Genuine Savings and Sustainability

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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. We discuss the theoretical underpinnings of GS, focusing on the relationship between changes in a nation's extended capital stock and the future path of consumption. The indicator has entered widespread use propelled by the World Bank's publications, despite its varying performance as a predictor for future consumption. Notwithstanding the extensive body of literature reviewed, promising future research avenues are identified.

KEYWORDS: Sustainable development, Genuine Savings, Comprehensive Wealth, Future well-being, Intergenerational equity, Resource Allocation Mechanism, Dynamic Optimisation, Natural Capital

JEL CLASSIFICATION: D90, E21, E22, Q00, Q01, Q20, Q30, Q50

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Introduction

The purpose of this paper is to set out the theoretical and empirical under-pinnings 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 Comprehensive Wealth (all of these terms are explained below). Genuine Savings (GS) is a measure of how a nation's total capital stock changes year-on-year in real terms. It is thus firmly based on the idea of wealth accounting (Hamilton and Hepburn 2014).

Total capital includes all 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 comprises all "gifts of nature": non-renewable and renewable resources such as oil reserves and fisheries, but also ecosystems, the functions of which generate flows of ecosystem services over time (UKNEA 2011). 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. The addition of all these capital stocks (or *instruments of wealth*, to use the terminology of section 1), under a defined set of shadow prices (see below), composes comprehensive wealth. Changes in total capital then defines changes in future well-being.

Why "Genuine Savings"?

The economics of sustainable development is typically viewed as being based around two alternative definitions of what characterises sustainable development:

- Capabilities based: sustainable development is a path for an economy where the (per capita) real value of changes in the capital stocks (wealth instruments) is non negative.
- Outcome based: sustainable development is a path for an economy where utility or real

> consumption per capita is not declining; or where utility or consumption can potentially be sustained over time.

At any point in time, the possibility set for an economy will depend on its resources, technology, the current level of consumption and population. This possibility set is reflected in the Resource Allocation Mechanism (RAM), which may or may not be *optimal* and may or may not yield a *sustainable* path for development. If governments wish to intervene on behalf of citizens on normative grounds they need to know what "rules" will move the economy closer to a sustainable 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 *capabilities based* definition and the GS literature (Pearce and Atkinson 1993). An existing measure of capabilities based sustainability is green Net National Product (NNP) which measures the productive capacity of the economy. As Pezzey et al. (2006) show, green NNP is an expanded measure of GS, whilst the relationship between Green NNP and GS was set out in Asheim and Weitzman (2001). Introducing concerns about equity between generations first led to a famous sustainability rule, the Hartwick rule, discussed below.

Equity concerns also led to the *outcome based* definition of sustainability. Under restrictive assumptions regarding the optimality of sustainable paths for development (Pezzey 1997) outcome based and capabilities based sustainability can be both assessed using Genuine Savings. This explains the lead taken by Genuine Savings as an indicator of sustainability and the progressive incorporation of the indicator in accounting settings. 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.

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. 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 (WS), and the second as representing the idea of strong sustainability. As explained below, WS 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 capital or comprehensive wealth, not what is happening to any individual component of this total. Since it is difficult 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.

The work of Pearce and Atkinson (1993) in developing the idea of Genuine Savings as an indicator of sustainability moves away from a strict strong sustainability perspective since GS allow for reductions in natural capital to be offset by increases in human or produced capital. The Genuine Savings concept does not rest *formally* on weak sustainability (Dasgupta 2009). The only critical assumption regarding substitutability for GS is acceptance of the monetary valuation of natural capital.[1] However, GS is typically viewed as an empirical measure of the weak sustainability of an economy.

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[1] And indeed, acceptance that the notion of natural capital itself makes sense!

We present in section 1 the underlying model of weak sustainability on which most economic analysis of sustainable development is based. Section 2 explains how Genuine Savings is calculated in practice. Section 3 of the article is concerned with empirical testing of Genuine Savings as a predictor of changes in future well-being, and Section 4 concludes by setting out ways in which the theory and practice of Genuine Savings could be usefully improved.

1 The weak sustainability model and Genuine Savings

The weak sustainability model links variations in future well-being to changes in the value of capital stocks. It uses the Brundltand Report definition (World Commission on Environment and Development 1987) to define a path satisfying a criterion for intergenerational equity, through the ideas of consumption and wealth (Arrow et al. 2012). A necessary step before presenting the model is to lay a common ground in the terminology used.

Fisher (1906) made the first attempt at defining wealth and its instruments.[2] In his view, wealth is simply a physical capital stock, *an instrument of wealth* multiplied by an observable, *current* price. It includes all the elements that are consumed or used in the production processes composing the economy. This wealth estimated with observed prices we call *Fisherian* wealth.

Consumption represents the share of income destroyed every period to satisfy human needs and wants. Following Arrow et al. (2012), our definition of consumption is again Fisherian, i.e. it includes all the services, marketed and non-marketed produced from the available wealth instruments.[3]

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[2] "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).

[3] This is what Fisher calls *income* (services rendered by (any)one wealth instrument) *outgo* (services rendered to (any)one wealth instrument). Leisure is understood in this context as a reduced contribution to the maintenance some instruments of wealth (lower use of labour services), and an increased used of services from wealth instruments such as parks and gardens.

1.1 The general model: capabilities based sustainability

The intuition that savings and investment should be the prime indicator of sustainability comes from the late David Pearce (Hamilton and Atkinson 2006).

The formal relation between well-being, wealth, consumption is presented in a general model of sustainability. The weak sustainability model reviews potential paths characterised by levels of wealth and consumption. Paths are then classified based on an equity criterion. These paths may or may not be optimal/efficient depending on the structure of the economy and the information content of prices. The Genuine Savings indicator emerges from this model. GS are affiliated to the *capabilities based* view on sustainability: they are the real value of changes in the capital stocks/instruments of wealth.

The theoretical basis for the weak sustainability model goes back to the presentation of the DHS or DHSS model[4] and has been subsequently expanded in many contributions. 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.[5] Each argument is essential in production, so that $F = 0$ if A, K, L or $R = 0$. A

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

[5] The function F is not assumed to be concave at this stage.

represents total factor productivity, the general effectiveness of institutions and the ability of the economy to combine inputs in an efficient fashion. A also represents the state of technology.

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 $U(t) = U(C(t))$[6] with $U'(C) > 0$ and $U'' < 0$. The value of V in t is given by:

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

with β the discount rate ($\beta > 0$) 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 "wealth instrument" in the economy has an idiosyncratic pattern of accumulation and depletion. Man-made capital K depreciates at a given rate $\lambda > 0$. The stock of human capital L depreciates at a rate μ as people die. This yields the following budget constraint:

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

A balanced budget means that output is consumed, invested to expand the productive base or used to offset the depreciation ("wear and tear") of wealth instruments.

$R(t)$ represents the services from natural capital used in the production process, when the stock $N(t)$ regenerates at a natural growth rate M:[7]

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

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[6] 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), Arrow et al. (2012), 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. As stated above, consumption is the consumption of services, including leisure. All services are assumed to behave and yield utility the same way. In a similar vein, any effort reducing technology will be captured by the $A(t)$ term or the characterisation of the RAM (see below).

[7] This dynamic can 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.

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.[8] A given *state* for the economy is defined in this example by the triplet (K, L, N) by $\underset{\sim}{S} = (K, L, N)$.[9]

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 form the superstructure for decisions regarding resource allocation[10]. Formally, α represents the RAM that maps a given state $\underset{\sim}{S}$ in t to an observed broader set of economic variables[11] in τ (with $\tau > t$) defined as $\{\underset{\sim}{E}\}_t^{\infty} \equiv \{C(\tau), R(\tau), J(\tau), K(\tau), L(\tau), N(\tau)\}_t^{\infty}$:

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

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:

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

So that the value function V depends on time and exogenous shocks are possible. [12]

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[8] 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.

[9] As we did not assume concavity in production, we do not assume a convex set of production or an optimal economy.

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

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

[12] The only constraint put on the mathematical properties of α is that V must be differentiable. See Dasgupta (2009, P. 14) for a full discussion of the mathematical properties of the value function.

Sustainability is introduced in our framework via the use of discounted utilitarianism to describe intergenerational well-being through the value function. *Optimality* is associated with the conditions of the resource allocation mechanism (RAM) of the economy.

The properties of the price system are related to the the mathematical transcription of the "imperfections" of the economy. Some RAM are so imperfect as to prevent the definition of shadow prices altogether. If the RAM is merely "inefficient", the marginal contribution of a given instrument of wealth will differ across industries. Shadow prices for the same wealth instruments will then differ across sectors.

We then define shadow prices associated with our three “instruments of wealth”, capital stocks K, L and N:

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

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

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

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).

If shadow prices can be computed for *all* the wealth instruments in the economy, then what we called *Fisherian wealth* becomes *Comprehensive wealth*, that is wealth assessed using shadow prices. Using shadow prices, we can propose a formal definition for genuine savings, in two broad categories of RAM: (time) autonomous and non autonomous. 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:

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

We now define 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:

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

The quite powerful conclusion of the general model is therefore that the level of GS 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 the effect of "time passing" as an investment. 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 (12):

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

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

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, such as exogenous technological progress.

Assessing sustainability means 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 (i.e. GS) will indicate evolutions in intergenerational well-being. Genuine Savings is therefore an indicator of sustainability at a given point t looking forward over a succession of τ periods. Genuine Savings can inform about the future sustainability and the sustainability of a given consumption path or pattern of resource use.

Particular forms of this general model aim at either extracting observable characteristics of the RAM so they can be incorporated into the pool of known instruments of wealth with an associated shadow price or deriving a better understanding of the structure of the economy, that is exogenous elements in the RAM itself.

1.2 Outcome based sustainability: consumption, prices and discounting, NNP and the Hartwick rule

Starting from the general form 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. This includes additional assumptions on the price index used to estimate shadow prices and the treatment of technical change, population growth and international trade.

Practical implementation of sustainability requires rules that can be assessed and followed, grounded in welfare/utilitarian theory while taking into account physical and environmental constraints. The most prominent of these sustainability rules based on the DHSS model is the Hartwick (1977) rule, linking conditions on consumption and wealth instruments. Hartwick (1977) show that a sufficient condition to maintain consumption *constant over time in value terms* is that all rents and profits from the depletion of instruments of wealth available in the economy are reinvested into man-made (renewable) capital. This result is based on the

Solow (1974) model. Hartwick (1977) assumed a Cobb-Douglas production function,[13] constant returns to scale in production and optimality in the exhaustible resource extraction plan.

As a consequence, sustainability is obtained when net savings in each period are equal to zero so that total capital is maintained.[14] 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. Does this make the Hartwick rule a prescriptive rule? Solow (1986) supports the prescriptive use of the Hartwick 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.

Asheim et al. (2003) offer to clarify the terms of 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.[15] 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.[16]

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.

Asheim et al. (2003)'s argumentation rests on more than two decades of work on the prop-

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[13] So that each input in the production function is essential.

[14] This proposition is valid in a closed economy context, and in equilibrium in all economies in an open setting.

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

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

erties of competitive settings, defining sustainable levels of consumption and investment. 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).

First in this line of works is the seminal contribution of Weitzman (1976) who showed, in a framework with no technical change or population growth that Net National Product[17] (NNP) is the stationary equivalent of future consumption[18]. As a consequence, NNP can be used as a predictor of the maximum sustainable level of consumption reachable over future time.

The work of Weitzman (1976) associated with the Hartwick rule led to the definition of *outcome based sustainability*. A sustainable path is a path where consumption per capital (measured in terms of utility) is not declining in real terms. Thereafter, the literature focused on characterising optimal paths that would satisfy conditions of equity, and used 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[19] (1971) and endeavour to relate the Hartwick rule to Maximin-efficient paths. They conjecture that any Maximin 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. This result was proved many years later by Mitra (2002). Buchholz et al. (2005) show how conversely, an equitable competitive path must follow the Hartwick rule.

Two important assumptions of the competitive settings need to be discussed here. Intertemporal optimisation is the core of the competitive setting, so what would be an appropriate parameter for discounting future flows? The Hartwick rule is linked to the NNP to derive the

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[17] Defined as the sum of consumption and net investment.

[18] This result hold under discounted utilitarianism if NNP and consumption are measured in terms of utility (or if the utility function is linearly homogeneous). Otherwise, NNP is the present value of the interest on future consumption, where the interest rate need not be constant.

[19] Or more precisely the Solow (1974) interpretation of it as an intergenerational equity criterion.

Hartwick result. But as Brekke (1994) wonders: what actual prices should be used to measure NNP?

Following Asheim et al. (2003)'s interpretation of the Hartwick rule, we may weight all future periods the same way, as violation of the Hartwick rule at *any* time nullifies the Hartwick result. Without discount rates, Ramsey (1928) propose to use an upper-bound to the maximum level of utility it is possible to reach, as a way to ensure stable equilibria.

We may alternatively decide to weight future flows less than the present, but at varying rates. Asheim (1994) investigates the potential impact of a non-constant rate for utility discounting, while Gollier (2010) argues that changes in consumption and changes in wealth instrument should be discounted differently. See Gollier (2012) for a review of the different interpretations and computation methods for discount rates.

What about price indexes? The importance of measuring prices to maintain the welfare measurement properties of NNP led Asheim and Weitzman (2001) to propose a 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 objection (Brekke 1994) that current prices do not represent welfare changes accurately. 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 starts 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) even though 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 observable and more volatile components. This is the reason why Arrow et al. (2003*a*) define sustainability as "non-negative growth of wealth in *constant capital prices*" (our emphasis). Asheim (2010) notes how the potential discrepancy gets worse at the international level, when purchasing power parity measures need to be used.

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[20]. Instruments of wealth in the economy are summarised by a vector $K(t)$. Investment (net of depreciation) is 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:

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

Subject to:

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

with $\beta > 0$. 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

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

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[21] for prices along the optimal path, "Green" NNP can be expressed as:

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

with $Q(t)I(t)$ the real value of investment, effectively 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.

The logic of the argument is that if the current positive level of utility $U(C(0))$ is sustainable while the current value of investment at shadow prices $\Psi(0)I(0)$ is negative, we reach a contradiction. The current value Hamiltonian computed starting in period 0 would then yield higher inter-temporal utility than the same Hamiltonian computed from any subsequent period. It follows from this that an economy is unsustainable if $Q(t)I(t) \leq 0$ *on the optimal path.*

As a result, outcome based sustainability and capabilities based sustainability are two sides of the same coin in an optimal setting. A path where consumption expressed in utility is constant in real terms and the path where the value of changes in the wealth instruments is non-negative are one and the same path. The World Bank (2006) uses the outcome based definition to obtain a value for wealth from consumption flows, while genuine savings are obtained estimating the change in the value of the wealth instruments (see section 2 below). This result is also critical for what it *does not* say, namely that positive GS *necessarily* implies

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

sustainability (Asheim 1994). As in the Hartwick rule, the unsustainability test presented here is slightly more general as optimal instantaneous 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 into 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 is effectively a predictor of future consumption. GS will fall and then become negative before consumption peaks. Positive GS indicate that consumption will not peak in the near future. A positive value of GS is an indicator of rising future consumption, as long as savings are not "too high": that is, so long as GS is growing at a slower rate than the real interest rate. Hamilton and Withagen (2007) then show how a negative value for GS in time t implies that well-being is likely to decline in future time periods. This is the procedure used to test the predictive power of GS, in the final section of this contribution.

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 of the framework for the non-autonomous cases.

1.3 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 unsustainability tests in non-autonomous contexts in Pezzey (2004). Using the model in section 1.2 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 1.1. Capital stocks are now $K' = (K, t)$ so that *time-augmented* net 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, technical change is the equivalent of introducing a new time dependent capital stock for which investment is 1 in every period. The "augmented" unsustainability test (Pezzey et al. 2006) straightforwardly becomes:

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

Technical progress acts as another instrument of wealth or capital stock and increases the maximum level of sustainable consumption . Technical change is therefore unequivocally good for sustainability. Population growth is intuitively less obviously beneficial.

Higher population increases the quantity of human capital available (capability side),[22] while it increases resource consumption (and congestion), with negative consequences for present and future utility. Arrow et al. (2003*b*) include population growth showing that under the 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 ($S(K, N, t)$).[23] $N(t)$ 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

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[22] Although it might lower average quality depending on available education.

[23] Population affects both the production function and the maximand as it is both population and the labour force. Hence, population size determines how total utility is divided to yield per capita utility. The rationale for including population as an argument in the utility function is presented in full in Arrow et al. (2003*b*).

show, under quite restrictive assumption that the following *individual* unsustainability 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 a revised measure of 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 combine 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) consider 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.

1.4 Trade openness and beyond: does structure matter?

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 (Samuelson 1949) with factor price equalisation, the law of one price, and no border frictions, the answer is simple. A competitive setting makes national borders, if not *de jure*, *de facto* irrelevant.

Still, international borders matter. Institutional differences and trade costs set open economy issues in the realm of non-optimal RAMs. In a closed economy, institutions (governments or others) exist to promote intergenerational equity concerns. 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. Forming and then maintaining a comparative advantage is imperative for open economies with consequences for optimal growth, consumption and depletion paths. International trade is therefore a complex problem where aggregate sustainability results are hard to obtain.

Asheim (1986) first examined the consequences of economic openness for the Hartwick rule. From a sustainability perspective, openness introduces an element of uncertainty regarding resource prices as single countries are price takers. Countries can expect a long run improvement in the terms of trade (the ratio of import prices to export prices) for natural resources as scarcity starts to bite. Economic openness acts as a violation of the constant technology assumption so that terms of trade variations have been considered as "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) propose an assessment of the capital gains based on the example of Indonesia. Using 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 $Q^V(t)$.[24] Assume the economy's total domestic endowment is composed of the non-renewable resource and 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. Pezzey et al. (2006) offers a method to include capital gains for natural resources in GS, and calculate the impact this adjustment implies for GS.

Considering the volatility of commodities market, capital gains are sometimes considered to have a small impact over the long run and could/should therefore be neglected. Hamilton and Bolt (2004) 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 capital gains alone do not alter significantly overly negative or positive GS. Although capital gains can theoretically be a reason to violate the Hartwick rule, they do not appear to be large

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[24] Exchange rates are not considering: the world economy works under a single price system.

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 the 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 sum 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. However, this will be very difficult to implement empirically.

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 illustrates how trade patterns may set economies on unsustainable patterns of resource depletion with a) the sole intent of maintaining a comparative advantage and b) at the cost of potential growth and future consumption (Van Der Ploeg 2011). 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 12, potentially through accounting for a new instrument of wealth, namely institutional capital. 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 national perspective. Combining inputs from the resource curse, sustainability literature and neoclassical growth theory (Ventura 1997), Dupuy (2015) 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.

The study of the consequences of trade on sustainability is therefore promising. It may lead to new amendments of GS to account for indirect trade effects. It may also be an interesting way to understand the sustainability consequences of non-optimal RAMs and the dependence on scarce, exhaustible wealth instruments.

1.5 Other issues: Strong sustainability & Equity concerns

In Fisher's (1906) original definition of wealth there was a clear dissociation between capital theory (Victor 1991) and the theory of value.[25] The core of the weak sustainability paradigm is therefore not so much in capital theory but in the theory of value used to assign prices to instruments of wealth. As a result, genuine savings do not carry any particular assumption regarding the potential substitutability of the *physical* stocks. They rest on the degree of substitutability as measured by shadow prices. The weak sustainability paradigm sees the problem of substitutability as a dilemma akin to the famous macro-Trilemma. It is impossible to have simultaneously a constant or growing population, imperfect substitution between instruments

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[25] 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.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.

of wealth and no technical progress. But assuming that population is growing “slowly enough", or that technical progress is "fast enough" or that physical substitutability is "high enough" then there is no real issues with critical levels for a given instrument of wealth. Use of GS rests on the existence of a RAM, however imperfectly this produces shadow prices. It remains to be seen whether a system where critical physical limits (or safe minimum standards) have been reached would still rely on market mechanisms and prices to construct a sustainability indicator.

The very issue of incommensurable instruments of wealth is therefore by assumption, a different question. The "weak versus strong sustainability" question has been the background of sustainability studies since at least the Meadows et al. (1972) report.[26] Hartwick (1978) tried to estimate the consequences of multiple exhaustible resources for the DHSS model and found no incompatibility. Asheim et al. (2003) studied the importance of perfect substitutability in an optimal setting. They find that perfect substitutability is not required as long as the technology exist for an "eventual productivity path" (i.e. as long as the sustainability macro-Trilemma can be solved). The World Bank (2006) and Markandya and Pedroso-Galinato (2007) consider empirical evidence on the substitutability and find high substitutability so far.

The common view today is that weak sustainability is in essence a special, regular case in what would be a unified strong sustainability (Hediger 2006) paradigm. The weak sustainability model seems suitable for most historical situations. Strong sustainability indicators could be used instead of GS when dealing with irreplaceable ecosystem services or irreversible biodiversity losses, where shadow prices cannot be computed.

A more potent criticism of the strong sustainability paradigm has to do with the links between physical constraints/substitutability and equity. Any model based on the notion of value has a *normative* perspective. Norms 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

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[26] See Sabin (2013) for a historical discussion of the debates.

paths form a realistic aim for the considered economy. We showed how the weak sustainability model is also workable in *kakotopia* the "not-so-good society" of inefficient RAMs that is the reality of most developing countries today.

In the original Solow (1974) model, equity is based on Rawls (1971)'s criterion for intergenerational equity.[27] Solow 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).

An application of the Maximin in economics[28] is therefore a) an objective of constant consumption over time as the condition for intergenerational equity and b) 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 version of the Maximin proposed by Solow delivered a criterion for *outcome based sustainability*: some definition of consumption should be kept constant over time. Its formalisation is detailed above. But the transmission of capital from a better-off individual in the (theoretical) early generation should also be scrutinised to make sure this transmission will be to the benefit of the "least advantaged members of society".

In the RAMs scrutinised by the strong sustainability paradigm, the problem is entirely different. Individuals in a generation own instruments of wealth that are either non-substitutable or imperfectly substitutable, for physical reasons or lacking trading possibilities. Should the share of these non-substitutable wealth instruments owned by each individual not be the same[29],

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[27] "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).

[28] Note that Solow used the Maximin criterion to tackle intergenerational equity when Rawls opposed it being used this way (Rawls 1974).

[29] See Hanley et al. (2014) for a presentation of the links between intragenerational equity and strong sustainability.

intragenerational inequalities will endure. They may feed into intergenerational equalities depending on the evolution of physical substitutability.

Although the DHSS model would become the basis of the weak sustainability model, intragenerational equity is, to our knowledge, not addressed in it. It is usually argued that intragenerational equity is addressed with different tools and in different models with an ambition to tackle this particular issue. 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).

Intragenerational equity is discussed in the literature on the resource curse (Van Der Ploeg 2011) and the many commentaries on the best possible use for resource windfalls (Kuralbayeva and Stefanski 2013, Oleson 2011). Reinvestment of resource windfalls could be tailored for redistributive purposes, but in the literature on GS, emphasis is put on optimal reinvestment (Van der Ploeg 2010) to counter rent-seeking and corruption. Windfall management and redistribution should be undertaken to fulfil the equity imperative of constant consumption (in value terms) over time within *and* between generations.

It is not clear whether this equity rule for consumption, as in Hartwick (1977), was defined primarily as a desirable contract between current generations to preserve far-off future generations capabilities to maintain utility levels. In value terms, the constant consumption target is also an incentive to increase productivity (hence sparing resources via increased efficiency) so that consumption of *physical* quantities can effectively increase at constant value. Future generations experience physical gains on top of value gains for effort and thrift.

The trade-off between consumption and investment in the productive base (the wealth instruments) is ethically indefensible if not grounded in robust intra- and inter-generational equity criteria. This leaves the amount of needed reinvestment and the actual level of constant consumption attainable to be quantified.

2 Genuine Savings: empirical methods

The World Bank produces 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).

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

$$W_t = \int_t^{\infty} C(s)^{-r(s-t)} ds \tag{31}$$

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. This value of wealth is obtained by assuming that the original observed level of consumption is sustainable, and 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.[30] Estimates of the subcomponents of intangible capital can be found in the previous report (World Bank 2006, chap. 7, p.87). The authors show that the biggest component of intangible capital is likely to be the quality of institutions, followed by human capital.For the World Bank, Genuine Savings is the year-on-year change in the value of a country's total capital.[31]

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

[31] The use of the Maximin criteria also imposed restrictions on consumption so that consumption is kept constant over time. As Dasgupta (2009) reminds us, the second order derivative of consumption is assumed to be constant and not negative in most papers. 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. GS are less demanding in imperfect economies.

2.1 Empirical evidence on GS

A number of studies have constructed empirical estimates of GS, and these are summarised in Table 1. Empirically, there are a number of challenges to produce empirical values which correspond closely to 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.[32] 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 marginal 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, the choice of 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

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[32] Atkinson and Hamilton (2007) discuss issues measuring nonrenewable natural resources and pollution.

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

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

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

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

[**8**] Trade adjusted GS: [3] or [4] augmented by the present value of Capital Gains from Trade

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 are 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 ecosystem service values) are not included and thus are undervalued.

Technological change is an important concept in constructing sustainability indicators and a number of questions arise empirically: should it be included, how can it be measured, and how can it be incorporate into the GS framework. Theoretically, Weitzman (1997, p. 2) argues for the inclusion of a measure of technological progress because ‘future growth is driven by the rate of technological progress, however it is conceptualised’. However, this leads to the issue of how to measure technological progress. A number of indicators are available such as patents, R & D expenditure, energy intensity and Total Factor Productivity (TFP). Incorporating some of these indicators is empirically difficult given the monetary unit of measurement of GS. In the existing literature two different approaches have been adopted to incorporate technological change, both based on TFP. Changes in TFP are used as an indicator of technological progress. Pezzey et al. (2006), following Weitzman (1997), calculate the present value contribution of TFP growth to future income. In contrast Arrow et al. (2012) incorporate a measure of TFP by adding the TFP growth rate to the wealth per capita growth rate; see Greasley et al. (2014) for more discussion. However, as TFP is a growth accounting residual, in the words of Abromovitz (1956) a "measure of our ignorance", future research could attempt to incorporate alternative indicators of technical change such as patents, R & D expenditure, and energy intensity.

Another empirical issue relates to the choice of discount rate. This is important for any variable that is measured by discounting (e.g. pollution damages, TFP, values of resource depreciation). The underlying theory considers a social discount rate which is empirically not possible to observe (Gollier 2012). In practice, empirical studies incorporate proxies such as measures of long run real discount rates using long run growth rates, long run interest rates and central bank discount rates .

One of the first measures of GS was by Pearce and 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 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).[33] 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 ecosystem service values. Other 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. 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) present and analyse GS data constructed at a national level and for different geographic regions. They provide information on how these estimates were constructed.[34] 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. Pezzey and Burke (2014) include measures of

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

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

technological change and population growth ([6]& [7]), and 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)), they modify the underlying DICE (Dynamic integrated model of Climate and the Economy) models on which the World Bank's carbon price estimate was based. They 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. They 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.

Likewise, Ferreira and Moro (2011) construct comprehensive estimates of Genuine Savings for Ireland and found negative estimates of GS from 1995 to 1997 which they attributed this to environmental degradation. Their GS calculations were also significantly lower than the World Bank estimates for Ireland and they argued that this illustrated the importance of expanding the comprehensiveness of the World Bank estimates as they overestimated Ireland's sustainability path. However, Edens (2013) is critical of the findings of Ferreira and Moro (2011) and outlines how they made errors in their calculations of the pricing of pollutants. Yet, Ferreira and Moro (2013) illustrate how their finding of negative GS for two consecutive years were still valid when environmental damages were priced accordingly.

Longer-run estimates of GS have also been constructed. Rubio (2004) constructed long-run indicators of [1],[2],[3] and [8] for Venezuela and Mexico from the 1930s to the 1980s, but natural capital only considered one asset: oil. However, in the case of Venezuela, the subtraction of oil rents from net capital resulted in negative GS throughout almost the entire period of the study. Mexico also experienced large negative GS in the early 1980s. Rubio (2004) attempted to reconcile these persistent negative genuine savings with historical experience of both countries that indicated neither had in fact been 'unsustainable'. Rubio (2004) addressed this by incorporating capital gains in the measures of GS, [8] above, but even here calculations did not indicate positive GS. A result Rubio (2004) attributed to the fact that technological change was not included in the measure of genuine savings.

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. However, as with Ferreira and Moro (2011), this seems to be a reflection of how pollutants were priced when incorporated into the measures of 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, Kunnas 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).[35] There are essentially two approaches to the measurement of wealth. First, capital stocks (Reproducible, Natural, Human and Health) are estimated and a measure of comprehensive wealth is aggregated. 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.

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[35] See also the recent special issue on Wealth in *Oxford Review of Economic Policy*, 2014, 30.

As various studies indicate, there are numerous 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 of sustainability/unsustainability are drawn from a small number of outliers that are mainly fuel-rich countries. Pillarisetti (2005) illustrates that 50 developed countries indicate positive GS but when ecological indicators are used they display negative signals. He thus argues that GS 'by ignoring global externalities, portrays a positive picture of sustainability for advanced countries and vice versa [for developing countries]'. Furthermore, since conventional net investment [2] and GS [4] are highly correlated, 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 it "corrects" the slope and aligns it with the theoretical properties of the GS model outlined above.

3 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 countries. 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):[36]

$$PV\Delta C_{it} = \beta_0 + \beta_1 g_{it} + \epsilon_{it} \tag{32}$$

$$PV\Delta C_{it} + PV(\Delta y_{it} w_{it}) = \beta_0 + \beta_1 g_{it} + \epsilon_{it} \tag{33}$$

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 $\beta_1 = 1$
2. $\beta_1 > 0$ 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 tests do not find evidence for hypothesis

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[36] Ferreira and Vincent (2005) use $\overline{C}_{it}$ - C_{it}, average future consumption minus current consumption, as a measure of future well-being, however later studies incorporate an alternative dependent variable PV ΔC_{it}, the present value of future changes in consumption.

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 in 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 (2005) argue that this reflects the shortcomings of this variable as a proxy for human capital formation. When using alternative specifications, they 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 these findings, 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'. The inclusion of the wealth dilution effect incorporates population growth into a GS framework. 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 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 '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.[37] 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

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

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) and Ferreira 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.

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.

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. They 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:

$$W_{it} = \beta_0 + \beta_1 S_{it} + \epsilon_{it} \tag{34}$$

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.

4 Conclusion

This article surveys the current literature on Genuine Savings (GS) and the weak sustainability model. The combination of capital theory and equity concerns in the neoclassical theory of value in the 1970s set the theoretical foundations for the indicator. Empirical work from the late 1980s onwards demonstrated the practical applications. The indicator then gradually entered widespread use in the early 2000s, propelled by World Bank publications.

We discuss the theoretical underpinnings of GS in section 1. GS can be most naturally derived from a *capabilities based* definition of sustainability. GS emerges as the rate of change, using shadow prices, of total capital: it indicates future change in intergenerational well-being. An important result as it shows that a negative value for GS implies following future well-being, as measured by consumption. GS are robust to limited physical substitutability in its intergenerational dimension, but fails to take intragenerational equity issues into account. We showed how, within the limiting assumptions of a competitive framework, GS can be amended for technical change, population growth and international trade.

In section 2 we outline various empirical measures of GS including a presentation of the World Bank's method to compute GS. We review extant GS estimates for many countries and regions. We find these studies are not directly comparable, as different authors tend to use different versions of GS. As a rule of thumb, greater accounting of all instruments of wealth (including human capital, TFP growth) tends to bring about a message of probable sustainability for many countries over the long run.

We discussed in section 3 how, as a predictor of future consumption, GS tends to perform poorly when a limited number of instruments are considered over short horizons. Longer time horizons typically improve the predictive power of the measure. So does the addition of measures of the gradual improvement of productivity and technology (mostly via the addition of an extra total factor productivity term in econometric tests).

More work could be done to improve the indicator. The better performance of the indicator on longer time horizons and the important empirical role of technical change both suggest that a better way to account for the economic structure for which GS is measured is needed. Institutions matter, but how to include measures of change in the quality of institutions over time is unclear. 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 of the approach is needed.

In the short run, some 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 on sustainability of an asymmetric distribution of instruments of wealth across agents.

GS as a concept is essentially forward looking; however, the only way to effectively test the implications of the theory is to use long run 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. In general, the sensitivity of GS estiamtes to how changes in capital stocks - especially natural capital - are valued is problematic.

Furthermore, attention needs to focus on 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 (e.g. see Ferreira and Vincent (2005)). 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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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]
Rubio (2004)	2	1936-1985	[1], [2], [3], [8]
World Bank (2006)	123	2000	[1], [2], [3], [4], [5]
Pezzey et al. (2006)	1	1992-1999	[1], [2], [3], [7], [8]
Mota and Martins (2010)	1	1990-2005	[1], [2], [3], [4], [5], [7]
Ferreira and Moro (2011)	1	1995-2005	[2], [3], [4], [5]
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]

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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	$\overline{C}_{it} - \mathrm{C}_{it}$	$\overline{C}_{it} - \mathrm{C}_{it}$	PV ΔC	PV ΔC	$\overline{C}_{it} - \mathrm{C}_{it}$	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	-