since the economy is saving "too little".

Why "Genuine Savings"?

The economics of sustainable development is based around two alternative definitions of what characterises sustainable development:

- Outcome based: sustainable development is a path for an economy where utility or consumption per capita is not declining.
- Capabilities based: sustainable development is a path for an economy where the (per capita) value of the total capital stock is not declining.

Whilst clearly closely-related to each other, these two views on what sustainability means has led to the development of two alternative means of measuring sustainability explained below: green Net National Product (relating to outcomes) and genuine savings (relating to capital stocks). As Pezzey et al. (2006) show, green NNP is actually an expanded measure of GS. Both definitions of sustainability point to the main issue at hand here, namely intergenerational equity. A desire to move a country onto a sustainable path arises out of a concern for fairness over time. Many such sustainable paths may be available, some less desirable than others (Pezzey 1997). At any point in time, the possibility set for an economy will depend on its resources (*instruments of wealth*, to use the terminology of section 2), technology, the current level of consumption and population. A competitive economy may not attain a sustainable path, so that if governments wish to intervene on behalf of citizens on normative grounds they need to know what "rules" will move the economy closer to such a path, and how to measure progress towards and along such a path. It is this desire for such a measure of progress that gave rise to the GS literature (Pearce and Atkinson 1993). Since the System of National Accounts framework is the dominant global approach to measuring national economic performance in a consistent manner, it would be advantage if GS could be shown to be consistent with the principles of the SNA, and indeed to be an extension of this system.

Underlying GS is an assumption about how the different forms of capital combine to produce a stream of well-being over time and to maintain the functioning of the economy-environment system. This assumption is known as weak sustainability. As explained below, this implies that a $1 decline in the value of any asset (any instrument of wealth) can be potentially offset by an increases in the value of some other asset or assets. That is, a country just needs to worry about what is happening to the value of its total or comprehensive wealth, not what is happening to any individual component of this total. This implies both monetary and physical substitutability across all assets (Neumayer 2010). An opposing view is obviously that there are limits to the extent to which we can substitute between different assets (especially how much natural capital can be replaced by other forms of capital), and/or that there are critical values associated with system performance which can be attributed to specific assets. Since it is hard to test empirically whether the weak sustainability hypothesis is supported by the data (Markandya and Pedroso-Galinato 2007), adherence to either paradigm is largely a matter of beliefs.

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

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

We now view the first as representing the idea of weak sustainability, and the second as representing the idea of strong sustainability. Interestingly, whilst most focus today is on the degree of substitutability between produced, human and natural capital in deciding which of the above is consistent with non-declining well-being over time, Pearce et al. (1989) provide four reasons why we might need to impose rule (2) rather than rule (1) for welfare to be non-declining. These are (i) lack of sufficient substitutability (ii) irreversibility (iii) uncertainty and (iv) intra-generational equity, on the grounds that the poor are often more adversely affected by poor environmental quality than the rich. There are indications in the text that Pearce et al thought that constraint (2) should always be taken account of in some way, as sustainability could not be assured regardless of the state of a country's natural capital. For example, on page 48 they note: "*...there are strong reasons to think of sustainable development as involving. . . .that the stock of environmental assets as a whole should not decrease*." This is more consistent with the idea of strong sustainability than weak sustainability. Later on, they propose implementing this at the level of programmes of investment by requiring shadow projects which offset the value of environmental losses.

The idea that sustainable development requires non-declining natural capital is stated more clearly in Pearce et al. (1990). They define natural capital as "*...the stock of all environmental and natural resource assets...from oil in the ground to the quality of soil and groundwater, from the stock of fish in the oceans to the capacity of the globe to recycle and absorb carbon*". How this natural capital stock can be maintained as non-declining is put in terms of the net value of environmental damages. When evaluated at the programme level, this net environmental damage value should be zero or negative, either when discounted across time or at each point in time. This outcome, they wrote, could be achieved by commissioning shadow projects which have the purpose of off-setting environmental damages from other projects in the programme. Such shadow projects might well yield negative NPVs when appraised in isolation, implying that there is a sustainability "price" being paid by the economy, which is the marginal cost of imposing a constraint of no positive environmental damage. The work of Pearce and Atkinson (1993) in developing the idea of Genuine Savings as an indicator of sustainability moves away from the notion that sustainability by definition requires zero net loss of natural capital (zero environmental damage, in the language of the previous paragraph), since GS allows for reductions in natural capital to be offset by increases in human or produced capital.

In what follows, we first review the theoretical underpinnings of the GS measure based on the standard Dasgupta-Heal-Solow-Stiglitz or DHSS model. We then show how the "standard" GS index can be adjusted to deal with issues of technological change, population growth and international trade. We also return to the issue of comparing weak and strong sustainability in terms of exactly what world view the GS measure is trying to capture. The next section explains how to calculate GS empirically, and reviews evidence on GS values across the world. The following material concerns empirical testing of the predictive ability of GS using panel and time series data, which is based on the theoretical relationship between GS and the present value of changes in consumption into the future. A conclusion from this review is that there does seem to be some evidence of a long-run equilibrium relationship between GS and future consumption flows. Finally, we reflect on how GS could be improved as a sustainable development indicator.

2 The weak sustainability model: theoretical basis

Sustainability in the weak sustainability model is based on three elements:

- Wealth, which includes, following Fisher (1906),[1] all the elements that are consumed or used in the production processes composing the economy.
- Consumption, which represents the share of income destroyed every period to satisfy

[1] "Wealth is wealth only because of its services. And services are services only because of their desirability in the mind of the man, and of the satisfactions which man expects them to render" (Fisher 1906, p. 41)

human needs and wants. Intergenerational equity, following Solow (1974), is based on consumption being kept constant in value terms between generations.

- A path, which is defined by the states through which the economy passes over time. States are in turn defined by levels of wealth and consumption. Over time, a path characterises the dynamics of the economy.

Optimality is associated with the conditions of pure and perfect competition from neoclassical economics. Sustainability comes from ethical concerns regarding equity between and within generations, while optimality concerns are related to the properties of the resource allocation mechanism (RAM) of the economy (see below). The weak sustainability model is concerned with picking a path characterised by a sustainable level of wealth and consumption as defined by an equity criterion. Paths can also, but not necessarily, be optimal or efficient depending on the structure of the economy.

In this section we review the many potential indicators for sustainability yielded by the weak sustainability model and explain why from a conceptual perspective, Genuine Savings (GS) emerged as the indicator of choice. We shall then present the weak sustainability model in its competitive form, before discussing welfare implications and extensions. We will then discuss whether GS are still relevant when substitutability is limited between instruments of wealth, as in the strong sustainability paradigm.

2.1 The general weak sustainability model

The theoretical basis for the weak sustainability model goes back to the presentation of the DHS or DHSS model[2] and has been subsequently expanded by many publications. The model we present here is based on this rich tradition, from the seminal contributions by Weitzman (1976) and Hartwick (1977) to the more recent contributions of Hamilton and Clemens (1999), Dasgupta and Maler (2000), Asheim and Weitzman (2001), Pezzey (2004), Asheim (2007), Atkinson and Hamilton (2007), Dasgupta (2009) and Arrow et al. (2012). Our main reference for this section is the presentation in Dasgupta (2009). Consider a simple economy where production takes the form:

$$Y(t) = A(t)F(K(t), L(t), R(t)) \tag{1}$$

K, L, R are inputs used in the economy, K being reproducible (man-made) capital, L labour or human capital used in production and R a flow from a natural capital stock $N(t)$ used in the production process. F only needs to be non-decreasing and twice differentiable in each argument. Each argument is essential in production, so that $F = 0$ if A, K, L or $R = 0$. The function F is not assumed to be concave at this stage. A represents total factor productivity, the general effectiveness of institutions and the ability of the economy to combine inputs in an efficient fashion. A thus also represents the state of technology.

[2]For Dasgupta-Heal-Solow or Dasgupta-Heal-Solow-Stiglitz, listing the authors contributing to the all important 1974 seminar on exhaustible resources(Dasgupta and Heal 1974, Solow 1974, Stiglitz 1974*a*,*b*).

The representative agent maximises *intergenerational well-being* at t V(t) which depends on the succession of *instantaneous well-being* $U(t)$ as a function of consumption, so that $U(t) = U(C(t))$[3] with $U'(C) > 0$ and $U'' < 0$. The value of V in t is given by:

$$V(t) = \int_t^{\infty} [U(C(\tau))e^{-\delta(\tau - t)}]d\tau \tag{2}$$

with δ the discount rate ($\delta > 0$) and τ instantaneous utility in future periods. As mentioned in Dasgupta (2009), integral (2) can also be defined recursively (Stokey et al. 1989) for ease of computation, without discretisation altering the argumentation. Each and every "instrument of wealth" in the economy has an idiosyncratic pattern of accumulation and depletion. Man-made capital K is assumed to depreciate at a given rate $\lambda > 0$, while labour L depreciates at a rate μ. This yields the following budget constraint:

$$A(t)F(K(t), L(t), R(t)) = C(t) + \frac{dL(t)}{dt} + \mu L(t) + \frac{dK(t)}{dt} + \lambda K(t) \tag{3}$$

Every period, a balanced budget means that output is consumed, invested to expand the productive base and used to offset the depreciation ("wear and tear") of produced capital.

$R(t)$ represents the services from natural capital used in the production process, when the stock $N(t)$ regenerates at a natural growth rate M[4]:

$$\frac{dN(t)}{dt} = M(N(t) - R(t) \tag{4}$$

We follow Dasgupta (2009) in giving the natural renewal rate a quadratic form:

$$M(N(t)) = -b + mN(t)[\frac{1 - N(t)}{Q}], for N(t) > 0 \tag{5}$$

$$M(N(t)) = 0 for N(t) = 0 \tag{6}$$

Total depletion of the stock wipes out natural capital without the possibility of regeneration and therefore halts any production. For N to be positive, we assume also that $Q > 4b/m$ so that the renewal threshold is $Q[1 - (1 - 4b/mQ^{1/2}]$. Should N reach a value below this level, the stock will converge towards 0 over time and production would halt. A given *state* for the economy is defined in this example by the triplet (K, L, N) by $\underline{S} = (K, L, N)$. As we did not assume concavity in production, we do not assume a convex set of production or an optimal economy.

We now introduce the concept of a Resource Allocation Mechanism (RAM) from Dasgupta and Maler (2000). A RAM characterises all the constraints on a given economy (whether they be technical, institutional or environmental) that co-evolve over time with the economy and

[3]Considering the richness of the literature on amenities entering as arguments in the utility function (Krautkraemer 1985) using only C seems limiting. As shown in Dasgupta (2009), adding more arguments to the utility function merely affects the structure of shadow prices. So we can consider C as an expanded vector of consumption goods

[4]This dynamic can naturally be altered to reflect exhaustible resources. Using this general form from Dasgupta (2009) nests the non-renewable exhaustible resources case into the renewable exhaustible resources case.

form the superstructure for decisions regarding resource allocation[5]. Formally, α represents the RAM that maps a given state $\underset{\sim}{S}$ in t to an observed broader set of economic variables[6] in τ (with $\tau > t$) defined as $\{\underset{\sim}{E}\}_t^\infty \equiv \{C(\tau), R(\tau), J(\tau), K(\tau), L(\tau), N(\tau)\}_t^\infty$:

$$\alpha : \{\underset{\sim}{S}(t), t\}\{\underset{\sim}{E}(\tau)\}_t^\infty \tag{7}$$

The term α is time dependent as superstructures co-evolve over time with economic conditions. Under a given (and unobservable) α, equation (2) can be written as:

$$V(\underset{\sim}{S}, t) \equiv \int_t^\infty [U(C(\underset{\sim}{S}, \tau))e^{-\delta(\tau - t)}]d\tau \tag{8}$$

So that the value function V depends on time and exogenous shocks are possible. V is assumed to be differentiable, the only constraint put on the mathematical properties of α. We then define shadow prices associated with our three "instruments of wealth", capital stocks K, L and N:

$$p(bS, t) = \frac{\partial V(\underset{\sim}{S}, t)}{\partial K(t)} \tag{9}$$

$$q(bS, t) = \frac{\partial V(\underset{\sim}{S}, t)}{\partial L(t)} \tag{10}$$

$$n(bS, t) = \frac{\partial V(\underset{\sim}{S}, t)}{\partial N(t)} \tag{11}$$

Those expressions take felicity (well-being) as the *numéraire*. The evolution of shadow prices may be explained by variations in the marginal utility of consumption and the allocation process using equations (2) or (8) and (9) to (11). The RAM is inefficient, the marginal contribution of a given instrument of wealth will differ across industries. A different shadow price then needs to be defined for each sector. As a consequence, a full characterisation of well-being in imperfect settings requires a high level of disaggregation in the data.

Let us assume temporarily that changes in total factor productivity $A(t)$ are exogenous and the RAM does not co-evolve with the economy over time. The value function defined in (2) is now equal to the RAM-contingent value function in (8). Differentiating $V(t)$ with respect to t using the definition of shadow prices in (9) to (11) gives:

$$\frac{dV(\underset{\sim}{S}(t))}{dt} = p(t)\frac{dK(t)}{dt} + q(t)\frac{dL(t)}{dt} + n(t)\frac{dN(t)}{dt} \tag{12}$$

We now define *comprehensive investment* (Genuine Savings) as the rate of change in stocks multiplied by shadow prices:

$$I(t) = p(t)\frac{dK(t)}{dt} + q(t)\frac{dL(t)}{dt} + n(t)\frac{dN(t)}{dt} \tag{13}$$

which leads to the logical conclusion that:

$$\frac{dV(\underset{\sim}{S}(t))}{dt} = I(t) \tag{14}$$

[5]As stressed by Dasgupta (2009), this superstructure does not need to be efficient, include a benevolent social planner or exclude any real life distortions.

[6]Which Dasgupta (2009) calls an "economic programme".

The quite powerful conclusion of the general model is therefore that the level of comprehensive investment at time t $I(t)$ corresponds to variations in intergeneration well-being $V(t)$ in t.

We obtained this result under the assumption that the RAM (including total factor productivity evolution) is time invariant (the autonomous case). Starting with Pemberton and Ulph (2001), various authors considered that a time dependent RAM could be formalised considering as an investment the effect of "time passing". Let us relax the autonomy assumption so that V is now time dependent: $V = V(\underline{S}(t), t)$ Differentiating V now adds the time derivative of V to equation (15):

$$\frac{dV(\underline{S}(t))}{dt} = \frac{\partial V}{\partial t} + p(t)\frac{dK(t)}{dt} + q(t)\frac{dL(t)}{dt} + n(t)\frac{dN(t)}{dt} \tag{15}$$

$$\frac{dV(\underline{S}(t))}{dt} = \frac{\partial V}{\partial t} + I(t) \tag{16}$$

In the non-autonomous case, time passing can be thought of as investment in a virtual instrument of wealth the size of which expands every period endogenously. Defining this new instrument of wealth as Z, its accumulation dynamics is simply $dZ/dt = 1$. This conceptual trick allows us to account for the unobservable (or observable but yet unaccounted for) characteristics of a given RAM. We will see in the rest of this section how particular forms of this general model all aim at extracting from this general term observable characteristics of the RAM so they can be incorporated into the pool of known instruments of wealth with an associated shadow price.

From this general model, assessing sustainability boils down to assessing changes in the pool of instruments of wealth (capital stocks) priced using the relevant shadow prices, so that the rate of change of comprehensive wealth (comprehensive investment) will indicate evolutions in intergenerational well-being.

The intuition that savings and investment should be the prime indicator of sustainability comes from the late David Pearce (Hamilton and Atkinson 2006). This intuition was quite original and powerful in the context of the end of the 1980's, when the dominant metric in sustainability assessment was the maximum level of consumption attainable. The emphasis on consumption derived from the philosophical debate of the 1970's about the actual meaning of sustainability and the definition of an intergenerational contract. It is not clear whether constant consumption, as in Hartwick (1977), was a means to an end (that end being the maintenance of wealth and therefore income streams) or an end in itself. Indeed, constant consumption over time (in value term) could be perceived as a desirable contract between generations to preserve far-off future generations. It could also be argued that, as consumption is defined in value terms, the imperative of constant consumption is an incentive to increase productivity (hence sparing resources via increased efficiency) so that *physical* consumption increases at constant value, rewarding effort and thrift.

GS is therefore an indicator of sustainability at a given point t looking forward over a succession of τ periods. But beyond instantaneous sustainability and given some restrictions on the RAM, GS can also inform us about future sustainability and the sustainability of a given consumption path. Discussing those cases is our next object.

2.2 Sustainability rules and alternative indicators: some basic results

From the general case of the DHSS model, authors have imposed restrictions on either the production function or the set of production possibilities to offer both *prescriptions for* and *descriptions of* sustainability. Practical implementation of sustainability requires rules that can be assessed and followed. Tremendous efforts were devoted to build an indicator that would be grounded in welfare/utilitarian theory while taking into account physical and environmental constraints. The most famous of those sustainability rule follow directly from the implementation of the DHSS model. This is the Hartwick (1977) rule.

Hartwick (1977) showed that following Solow's (1974) model, maintaining consumption *constant over time* in value terms, required all rents and profits from the instruments of wealth available in the economy to be reinvested into man-made (hence renewable) capital. Hartwick (1977) assumed a Cobb-Douglass production function,[7], constant returns to scale in production and optimality in the exhaustible resource extraction plan. The Hartwick rule follows naturally from the Keynes-Ramsey rule that characterises a steady-state for consumption, as in the DHSS model.

The Hartwick rule is associated with the optimal path for constant consumption in an open economy, but does not effectively yield a rule for local deviations from the path. Critically, it gives a criterion that defines *unsustainability* as all paths outside the optimal constant consumption path. As a consequence, sustainability is obtained when net savings in each period are equal to zero so that comprehensive wealth is maintained.

This result should be paralleled with the seminal contribution of Weitzman (1976) who showed, in a competitive framework with no technical change or population growth, that Net National Product[8] (NNP) is the stationary equivalent of future consumption. As a consequence, NNP can be used as a predictor of the maximum sustainable level of consumption reachable over future time. An important literature has been developed on the welfare significance of NNP since.

The Hartwick rule and the Weitzman (1976) result form the basis of efforts to define levels of consumption and investment that are compatible with sustainability. Dasgupta and Mitra (1983) formulate the challenge clearly: the model should be defined so that it is efficient in economic terms (i.e. yielding an optimal path) and equitable (i.e. yielding basic conditions for sustainability such a distributive justice between generations). Thereafter, the literature focused on characterising optimal paths that would satisfy conditions of equity and use the NNP (and its rate of change) as the indicator of sustainability in this optimal context. Unless stated otherwise, all the contributions listed assume an autonomous (time independent) RAM.

Dixit et al. (1980) define equity as the maximin criteria from Rawls[9] (1971) and endeavour to relate the Hartwick rule to some maximin-efficient paths. They show that any maximin

[7]So that each input in the production function is essential.
[8]Defined as the sum of consumption and net investment.
[9]Or more precisely the Solow (1974) interpretation of it as an intergenerational equity criterion.

efficient path satisfies the Hartwick rule, so that the Hartwick rule is a necessary but not sufficient condition for equity on an optimal (competitive) path. Many years later, Buchholz et al. (2005) show how conversely, an equitable competitive path must follow the Hartwick rule.

Solow (1986) supports the use of the Hartwick rule as a prescriptive rule. He shows how, consumption being the interest on comprehensive wealth, maintaining the productive base constant over time naturally leads to constant consumption over time. After many years of possibly inaccurate use of the term "Hartwick rule", Asheim et al. (2003) offer to clarify the debate over the prescriptive character of the rule. A first important observation is that both descriptions and prescriptions are obtained in a competitive and autonomous context.[10] A useful difference can be made between the *investment rule* and the *Hartwick result*. The *investment rule*, as in the original Hartwick (1977) contribution, is a prescription to hold the value of net investments constant and equal to zero. The *Hartwick result* shows how this prescription leads to constant utility.[11]

The authors show how in a perfectly competitive economy following the investment rule yields constant utility and sustainability if and only if the Hartwick rule applies to all periods $\tau \in (0, \infty)$. However, should the Hartwick rule only be applied over an interval (t_1, t_2) then the corresponding level of constant utility cannot be sustainable forever, so that the investment rule does not yield the Hartwick result. As a consequence, the Hartwick rule should not be considered to be prescriptive as the assumptions that are needed for satisfying it to yield desired results (constant utility/consumption in value terms/sustainability) are out of reach.

This critique, although perfectly fair and grounded, could nonetheless be applied to any result coming from a theoretical model that assumes a form of optimality, which would rule out many of the findings in economics! The Hartwick rule is still used implicitly or explicitly as a rule of thumb in empirical sustainability assessments, in a role similar to the Hotelling role for extraction or the Keynes-Ramsey rule for optimal consumption.

Uncertainty around future and past conditions along the optimal path are compounded with another, more practical problem. The Hartwick rule in linked to the NNP (income) to derive the Hartwick result. But as Brekke (1994) wonders: what actual prices should be used to measure NNP? This problem led Asheim and Weitzman (2001) to propose a price index fit for the job namely the Divisia (1925) price index. Divisia price indices apply weights based on consumption and investment flows, so that the path followed by prices is taken into account, not only the start and ending points (Asheim 2007). This is the solution to the Brekke (1994) objection which again relates to optimality over the whole path.

The use of a divisia price index will yield shadow prices in a competitive setting, in discrete or continuous time. The divisia price index simply start from nominal prices to obtain real prices that are effectively shadow prices. Shadow prices for instruments of wealth do not change much over the short run (as they reflect changes in large stocks) whilst observed nominal prices may be more volatile. To build an empirical sustainability indicator, a full characterisation of shadow prices is not required as the rate of change in prices will be mostly driven by the

[10] So that again, technology and population are both constant over time.

[11] And by means of definition, constant consumption.

observable and more volatile components. Asheim (2010) notes how the potential discrepancy gets worse at the international level, when purchasing power parity measures need to be used.

A final question about future flows concerns the discount rate to be used and whether it is changing over time. Asheim (1994) investigates the potential impact of a non-constant rate for utility discounting. There are two possible methods to discounting. The first one, used by Ramsey (1928) is to provide an upper-bound to the maximum level of utility it is possible to reach. This way, convergence of the integral is not a problem. Otherwise, future utility flows must be discounted to reflect the preference for the present and the integral converges over time. One also needs to distinguish between normative and positive interpretations of the long run discount rate (Gollier 2012).

Pezzey (2004) provides us with a clear account of the Asheim and Weitzman (2001) results, describing a sustainability rule in the autonomous case. We call $C(t)$ a vector of multiple consumption goods, including environmental amenities. Consumption is the sole argument in the utility function $U(C(t))$ with U the instantaneous utility function[12]. The instruments of wealth in the economy are summarised by the vector $K(t)$. Investment in those instruments of wealth (net of depreciation) are defined as $I(t) = \dot{K}(t)$. Values for K are obtained in a set $S(K)$ starting from a given $K(0) = K_0$. The agent maximises inter-temporal welfare which is the present value of instantaneous utilities in all t, using a constant discount rate:

$$V(C(t)) = \int_0^\infty U[C(t)]e^{-\rho t}dt \tag{17}$$

Subject to:

$$(C(t), I(t)) \in S(K(t)) \tag{18}$$

with $\rho > 0$. Assuming all externalities are internalised, this program yields an optimal path. The current value Hamiltonian of the problem is:

$$H(C, I, \Psi) = U(C) + \Psi I \tag{19}$$

As in Weitzman (1976). $\Psi(t)$ are the shadow prices for investment in each instrument of wealth at period t. Consumption and investment along the optimal path are priced using the marginal utility of consumption $\lambda(t) > 0$ and a divisia price index $\pi > 0$ so that:

$$P(t) = \frac{[\nabla U(C)(t)]}{[\lambda(t)\pi(t)]} \tag{20}$$

$$Q(t) = \frac{[\Psi(t)]}{[\lambda(t)\pi(t)]} \tag{21}$$

$$\tag{22}$$

Using this definition[13] for prices along the optimal path, "Green" NNP can be expressed as:

$$Y(t) \equiv P(t)C(t) + Q(t)I(t) \tag{23}$$

[12]Satisfying the usual conditions: concave, twice differentiable.

[13]$\nabla U(C)(t)$ is a vector of partial derivatives as C is a vector of multiple consumption goods.

with $Q(t)I(t)$ being the real value of investment representing GS. An economy is sustainable at time t if $U(C(t)) \leq U^m(t)$, where $U^m(t)$ is the maximum sustainable utility at time t, i.e. the instantaneous utility level delivered on the optimal path. Any value below $U^m(t)$ is sustainable, but only $U^m(t)$ would be both optimal and sustainable.

It follows from those definitions and results that an economy is unsustainable if $Q(t)I(t) \leq 0$ on the optimal path. This result is critical for what it does not say, namely that positive GS *does necessarily* imply sustainability (Asheim 1994). As for the Hartwick rule, the unsustanability test presented here is slightly more general as optimal intantaneous utility is not assumed to be constant.

As a consequence of this, negative GS implies unsustainability in a competitive framework, but does not seem to be able to bring information on sustainability. It is thus a "one-sided indicator" (Pezzey 2004). Even worse, observed consumption is increasing over time, making tests based on constant or capped consumption of little practical use. This interrogation translated in to concerns about a potential peak in consumption, where a trend of increasing consumption peaks before collapsing (Sato and Kim 2002, Hartwick et al. 2003).

Hamilton and Hartwick (2005) show how, in consumption peak models, GS prior to the peak are effectively predictors of future consumption. GS will fall and then become negative before consumption peaks, so that positive GS indicate that consumption will not peak in the near future. A positive value of GS, here, is an indicator of rising future consumption, so long as savings are not too high. So long as GS is growing at a slower rate than the real interest rate.

It should by now be obvious that in perfectly competitive economies with welfare assessed on the basis of an intergenerational equity criterion and constant consumption sustainability can be assessed interchangeably with "green" NNP or GS. We will now discuss extensions form the NNP framework for the non-autonomous cases.

2.3 GS extensions: population growth and technical change

The two main sources of time dependence in competitive settings are technical change and population growth. Technical change as a source of time dependence was first explored by Weitzman (1997) and then used to propose a definition of un-sustainability tests in non-autonomous contexts in Pezzey (2004). Using the model in section 2.2 it is easy to see how technical change can be considered as one of the unaccounted time dependent productive stocks $\frac{\partial V}{\partial t}$ that affects the RAM, as in section 2.1. Capital stocks are now $K' = (K,t)$ so that *augmented* investment is $I' = (\dot{K}',1) = (I,1)$. The Hamiltonian becomes:

$$H(C,I,\Psi) = U(C) + \Psi' I' = U(C) + \Psi I + \Psi' \tag{24}$$

As in the general model, time dependent capital stocks can be linearly separated from non time dependent ones, so that technical change is the equivalent of introducing a new time dependent capital stock for which investment is 1 every period. The "augmented" un-sustainability test

(Pezzey et al. 2006) straightforwardly becomes:

$$Q'(t)I'(t) \leq 0 \quad \text{or} \quad Q(t)I(t) + Q'(t) \leq 0 \tag{25}$$

As a consequence, technical progress acting as another instrument of wealth or capital stock raises the maximum level of sustainable consumption in this model. Technical change is therefore unequivocally good for sustainability. Population growth is intuitively less obviously beneficial as a higher population increases the stock of labour available (and thus potentially the value of human capital) but also increases resources consumption.

Arrow et al. (2003) include population growth showing that under the implausible assumption that growth is exponential, sustainability criteria should be considered in per capita terms. Other growth profiles require more complex amendments. Using again the framework from Pezzey (2004) we present the reasoning for the case of a given constant growth rate. Assume that population in t $N(t)$ enters the utility function $(U(C,N))$ and the production set $(S(K,N,t))$. $N(t)$ is exogenous and time-dependent. Assume that the objective is the maximise individual utility $u(C,N)$ multiplied by a weighting function $G(N)$. It is then possible to show, under quite restrictive assumption that the following *individual* un-sustainability criterion holds:

$$Q(t)[i(t) - nk(t)] + q'(t) \leq 0 \tag{26}$$

with n the rate of population growth and k the per capita stock of man-made capital and q the individual price of time. It is then possible to obtain the global rule by multiplying the individual rule by $N(t)$:

$$Q(t)I(t) - nQ(t)K(t) + Nq'(t) \leq 0 \tag{27}$$

With population growth, a share equal to the growth rate of the existing stock of produced capital must be deducted and the global increase of time dependent stocks added to obtain comprehensive GS. The impact of population is further explored in Asheim et al. (2007) where the authors show that population growth needs to be quasi-arithmetic to be compatible with sustainability in a competitive framework. Li and Löfgren (2013) then show how uncertainty regarding population growth requires us to subtract a term from GS reflecting the welfare loss from risk aversion.

Extensions of the competitive models tried to mix the approaches presented here. Man-made capital is subject to wear and tear so that the stock depreciates over time. Cheviakov and Hartwick (2009) study how technical change can compensate man-made capital depreciation in the DHSS model with two patterns of population growth. They conclude that technical change should be maintained sufficiently high to compensate for produced capital depletion and avoid economic collapse. D'Autume and Schubert (2008) considers the case where natural capital is an argument in the utility function. They show how this creates an incentive to preserve a minimum critical stock of natural capital and how higher amenity values lead to lower depletion rates and a higher stock of natural capital over time.

2.4 Trade openness, time effects and beyond: does structure matter for sustainability?

The impact of trade openness on weak sustainability models is somewhat tough to comprehend, although not for technical reasons as in the population growth case. International trade is first a question of scale: shall we assess sustainability at the country level or the global level? In an integrated world with factor price equalisation, the law of one price and generally no border frictions, the question is quite simple. It is about accounting for the income generated by instruments of wealth owned abroad by country nationals and the impact of exogenous world prices, as every country becomes a price taker for every good and for each capital asset.

Still, international borders matter, and institutional differences between countries bring considerations regarding international trade in the realm of non-optimal resources allocation mechanism (RAM). In a closed economy, institutions (governments or others) exist to effectively organise intergenerational equity. No such institutions exist yet at the international scale, which begs the question of who is ultimately responsible for the use and depletion of resources.

Finally, international trade is organised around the notion of comparative advantage, based on the many different sources of comparative advantage: productivity differences (Ricardo 1817), differences in endowments (Ohlin 1933), preference for variety (Krugman 1980), and international economies of scale (Ethier 1982). Forming and then maintaining a comparative advantage is a new imperative for open economies with an impact on optimal growth, consumption and depletion paths. Trade is therefore a complex problem if we want to derive aggregate sustainability results.

Asheim (1986) first examined the consequences of economic openess for the Hartwick rule. From a sustainability perspective, openness introduces an element of uncertainty regarding resource prices as single countries are now price takers. Countries can expect a long run improvement in the terms of trade for natural resources as scarcity starts to bite. Therefore economic openness is similar to a violation of the constant technology assumption and should be accounted for in GS. As a consequence, terms of trade variations have been termed "capital gains" from trade.

This result was then adapted to different modelling structures in Hartwick (1990) and Hartwick (1995), the latter exploring the consequences of endogenously determined world prices in a two country setting. Vincent et al. (1997) then proposed an assessment of the capital gains based on the example of Indonesia. Using again the model from Pezzey (2004) we call $\Sigma(t)$ a non-renewable resource stock in t whose depletion rate is $V(t)$ so that $\dot{\Sigma} = -V$. The resource is exported at a time varying exogenous world price $Q^V(t)$. Assuming the economy's total domestic endowment is composed of the non-renewable resource and that all man-made capital $K(t)$ is owned and maintained abroad earning an interest rate R. Total capital evolution (domestic and foreign) is:

$$\dot{K} = RK + Q^V(t)V - C - X(V) \tag{28}$$

With $X(V(t))$ the extraction cost and $U(C)$ the utility function. Augmented net investment becomes:

$$Q'(t)I'(t) = \dot{K} - Q^{\Sigma}V + Q' \tag{29}$$

$$Q'(t)I'(t) = \dot{K} - [Q^V(t) - X_V]V + \int_t^\infty \dot{Q^V}(s)V(s)e^{-R(s-t)}ds \tag{30}$$

(See Pezzey (2004) for more details.). GS including the terms of trade is therefore the sum of net investment, net extraction and the impact of the world resource price evolution considering a given level of extraction $V(t)$. The amendment is somewhat similar to the amendment for technical change, only more volatile with resource prices and even harder to assess in its forward-looking component. See Pezzey et al. (2006) for details on how reserve price capital gains can be included in GS.

Capital gains, considering the important volatility in commodities market are sometimes considered to have a small impact over the long run and could/should therefore be neglected. Hamilton and Bolt (2004) estimate these and find them to be a sizeable share of GS for low income countries, transition and emerging economies. Rubio (2004) and Van der Ploeg (2010) investigate some specific cases, wondering whether capital gains could correct apparent unsustainability. They both conclude that the capital gains alone do not alter significantly overly negative or positive GS. Although theoretically capital gains can be used as an excuse to violate the Hartwick rule, they do not appear to be large enough empirically.

Chichilnisky (1994) showed how ill-defined property rights in one trading partner may bias trade flows and increase depletion in an institutionally weaker country. Based on this intuition that property rights and rent seeking behaviour may foster over-depletion, Proops et al. (1999), Atkinson and Hamilton (2002) and Atkinson et al. (2012) estimated the natural resources content of imports and exports for a selection of regions and individual economies. They offer the concept of virtual sustainability to characterise the total of GS and the consumption-induced depletion in trading partners.

In the same vein Okumura and Cai (2007) show how when instruments of wealth enter as complements in the production process, countries favour depletion of the non-renewable factor in the foreign country before using up domestic resources. This strategic result is further explored by Oleson (2011) who suggests that export dependence may undermine sound domestic management and compromise long run sustainability by increasing reliance on unsustainable partner countries. Those results, although not yet as formal as those obtained in competitive frameworks, suggest that GS should be amended for resources trade strategies, to factor in the risks associated with dependence on foreign assets.

The final consequence of trade on GS estimates is related to the notion of comparative advantage. Economic openness is not neutral for an economy, as economic structures need to adapt to develop and foster comparative advantages. The literature on the resource curse, starting with Corden and Neary (1982) and surveyed in Van Der Ploeg (2011) illustrates how trade patterns may set economies on unsustainable patterns of resource depletion with the sole intent of maintaining a comparative advantage but at the cost of potential growth and future consumption. Bogmans and Withagen (2010) show how variations in the discount rate of future utility flows between trading economies may also modify economic structures and impact the location of polluting industries.

The resource curse is now depicted mostly as a consequence of poor quality institutions or low levels of social capital (Acemoglu and Robinson 2012, Van Der Ploeg 2011). Examining the impact of trade on economic structure and sustainability would be a way to better understand the RAM and reduce the influence of the time dependent term in equation 15, potentially through accounting for a new instrument of wealth. In line with the Hartwick rule, sustainability concerns are related to the notion of structural change, where a given economy goes from sole reliance on labour and exhaustible resources to reliance on man-made capital and knowledge. It is even likely that natural resource depletion is one of the main motives behind structural change (López et al. 2007). Therefore, a trade-induced economic specialisation may lead to path dependence in GS, as the economy develops an economic structure that is optimal from a global perspective, but less so from a domestic perspective. Combining inputs from the resource curse, sustainability literature and neoclassical growth theory (Ventura 1997, Cuñat and Maffezzoli 2004), Dupuy (2014) shows how countries with a strongly asymmetric distribution of instruments of wealth may be better-off in autarky than free-trade, considering the induced pattern of economic specialisation. This result is obtained in an dynamic Heckscher-Ohlin model, despite the materialisation of gains from trade should countries engage in free-trade.

The study of the consequences of trade on sustainability is therefore promising, not only as it may lead to new amendments of GS to account for indirect trade effects, but also as it may help us understood the general impact of economic structure on sustainability. Trade models may be an interesting way to understand the consequences of inefficient RAM and dependence on scarce factors, and to explore the possibility of non-flexible pricing of resources.

2.5 Weak versus strong sustainability: conflict or complementarity?

Most economic analysis of sustainable development is based on a background of weak sustainability. The question of the assumption regarding substitutability between incommensurable instruments of wealth (the "weak versus strong sustainability" question) has been the background of sustainability studies since at least the Meadows et al. (1972) report. Hartwick (1978) tried to estimate the consequences of multiple exhaustible resources for the DHSS model and the Hartwick rule and found no incompatibility. Asheim et al. (2003) studied the importance of perfect substitutability for the Hartwick rule. They also find that perfect substitutability is not required as long as the technology exist for an "eventual productivity path". See also Markandya and Pedroso-Galinato (2007), who consider empirical evidence on the substitutability of energy resources.

As Neumayer (2010) presents it, the strong sustainability paradigm considers the question to be more fundamental. Georgescu-Roegen (1971) described economic operations as processes characterised by increasing entropy. By this view, transforming or substituting one instrument of wealth for another increases the overall entropy of our closed system (the earth). Actual substitutability is therefore impossible as the new instrument at the very least added to the overall entropy in the system. Daly and Cobb (1989) and Daly (1996) offered a somewhat less radical perspective, stressing that any economic/ecologic system has a limited "carrying capacity", whilst it should be noted that the earth is not actually a closed system, as it receives inputs of solar energy. Put under pressure by an increasing population, increasing needs and wants or both, the system may slowly degrade in its ability to provide services or even suddenly collapse.

The weak sustainability paradigm sees the problem as a dilemma akin to the famous macro-Trilemma. It is impossible to have simultaneously a constant or growing population, imperfect substitution between instruments of wealth and no technical progress. But assuming that population is growing “slowly enough", or that technical progress is "fast enough" or that substitutability is "almost perfect" then there is no real issues with critical levels for a given instrument of wealth (or safe minimum standards), let alone a complex synergy of instruments such as an ecosystem. The strong sustainability paradigm rejects this "optimistic outlook" on physical grounds.

The common view today is that weak sustainability is in essence a first step or a special case of strong sustainability (Hediger 2006). Weak sustainability should be achieved first and then strong sustainability could be used to target irreplaceable ecosystem services and endangered instruments of wealth or biodiversity. How can the divergence of weak and strong sustainability proponents be explained as they at first were worried about the same phenomena? And what are the consequences for GS?

It is first important to note that in Fisher’s (1906) original definition of wealth (as the sum of all the instruments of wealth available for consumption and/or investment in the economy) there was a clear dissociation between capital theory (which conceptualised the relationship between human-beings and the environment) and the theory of value (which is the ethical foundation behind the set of relative prices). Fisher defined a system centred on the needs and wants of human-beings, assuming that there is no value as we understand it outside of human perception, so that valuation is necessarily performed through the prism of the definition of value by human stakeholders. The source of the weak sustainability paradigm is therefore not so much in the idea that the environment can be perceived as a collection of instruments of wealth of a given value[14] but in the theory of value used to assign prices to those instruments of wealth.

In this perspective is it useful to briefly come back to the orignal Solow (1974) model which in turn was based on Rawls (1971)’s criterion for intergenerational equity. Rawls (1974) reminds us of the principle of democratic justice: “Each person has an equal right to the most extensive scheme of equal basic liberties for all” and “social and economic inequalities are to meet two conditions: they must be (a) to the greatest expected benefit of the least advantaged members of society (the maximin equity criterion) and (b) attached to offices and positions open to all under conditions of fair equality of opportunity” (Rawls 1974, p.142). Any effort to provide guidance regarding the transmission of capital that claims to rest on a form of maximin should therefore be preoccupied with point (a). A transmission of capital from a better-off individual in the (theoretical) early generation should therefore be scrutinised to make sure this transmission will be to the benefit of the “least advantaged members of society”.

[14]There is no intrinsic value in nature in that sense: the expression becomes in the framework we lay here an oxymoron, an opposition in the terms.

It is interesting to see how Solow used the maximin criterion to tackle intergenerational equity when Rawls probably never intended it to be used this way. There is a "fundamental disequilibrium" between generations. Indeed, future generations can inherit capital, institutions and other benefits from present, but the inverse is not true. Egalitarianist intergenerational equity ensures that the next generation inherits at least what the current generation inherited from the previous one. But it precludes any increase in the inheritance as then the next generation would be better-off than the current one. This would be a breach of intergenerational equity. Intergenerational equity understood as intergenerational equality leads to the purest egalitarianism and the impossibility of progress. Solow (1974) also shows that the maximin criterion is highly dependent on the initial condition. "if the initial capital stock is very small, no more will be accumulated and the standard of living will be low forever" (Solow 1974, p.11). Therefore an application of the maximin in economics should be understood as:

- An objective of constant consumption over time as the condition for intergenerational equity.
- An underlying condition on the capital stock from which the flows of services (i.e consumption) are to be derived. Early generations can have a higher consumption/capital ratio, because what they need to pass on is a sufficient technical progress adjusted capital to the next one.

The maximin criterion was used as ethical basis for an implicit behavioural rule regarding consumption and savings (in fact investment) in economics. But this "social contract" between generations was sealed in an implicit way and is based on relatively strong assumption regarding substitutability, the course of technical progress and productivity gains. As for population growth, it is assumed to be exogenous, as in the Solow (1956) model.

Although the DHSS model would become the basis of the neoclassical treatment of sustainbility, the question of intragenerational equity is, to our knowledge, never mentioned. It is usually argued that intragenerational equity is addressed with different tools and in different models with an ambition to tackle this particular issue. The DHSS model thus confirms the status quo in economics: market mechanisms take responsibility for capital accumulation whilst redistributive policies take responsibility for tackling inequalities. So economists continued to study inter and intragenerational equity separately. Intergenerational equity is dealt with via capital accumulation and it is as such fully integrated in the economic analysis. Intragenerational equity is a second rank objective as far as economic efficiency is concerned. It should be dealt with using relevant redistributive policy (depending on the preferences of voters) as "No reliable theory exists to integrate those to a comprehensive economic development approach" (Arrow et al. 2012).

How is this lack of intragenerational equity in the theory of value behind weak sustainability model related to the weak versus strong sustainability debate? Let us assume that in every generation, the distribution of wealth within the generation is not perfectly egalitarian. Let us also assume that the instruments of wealth used in production and consumption are not the same. If there is perfect substitutability between instruments of wealth in terms of their ability to generate well-being, then it is possible for individuals relatively less well-endowed with a given set of instruments of wealth to convert those into a different, desired set of production or/and consumption instruments of wealth.

Critically, in this scenario, market prices can be assumed to fully reflect the physical constraints on sustainability, so that *money value substitutability* reflects all the preferences and the constraints set by *physical substitutability* (Neumayer 2010) on the production and consumption process[15]. Under a scenario of perfect substitutability it is therefore possible for any agent, regardless of their initial endowment, to make an informed decision that will assign a value to all transactions and processes consistent with the set of preferences and the physical constraints of the economic system.

Under the strong sustainability assumption, the problem is entirely different. Under the same scenario of uneven distribution of instruments of wealth and consumption within a generation, there are individuals that own instruments of wealth that are either non-substitutable or imperfectly substitutable. There are then two possible scenarios:

- If money-value substitutability is higher than the observed, physical substitutability then individuals within this generation starting with this potentially disadvantageous distribution of the endowments of wealth instruments can obtain a more favourable one through market mechanisms. But they end-up depleting assets that are of potentially incommensurable value to themselves and hypothetically to others via amenities and externalities.
- If physical substitutability is still limited but higher than money-value substitutability (as in the case where markets do not exist for the services provided by the instruments of wealth) then the owners lose out on opportunities to acquire a distribution of instruments of wealth best suited to their needs and wants and intragenerational inequity may perpetuate over time.

The last scenario is especially problematic if one section of the current generation is well-endowed in consumption goods of limited market-value substitutability or limited physical substitutability. As individuals in this group will strive to acquire instruments of wealth to pass on to the next generation for production, they are likely to either fail in this endeavour or deplete critical natural capital in the process. Then, via inequitable ineheritence, intragenerational equity will endure.

The question of substitutability becomes a problem for the weak sustainability model because of the lack of explicit incorporation of intragenerational equity into the theory of value used to define prices for GS. This brings us back the debate about the RAM and what is not understood yet about the impact of wealth on institutional evolution. There is certainly a need for a theory linking wealth inequality, institutional developments and resource scarcity management, although the links between the last two are better understood now, thanks to the literature on the resource curse (Van Der Ploeg 2011).

Progresses also needs to be made to link wealth inequality with institutional evolution.

[15] By physical substitutability we understand the physical fact that turning for example oil into electricity and electricity into light is accomplished by increasing entropy.

Making GS a robust indicator in the context of limited substitutability is therefore not so much about finding an alternative to capital theory, but about the consideration of the distribution of instruments of wealth within a generation based on the equity criterion used to define the set of relative prices.

3 Genuine Savings and comprehensive wealth empirical methods

For some years now, the World Bank has produced estimates of Genuine Savings and wealth for most of the world's economies (World Bank 1997, 2006, 2011) for an extensive sample of countries and regions in the world. The World Bank method is based on a series of publications by Kirk Hamilton and his coauthors (Hamilton 1994, 1996, Hamilton and Clemens 1999). Economies are described by the current value Hamiltonian:

$$H = U + \gamma_K \dot{K} + \gamma_X \dot{X} + \gamma_S \dot{S} + \gamma_N \dot{N} \tag{31}$$

where U is the utility function (utility depends on both consumption and pollution), K is produced capital, X is the stock of pollution, S an exhaustible resource stock and N the human capital stock. The γs are the shadow prices. Dots indicate time varying variables. Adding international trade and capital depreciation, the measure of NNP is given by:

$$NNP = C + \dot{K} - \delta K + E - M + iA - (1 - be_F)F_r(R - g) - b(e - d) + \frac{q}{q'} \tag{32}$$

With C consumption, E exports, M imports, iA interests on foreign assets, R resources depletion, g renewable resources growth, d the dissipation of pollution, e the abatement of pollution, q the function of human capital accumulation, δ the produced capital depreciation, F_r is the resource rental rate, b the marginal cost of pollution abatement and be_F si the effective tax rate on production set by emission taxes. It should also be noted that under the assumptions of the model, human capital investment brings endogenous technical progress. Finally, the formula to calculate GS from data is given by:

$$GS = GNP - C - \delta K - n(R - g) - \sigma(e - d) + m \tag{33}$$

GS are thus equal to Gross Savings (Gross domestic product minus consumption) minus the depreciation of produced capital, minus the net resource rental rate times the variation of the stock of exhaustible resources, minus the marginal cost of social pollution times plus investment in human capital.

Besides yearly estimates of GS using accounting data, the World Bank provides an estimate of comprehensive wealth, or total capital. The method is best explained in World Bank (2011, p. 94). Wealth is defined as:

$$W_t = \int_t^\infty C(s)^{-r(s-t)} ds \tag{34}$$

Where C is consumption, s in the current period and r is the social rate of return. r is calculated using the Keynes-Ramsey formula:

$$r = \rho + \nu \frac{\dot{C}}{C} \tag{35}$$

where ρ is the pure rate of time preference and ν is the elasticity of marginal utility with respect to consumption. The final term is the rate of growth for consumption. This value of wealth is obtained by assuming that the original observed level of consumption is sustainable. This value of wealth gives an upper bound to the estimate of wealth for a given country. The next step is to estimate the relative size of the instruments of wealth (types of capital) within this total. Indeed, the very rationale for looking for an upper bound for wealth is precisely that some instruments of wealth can not be estimated in their entirety, or completely ignored. This claim is backed by the very high implicit rate of return on wealth if wealth was only composed of produced capital.[16]

The World Bank decomposes wealth into three instruments or capital types: produced capital, natural capital and intangible capital. Produced capital is estimated using the Perpetual Inventory Method (PMI). Natural capital is estimated using value for urban land, energy and mineral resources, timber and non timber resources, crop land, pasture land and protected areas. Intangible capital is estimated as the residual of wealth once the two previous instruments have been subtracted.[17] An attempt to estimate the subcomponents of intangible capital can be found in the previous report (World Bank 2006, chap. 7, p.87). By means of econometric estimates, the authors show that the biggest component of intangible capital is likely to be the quality of institutions, followed by human capital.

From the underlying theory of the DHSS model and the Asheim/Wietzman amendments regarding sustainability and optimality, the World Bank provides estimates using what we would describe as a “Top-Down” method: first estimate comprehensive wealth and then estimate the sub-components. This estimation method derives logically from data limitations and the rate of return puzzle. This method rests on competitive assumptions as it uses results from the NNP literature. Another method is proposed in Arrow et al. (2012), a method we would describe as “Bottom-Up” since, following the general model presented above, it focuses on estimating each and every instrument of wealth and the matching shadow price. The impact of time (technical change, institutions, the sum of the distortions in the RAM) is then simply added to comprehensive investment. The main difference between the “bottom-up” and the “top-down” method is therefore the way wealth is calculated.

The difference in philosophy between the GS literature and the NNP literature should by now be clear. NNP-leaning authors took as a starting point an optimal path, as those path already have desirable economic properties (so that the RAM is efficient) and assessed the conditions under which fairness could be added to those path. Under the assumptions of an optimal path[18] the flow (NNP) gives information about the stock (comprehensive) wealth so that the former can used as a sustainability indicator *in lieu of* the latter. The use of the

[16] In the example of Canada presented in World Bank (2011, p. 94) the implicit rate of return on produced capital is 35.9%.

[17] See World Bank (2011, p.141) for more details

[18] a limited number of those assumptions being relaxed at a time.

maximin criteria also imposed restrictions on consumption so that consumption is kept constant over time, and as Dasgupta (2009) reminds us, the second order derivative of consumption is assumed to be constant and not negative in most papers. Those extra assumptions are based on the equity criterion chosen, so that the models have a *normative* perspective. They characterise the properties of economic states and paths between states in what Dasgupta (2001) calls after Meade (1989) the "good enough society" where institutions exist to promote and implement first-best solutions so that optimal paths form a realistic aim for the considered economy. The GS literature takes a different view, as its focus is on producing a workable, empirically-grounded indicator for *kakotopia* the "not-so-good society" that is the reality of most developing countries today.

Using the NNP or GS is equivalent in a competitive setting. In this scenario, the two indicators of the weak sustainability model yield a similar information on dynamic welfare and sustainability. How to choose one against the other? A first argument is conceptual, about what authors assumed preferable to leave behind. Estimating GS and wealth using the general model method (Dasgupta 2009, Arrow et al. 2012) is more practical for empiricists and accountants but would require a tremendous effort to extend current datasets to account for all instruments of wealth and estimate all the respective shadow prices. On the other hand, starting from the non-autonomous competitive cases permits one to estimate GS and wealth from existing accounting data, even if heroic assumption needs adding (especially for the price system). Still, the extension of green accounting in the past decade seems to make assumptions of optimality less needed to estimate missing components, but the World Bank still uses all the results available, including results requiring a competitive setting, to produce its estimates. Since the focus of this special issue is on savings, we now ignore green NNP and deal only with GS.

Empirical evidence on the size of GS and the ability of GS to predict future well-being is presented below. It is fair to say that this endeavour is limited by the lack of data, whether on prices or instruments of wealth, both marketed and non-marketed. More importantly for potential users of the data is the nature of the bias induced by those missing data on the sustainability signal. If they are to be of any use in developing countries where the RAM is clearly non optimal, GS need to be robust to the most likely sources of distortion in those countries. These includes rent seeking, political corruption and market power.

3.1 Empirical evidence on GS

A number of studies have constructed empirical estimates of GS, and are summarised in Table 1. Empirically, there are a number of challenges to measuring variables to reflect their theoretical equivalents. One of the biggest challenges is the measurement of natural capital resource rents as in theory the marginal costs should be deducted from the market price, whereas in practice it is the average costs that are deducted from market prices. Hamilton (1994, p. 162) argues that this deviation will be small if it is assumed that there are distinct extraction costs for a number of resources and if for any given resource the difference in cost between the first and last unit extracted is small. Other measurement issues are the units of measure, spatial resolution, aggregation, abatement costs and lack of WTP (willingness to pay) measures for non market impacts (Hamilton 1994, p. 163-164). Also, for cross-country comparisons, exchange rates, deflators and discount rates are problematic. Given these issues, there is a trade-off between depth and scale: in order to obtain comparable estimates for as broad a range of countries and regions as possible it is necessary to make a trade-off in the accuracy of data (e.g. using international estimates of costs instead of country specific costs). For individual country studies it is possible to get more refined data but it is then difficult to make direct cross-country comparisons as data are not of similar consistency.

The following indicators of changes in the "instruments of wealth" are commonly constructed, with [3] and [4] the most common examples presented:

[1] Gross investment (savings): Gross fixed capital formation + inventories + net foreign investment

[2] Net investment (savings): [1] – depreciation of reproducible capital

[3] Green investment (savings): [2] + Δ natural capital

[4] Genuine investment (savings) (GS): [3] + Δ human capital

[5] Pollutant adjusted GS: [4] – damage from pollutants (typically CO2)

[6] Malthuasian savings/wealth dilution: [3] or [4] adjusted for population growth

[7] Technology augmented GS: [3] or [4] augmented by the present value of TFP

For all of these measures, the changes in capital are evaluated between adjacent years t and $t+1$ In [3], renewable and non-renewable natural capital are treated differently. Renewables such as forestry and fisheries are added to the measure if there is an increase in stocks and subtracted if there is a decrease. However, depletion of non-renewables is subtracted whereas new discoveries are either not counted or treated as windfalls. Hamilton (1994, p.167) and Hamilton, Atkinson and Pearce (1997, pp 17-18) argue that new discoveries should not be treated separately as they appear in [1] in the form of investment in exploration. In addition to [1]-[6] listed above, Hamilton, Atkinson and Pearce (1997) illustrate ways in which these indicators can be further expanded to take account of endogenous technological progress, resource discoveries and how to account for critical levels of natural capital. Commonly, only the most important market-orientated forms of natural capital are included in these measures and as a result non-market resources (such as many ecosystems services values) are not included and thus are undervalued.

One of the first measures of GS was by Pearce & Atkinson (1993) who constructed measures for 18 countries to determine if they were on sustainable (positive values) or unsustainable (negative values) development paths. The measures constructed were [1], [2] and [3] but they noted the difficulty of accurately measuring and valuing natural capital, a theme which is persistent in all estimates. Contemporaneously, Hamilton (1994) reported estimates of [4] for OECD countries and sub-Saharan countries from 1961-1991. Hamilton(1994, p. 166) compared various green accounting measures and argued that although measures of green national income

Table 1: Empirical estimates of Genuine Savings measures

Authors	N	Time period	Variables constructed
Pearce and Atkinson (1993)	20	1 year (c. 1990)	[1], [2], [3]
Hamilton (1994)	n/a	1961-1991	[5]
World Bank (1995)	n/a	1961-1991	[5]
Hamilton and Clemens (1999)	103	1970-1993	[4], [5]
World Bank (2006)	123	2000	[1], [2], [3], [4], [5]
Pezzey et al. (2006)	1	1992-1999	[1], [2], [3], [7]
Mota and Martins (2010)	1	1990-2005	[1], [2], [3], [4], [5], [7]
Lindmark and Acar (2013)	1	1850-2000	[2], [3], [4], [5]
Greasley et al. (2014)	1	1765-2000	[2], [3], [4], [5], [6], [7]
Oxley et al. (2014)	3	1870-2000	[4], [7]
Pezzey and Burke (2014)	Global ($\sum$120)	2005	[5], [6], [7]

were useful in their own right, measures of [2]-[4] 'provide a current measure of trends towards or away from sustainability, with concomitant signals for policy.'

Since the mid-1990s the World Bank has reported GS estimates for various countries (World Bank 1995, pp 52-56; Hamilton, Atkinson and Pearce, 1997). Data for World Bank GS estimates are available for almost every country from 1970 and these are annually updated (World Bank 2006, 2011).[19] World Bank (2006, p. 37) outlines the methods used to calculate these estimates. Natural capital is valued at world prices minus total costs of production. Non-renewable natural capital (fuel, metal and minerals) included in the estimates are 'oil, natural gas, and coal, bauxite, copper, gold, iron ore, lead, nickel, phosphate, silver, tin, and zinc'. Renewable natural capital, mainly forestry, is treated differently in that only extraction that exceeds natural growth is subtracted from net savings. Pollution damages from CO_2 and particulate damage are also subtracted from net investment. Expenditure on education is also included in the measure as a proxy for human capital formation. The World Bank (2006) urges caution when interpreting the resulting savings measures as there are a number of omitted assets, such as diamonds, fisheries, soil erosion and many ecoservice system service values. Some limitations of the World Bank measure are also evident, as resource rents in most cases do not rely on country specific prices or costs and forestry growth is not added to GS estimates. The human capital proxy is an underestimate as education expenditure does not equate to all investments in human capital, nor does the measure capture on the job-training or private education expenditure. The excluded intangible assets are also very difficult to measure and value. So essentially the construction of GS by the World Bank is a step towards a sustainability metric rather than an end in itself.

Hamilton and Clemens (1999) also present and analyse GS data constructed at a national level and for different geographic regions. They provide information on how these estimates

[19]Data is available online at: http://data.worldbank.org/topic/environment

were constructed.[20] The database constructed is for the period 1970-1993 and covers developing and developed countries. GS was constructed from national accounts using [1], depletion of natural resources, CO_2 emissions and also education expenditure. Hamilton and Clemens (1999) inferred from their data whether a country was on a sustainable/unsustainable path if it had a positive/negative value of GS.

More recently, Pezzey and Burke (2014) have constructed a global estimate of GS ([5]) using the World Banks country-level data set. In addition, Pezzey and Burke (2014) include measures of technological change and population growth ([6]& [7]). Pezzey and Burke (2014) compare conventional WB estimates of GS, which, on the whole, suggest global sustainability whilst other indicators of sustainable development, such as the Ecologial footprint, suggest the opposite. An innovation of Pezzey and Burke (2014) to resolve this discrepancy is through the selection of CO_2 prices. Rather than using a literature based estimate of the social cost of carbon (e.g.Tol (2009)), Pezzey and Burke (2014) modify the underlying DICE (Dynamic integrated model of Climate and the Economy) models on which the World Bank's carbon price estimate was based. Pezzey and Burke (2014) find that a DICE model in which future CO_2 emissions are optimally controlled leads to conclusions of sustainability not too dissimilar from the World Bank. However, a DICE model where future CO_2 emissions are uncontrolled (business as usual) leads to significantly different (i.e. unsustainable) conclusions to the WB measure of GS.

There are also a number of country specific estimates of GS in addition to the cross-country estimates. For example, Hanley et al. (1999) & Pezzey et al. (2006) have constructed measures of GS for Scotland over the periods 1980-1993 and 1992-1999 respectively. Using country-specific data they were able to calculate more refined variants of the natural capital than the cruder cross-country comparisons. The purpose of Hanley et al. (1999) was to construct a variety of sustainability indicators for Scotland over the period 1980-1993, one of which was GS. The measure of GS presented was [3] above with no inclusion of education expenditure. Hanley et al. (1999) found that inclusion/exclusion of offshore oil had a big impact on the GS estimate because the inclusion of oil extraction suggested an unsustainable path. However, when discoveries were included this suggested a more sustainable path. Pezzey et al. (2006) also constructed a variant of [3] with natural capital data including a variety of data on coal and other minerals, fisheries, forestry and oil. Pollution was calculated by sector of the Scottish economy. An innovation in this study was the inclusion of the value of time and terms of trade effects. The resulting estimates were positive and indicated that Scotland was not on an unsustainable development path.

In a similar vein to Pezzey et al. (2006), Mota and Martins (2010) constructed time series estimates of GS for Portugal over the period 1990-2005. Mota and Martins (2010) include a basket of pollutants and detailed data on forestry and other forms of natural capital. Also, as with Pezzey et al. (2006), they incorporate a measure of technological progress. Mota and Martins (2010) argued that the message of sustainability depended on the variant of GS used: excluding education expenditure resulted in a downward trend of GS resulting in negative values in the early 2000s; whereas including education and TFP signalled sustainable levels of development.

[20]See Bolt et al (2002) for a manual of how to construct GS.

Longer-run estimates of GS have also been constructed. Lindmark and Acar (2013) construct long-run time-series estimates of Swedish GS ([2], [3], [4], [5]) over the period 1850-2000. They incorporate pollutants (CO_2, SO_2, and NOx). They found a negative trend in GS in the 1800s and a gradual transition to positive GS around 1910 and continuing positive throughout the twentieth century. Lindmark and Acar (2013) argue that this shift from negative to positive supported their hypothesis that industrialisation was preceded by a shift from negative to positive GS.

Greasley and co-authors have also constructed long-run time series for Britain (1765-2000), Germany (1850-2000) and the US (1869-2000) (Greasley et al. 2014, Oxley et al. 2014). They find that for Britain there were times of negative GS in the early industrial revolution and during the two World Wars in the 20th century but that GS was positive for the most part. GS was also predominantly positive in the US except during the World Wars and the Great Depression. German GS was also mostly positive except during the aftermath of the Second World War.

Empirical work has also focused more explicitly on estimates and decompositions of wealth. Examples in this literature include World Bank (1995, 2006, 2011), UNU-IHDP and UNEP (2012), Arrow et al. (2012) and McLaughlin et al. (2014). There are essentially two approaches to the measurement of wealth, firstly capital stocks (Reproducible, Natural, Human and Health) are estimated and a measure of comprehensive wealth is aggregated or alternatively a measure of wealth is constructed from the present value of total consumption over a lifetime and estimates of the capital share of wealth are derived from available data. Using the latter approach, the World Bank (2006, 2011) finds a growing importance of what it deems 'intangible capital' which is approximated to be human capital and other factors not accounted for. Arrow et al. (2012), using the former approach, find that health capital is the most dominant form of wealth. These approaches are in similar vein to the GS approach as they view changes in wealth (i.e. investment/disinvestment) as indicating sustainable/unsustainable development.

As various studies indicate, there are numerous of ways of measuring sustainable development (income, savings or wealth based), however each measure offers different signals to policy makers for improving sustainability paths. The World Bank's preferred measure of GS is not without criticism. For example Vincent (2001) is critical of the consensus regarding the reporting and collecting of green national accounting estimates without regard to their predictive power. Ferreira and Vincent (2005) are also critical of the underlying assumptions in the construction of GS estimates. Elsewhere, Pillarisetti (2005) argues that GS is conceptually and empirically weak. From a conceptual perspective, Pillarisetti (2005) takes the view that as GS is a national measure of weak sustainability it overlooks key international externalities. From an empirical perspective, Pillarisetti (2005) is highly critical of the World Bank data and argues that the findings on sustainability/unsustainability are drawn from a small number of outliers that are mainly fuel-rich countries. Pillarisetti (2005) is also critical of the underlying model that is based on consumption growth which he sees as being more suited to proving the sustainability of developed countries. Furthermore, Pillarisetti (2005) illustrates that conventional net investment [2] and GS [4] are highly correlated and thus argues that GS adds little additional value to conventional concepts. However, from a predictive perspective, it is not the correlation between the indicators that is important but the slope of the regression line involving the indicator and a measure of future well-being. In this scenario, GS may be a useful measure if "corrects" the slope and aligns it with the theoretical properties of the GS model outlined above.

4 Testing the predictive power of GS

Whilst thanks to the efforts of the World Bank there are GS estimates available for almost every country, empirical tests of its predictive power are less common. Table 2 compiles a number of studies that have explicitly tested the theoretical properties of GS. However, an issue with comparability of these results is the lack of consistency of the variables under consideration. For the most part, studies have used data over different time periods and different country sets. In general, tests to date have differed in their methods (panel versus time series), time horizon and choice of discount rates. The formal framework for econometrically testing the theoretical properties of GS was set out by Ferreira and Vincent (2005):

$$\overline{C}_{it} - C_{it} = \beta_0 + \beta_1 S_{it} + \epsilon_{it} \tag{36}$$

where $\overline{C}_{it}$ - C_{it} is average future consumption minus current consumption, however later studies incorporate an alternative dependent variable where the econometric model is re-specified as:

$$PV\Delta C_{it} = \beta_0 + \beta_1 g_{it} + \epsilon_{it} \tag{37}$$

&

$$PV\Delta C_{it} + PV(\Delta y_{it} w_{it}) = \beta_0 + \beta_1 g_{it} + \epsilon_{it} \tag{38}$$

Where PV ΔC_{it} is the present value of future changes in consumption and PV $(\Delta y_{it} w_{it})$ is the present value of future changes in wealth per capita adjusted for population growth.

From these econometric specifications, Ferreira and Vincent (2005) set out 4 testable hypotheses:

1 β_1 =0 and $\beta_1 = 1$

1 $\beta_1 > 0$ and $\beta_1 \Rightarrow 1$ as the measure of S is extended to include more types of capital

3 $\beta_1 > 0$

4 the model will better predict $\overline{C}_{it} - C_{it}$ when a broader measure of S_{it} is used

The first hypothesis is the most stringent test of GS in that it tests for a 1-for-1 relationship between the savings indicator and future consumption, the second is less stringent but implies a relationship closer to 1 as more types of capital are included in the explanatory variable, the third is the least stringent of all and only implies that a positive relationship exists between the savings indicator and future well-being. As most of tests do not find evidence for hypothesis 1, the discussion below focuses on hypotheses 2 and 3, and Table 2 presents the β_1 coefficients from the various studies implicitly or explicitly using this framework.

One of the first tests is by Vincent (2001) using data constructed from 13 Latin American countries over the period 1973-1986. Vincent tests the predictive power of Green Net National Product and 'Genuine Savings', although for the sake of consistency this is labelled as 'Green savings' in Table 2 as it does not include a measure for human capital. Vincent (2001) tests both aggregate measures and disaggregate measures of Green Savings. For the aggregate data, Vincent (2001) finds a positive β_1 coefficients using both OLS and GLS panel estimators. For the disaggregate measure Vincent(2001, table 8), the various components of GS have their expected sign (+ Savings, - depreciation, + Natural capital appreciation, - Natural resource rents) and are closer to 1 than the β_1 coefficients of the regression from the aggregated data.

In their benchmark results, Ferreira and Vincent (2005) did not find any support for hypothesis 1, but did find some support for hypotheses 2 and 3. However, the coefficient on β_1 when education expenditure was included was a fourth of the size of the coefficient for green savings. Ferreira and Vincent argue that this reflects the shortcomings of this variable as a proxy for human capital formation. When using alternative specifications, Ferreira and Vincent found that increasing the time horizon increased the β_1 coefficients but that they were still significantly less than 1. Also, when the panel was disaggregated between OECD and non-OECD countries the resulting β_1 coefficients were significantly different and had opposing signs (e.g. for GS the β_1 coefficient for OECD v non-OCED was -0.274 v 0.322). Ferreira and Vincent (2005) suggest that the reason for the negative coefficient for OECD countries is due to the absence of any measure of technological progress and that net investment by itself underestimates average future consumption. In sum, Ferreira and Vincent (2005, p. 751) stated that 'results from our pooled analysis reject the hypothesis that even the broadest of the World Bank's net investment measures coincides with the difference between current and average future consumption.'

Building on the findings of Ferreira and Vincent (2005), Ferreira et al. (2008) focus on a sample of 64 developing countries. A key difference between Ferreira et al. (2008) and Ferreira and Vincent (2005) is a change in the specification of the dependent variable which is now the present value of changes in future consumption per capita and also the incorporation of 'wealth-dilution' – a term used to capture the effect of population growth on the spread of existing capital stocks. The inclusion of the wealth dilution effect incorporates population growth into a GS framework that implicitly assumes constant population growth. Over 20 year time horizons, Ferreira et al. (2008) find weakly negative β_1 coefficients for Gross and Net investment but they find much stronger positive β_1 coefficients for Green and population adjusted measures. Ferreira et al. (2008, 246) conclude that the results indicate that the GS indicators published by the World Bank should be interpreted 'as signals of future consumption

Table 2: Summary of tests of the predictive power of genuine savings

	Vincent (2001)	Ferreira & Vincent (2005)	World Bank (2006)	Ferreira, Hamilton & Vincent (2008)	Mota & Domingo (2013)	Mota & Domingo (2013)	Greasley et al. (2014)	Greasley et al (2014)
N	13	93	54; 69; 74; 74; 78	64	1	1	1	1
Time coverage of data	1973-1997	1970-2001	1970-2000	1970-2001	1990-2005	1990-2005	1765-2000	1870-2000
Test time horizon (years)	10	10	20	20	5;10	5;10	20;30;100	20; 30; 100
Time coverage in test	1973-1986	1970-1991	1976-1980	1970-1982	n/a	n/a	1765-1989; 1765-1959; 1765-1909	1870-1989 1870-1959; 1870-1909
Estimation	Panel	Panel	Yearly cross-sections	Panel	Time-series	Time-series	Time-series	Time-series
Discount rate (%)	2	3.5	5	Country-specific; minus population growth rate	4	4	2.5; minus population growth rate	2.5
Dependent variable	$\overline{C}_{it} - C_{it}$	$\overline{C}_{it} - C_{it}$	PV ΔC	PV ΔC	$\overline{C}_{it} - C_{it}$	PV ΔC	PV ΔRW	PV ΔC
Gross Savings (β_1)	-	-0.02	1.02; 0.76; 1.05 1.23; 0.83	-0.64	-0.11; -1.9	-0.11; -0.87	-	-
Net Savings (β_1)	-	0.128	0.66; 0.21; 0.65; 0.98; 0.71	-0.64	3.03; 2.76	0.62; 1.24	2.32; 0.37; 2.39	1.46; -0.22; 0.40
Green Savings (β_1)	0.492	0.129	1.28; 0.85; 1.26; 0.78; 0.99	0.43	1.66; 2.66	0.40; 1.28	1.62; -0.20; 2.89	0.65; -0.28; 0.68
Genuine savings (β_1)	-	0.037	-	-	-	-	1.85; 0.81; 2.71	1.14; 0.20; 1.04
Green Wealth dilution adjustment (β_1)	-	-	0.78; 0.57; 0.47; 0.36; 0.52	0.56	-	-	1.15; -0.69; -4.00	- -
GS Wealth dilution adjustment (β_1)	-	-	-	-	-	-	1.34; -0.10; -3.99	-
Green TFP (β_1)	-	-	-	-	2.19; 2.15	0.56; 1.13	0.97; 1.64; 1.37	0.79; 1.29; 1.13
GS TFP (β_1)	-	-	-	-	2.51; 2.56	0.70; 1.44	0.83; 1.50; 1.30	0.69; 1.18; 1.12
GS TFP wealth dilution adjustment (β_1)	-	-	-	-	-	-	0.71; 1.43; 2.41	-

paths if and only if the rates include this adjustment for natural capital.' However, Ferreira et al. (2008, 246) also note that better estimates of capital stocks are needed before it can be 'confidently be stated that this adjustment significantly improves the performance of genuine savings as an indicator of future consumption changes.'

World Bank (2006) provide an alternative test of the GS using yearly cross-sections from 1977-1980 to test the relationship between savings indicators and the present value of changes in future consumption.[21] However, as with Ferreira et al. (2008), these tests of GS use metrics that do not include education expenditure or pollutant damages. World Bank (2006) use a 20 year time horizon for the present value of future changes in consumption and find reasonably consistent positive β_1 coefficients for gross and 'genuine saving'. Furthermore, in line with Ferreira and Vincent (2005), World Bank (2006) finds that the various savings measures tested do not provide good predictors for future changes in consumption in developed countries arguing that this is a reflection of factors other than savings, such as technological innovation, learning by doing and institutional capital, being important in the growth performance of developed countries. However, World Bank (2006) also warns about the hazards inherent in attempting to test data given potential measurement error.

Mota and Domingos (2013) test Portuguese data over the period 1990-2005 using time-series methods. They test both specifications of the consumption variable with a host of GS measures, including models that incorporate technological progress. The tests were conducted over 5 and 10 year horizons and as with the finding of Ferreira and Vincent (2005) andFerreira et al. (2008) the indicators performed better over longer-term horizons. Although it is unclear from the text what the time horizon, or rather the sample size, to perform these tests was. In all, Mota and Domingos (2013) find that incorporating TFP does not improve the explanatory power of their tests as they argue that the underlying production function does not incorporate green capital. Mota and Domingos (2013) also test for cointegration and do not find strong evidence of cointegration for many of the test variables – none over 5 year horizons – and only for Net Savings, Net Savings + Forestry and Green TFP over 10 year horizons.

Greasley et al. (2014) test British data over a much longer time frame - 1765-2000 - and focus primarily on testing hypotheses 1 to 3. They use time series methods, especially cointegration, to test the strength of correlation coefficients and conduct tests over much longer time horizons: 20, 50 and 100 horizons. As the underlying theory is set in infinite time these time horizons are closer to the theoretical specification than the shorter horizons adopted by the other tests listed in Table 2. The tests were based on two welfare indicators, the present value of changes in real wages and the present value of changes in consumption per capita. Results were influenced by both the time horizon and the choice of discount over the period. In terms of real wages, the β_1 coefficients for net and GS were consistently positive over all time horizons but performed poorly over 50 year horizons, when notably cointegration was absent. Furthermore, measures of green investment performed poorly over all specifications. In terms of consumption, the various measures did not perform well. For net investment the β_1 coefficients ranged from -0.22 to 1.46 and for green the range was also broad from -0.28 to 0.68. All indicators performed especially poorly over the 50 year horizon and in no specification was a cointegrating relationship displayed.

[21]The tests draw on Hamilton (2005).

Following the observations by Ferreira and Vincent (2005) and World Bank (2006) that the poor applicability of GS indicators to OECD data was due to the underestimation of measures of technological progress, Greasley et al. (2014) then incorporate a measure of technological progress by augmenting GS with the present value of changes in TFP over 20 and 30 year horizons. β_1 coefficients for the 20 year horizons are reported in Table 2. Greasley et al. (2014) found that technology augmented measures of GS (and Green investment) had a significant impact on the resulting coefficient estimates and also found evidence of cointegrating relationships, thus strengthening the findings. In addition, Greasley et al. (2014) introduced a wealth dilution effect and found this had a dramatic impact on the resulting coefficients and in many cases reversed the sign of the β_1 coefficients. However, when technology was included in these specifications the resulting β_1 coefficients reverted to positive and displayed cointegrating relationships. Thus, Greasley et al. (2014) argued for the inclusion of measures of technological change in GS estimates.

In contrast to the studies above that focus on monetary measures of future well-being, Gnègnè (2009) adopts an alternative testing framework and focuses on the relationship between GS and non-monetary well-being indicators: infant mortality and the human development index. Using a panel of 36 developing countries over the period 1971-2000, the econometric model is specified as:

$$W_{it} = \beta_0 + \beta_1 S_{it} + \epsilon_{it} \tag{39}$$

where W is a well-being measure and S is a GS measure. The model is estimated over 5, 10 and 15 year sub-periods with the focus of the test being changes in the dependent variable. Gnègnè (2009) finds positive correlations between measures of [3] and changes in the HDI and IMR and also that the coefficients are higher the longer the time horizon used. In addition, Gnègnè (2009) tested [2], [3], [4] and [5] and found that [2] had a higher coefficient than the other measures but for changes in infant mortality [2] had the lowest coefficient. Gnègnè (2009) noted that 'these results support the idea of a broader view of savings that includes human and natural capital.' When tests are expanded to include other explanatory variables Gnègnè (2009) still finds a positive relationship between the savings indicators and well-being indicators. Overall, Gnègnè (2009) concludes that there is a positive relationship between [4] and future changes in well-being and that the results would be more consistent with theory if they could be tested over a longer time horizon.

As illustrated in Table 2, there are a variety of tests but a lack of consistency across studies. There are also inconsistencies depending on whether tests are performed on panel or time-series data. However, there is an emerging consensus that longer-term horizons are better for testing GS. In terms of panel data, the various tests cited that excluded OECD countries from panels found greater support for hypotheses 1 and 2. However, the longest and widest panels are only available to test for relatively short time-horizons. In terms of time-series tests, tests over short horizons (5, 10, and 20) perform poorly. However, over the longest horizon (50, 100 years) GS performs best when there is an adjustment for technological progress.

5 Conclusion

This article provided a survey of the state of the literature on Genuine Savings (GS) and the weak sustainability model. The combination of capital theory and the incorporation of the maximin criterion in the neoclassical theory of value in the 1970's form the basis of the empirical works at the end from the end of 1980's which first defend the usefulness of GS as a sustainability indicator. The indicator then gradually entered widespread use in the first decade of the 21$^{\text{st}}$ century, propelled by the World Bank's publications.

After discussing the rationale behind the indicator, we presented the theoretical basis for GS in section 2. GS is grounded in a general model for the maximisation of inter-temporal welfare that is suitable for both competitive and uncompetitive economies, regardless of the distortions involved. We showed how, within the limiting assumptions of a competitive framework, GS can be amended for technical change, population growth and international trade. We ended the theoretical presentation with a discussion of the role of the strong sustainability paradigm for GS, showing how accounting for intragenerational equity is probably the best way to account for the current uncertainty regarding substitutability.

In section 3 we outlined various empirical measures of GS including a presentation of the World Bank's method to compute GS. We then reviewed the many contributions in the literature proposing GS estimates for many countries and regions. GS can be computed by estimating the rate of change of all the instruments of wealth (capital stocks) in the economy, what we termed the "bottom-up" approach. Alternatively, consumption flows over a reasonably long interval can be used to estimate comprehensive wealth. Then using this value as an upper-limit, instruments of wealth and their rate of change can be estimated, following a "top-down" approach.

Results of those studies are not easily comparable, as different authors tend to use amended versions of GS with a more or less detailed selection of instruments of wealth. As a rule of thumb, greater accounting of immaterial instruments of wealth such as human capital, the stock of knowledge or total factor productivity growth tends to bring about a message of probable sustainability for many countries over the long run. Conversely, a greater role for exhaustible resources quickly move the indicator into unsustainable territory. This result has brought criticism over the indicator as poor countries (more reliant on exhaustible resources) are asked to correct un-sustainability and rich countries (well endowed in intangible instruments of wealth) tend to be exonerated from immediate action for sustainability, regardless of historical trends and import/export linkages in resource consumption.

As a predictor of future consumption, GS tends to perform poorly when a limited number of instruments are considered over short horizons. The predictive power of the measure greatly improves when longer horizons are considered and some room is made for the gradual improvement of productivity and technology (mostly via the addition of an extra total factor productivity term in econometric tests).

There is still a lot of work to be done to improve the measure. The better performance of the indicator on longer time horizons and the important empirical role of productivity improvements and technical change both suggest that a better way to account for the economic structure for which GS is measured is needed. Institutions matter. It is not yet clear whether the solution goes through the inclusion of more and more instruments of wealth, so as to "shrink" the impact of the total factor productivity term, or if a more fundamental amendment is needed.

In the short run, two avenues for theoretical research seems to be promising. The first comes through a better understanding of the impact of international trade on sustainability. It is not yet clear whether economic specialisation in a narrow range of productive activities is fostering or hindering sustainability. The second important avenue comes from the renewed interest in wealth inequalities. More investigation should be made on the impact of an asymmetric distribution of instruments of wealth across agents on sustainability.

GS as a concept is essentially forward looking; however, the only way to effectively test the implications of the theory is to use historical data. The scarcity of tests of GS suggests that the literature can benefit from more research in this direction. For example, there are geographic regions which are driving the cross-country comparisons - namely countries in Latin America, Africa and Asia - but more detailed country-specific studies would help expand our existing knowledge as to why this is the case. Is it simply the Pillarisetti (2005) critique that outliers are driving results or can GS say more about individual country experiences and future sustainability? Also, more needs to be done pre-1970s, as the GS estimates may be picking up price shocks from the various oil crises. Furthermore, attention needs to focus on the OECD countries that do not fit neatly into the GS framework. The solution heretofore has been to exclude them in cross-country studies but if the GS theoretical framework does not fit their economic record, then more needs to be done to explain why this is the case. Moreover, issues such as how governments influence consumption and savings can also be informative to the study of sustainability. Also, historical peculiarities may also shed light on future sustainability such as the collapse of consumption in post-War Germany, low TFP growth in Latin America and regulatory differences affecting savings rates in various countries such as Switzerland. Finally, the theoretical GS framework is set in infinite time, thus more long-run data for as broad a range of countries would help get a better understanding of the predictive power of GS and how well it matches the historical record, as in Greasley et al. (2014). An obvious limitation here is the lack of standardised national accounts pre-dating the 1940s both in terms of savings or consumption. Vincent (2001) in particular was critical of the conventional measures of reproducible capital in Latin American countries, so more could be done in this direction. Lastly, attention could be directed toward ways to include non-monetary measures of well-being, such as anthropometric indicators, into the testing framework.

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