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Measuring Sustainability in the UN System of Environmental-Economic Accounting

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Abstract. The adoption of the *System of Environmental-Economic Accounting 2012: Central Framework* as a UN statistical standard is a landmark in environmental accounting. The SEEA has the same authority and weight as the System of National Accounts in the pantheon of official statistics. The SEEA defines the unit value of depletion of an exhaustible resource to equal the average value of the asset (the total asset value divided by the physical stock of resource). By applying this definition to a non-optimal Dasgupta-Heal-Solow model of an extractive economy, we show that 'depletion-adjusted net saving' as defined in the SEEA supports a generalized version of the Hartwick Rule. This measure of saving can guide policies for sustainable development in extractive economies, in particular fiscal policies concerning consumption and investment expenditures funded by resource rents. The conditions required to support this finding are not unduly restrictive: that extraction declines over time at a constant rate, and that the marginal cost of resource extraction is constant.

1. Introduction

When the *System of Environmental-Economic Accounting 2012: Central Framework* (SEEA 2012) was adopted as a UN statistical standard, it set the stage for much wider adoption of resource and environmental accounting by countries across the world. This paper explores the extent to which the new standard can be used to measure the sustainability of development in extractive economies and, more broadly, to underpin policies for achieving sustainability.

There is by now a very large literature on the economics of sustainable development, as the *Handbook of Sustainable Development* (Atkinson et al. 2009) attests. Within this literature the essential question is whether wellbeing can be sustained in a world of finite resources. Solow (1974) boiled the problem down to its essentials by considering a simple economy with fixed technology, produced capital and a finite exhaustible resource that is essential for production. He concluded that constant consumption is feasible in this economy if investment is a linear function of time, and the elasticity of substitution between the two assets is equal to 1.[2] Dasgupta and Heal (1979) used this model economy to develop their pioneering book on the economics of exhaustible resources.

Hartwick (1977) showed that underpinning the Solow (1974) result is a simple policy rule. The Hartwick Rule states that if gross investment just equals the scarcity rent on resource extraction, then consumption will be constant. Investment in produced

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[2] Solow also required that the elasticity of output with respect to produced capital be greater than the elasticity of output with respect to the resource input.

capital just offsets the depletion of the resource. If this rule is applied at each point in time, then consumption can be sustained. This result rests upon the basic assumptions of Solow, including the requirement that the natural resource be priced efficiently – the Hotelling Rule. Hamilton and Hartwick (2005) and Hamilton and Withagen (2007) generalize this result to multiple consumption goods and multiple assets, showing that consumption and wellbeing will rise if ‘genuine saving’ – net saving including the depletion of natural resources – is positive and growing at a rate less than the interest rate for the economy. The more general relationship between an adjusted measure of net saving and the change in social welfare (the present value of future wellbeing) was established in Hamilton and Clemens (1999), Dasgupta and Maler (2000), and Asheim and Weitzman (2001).

While Pezzey (1989) defined a development path for an economy to be sustainable if current utility does not decrease at any point along the path, Dasgupta and Maler (2000) use a less stringent condition, that a path is sustainable if social welfare (the present value of utility) does not decline at any point along the path. In this paper we adopt the Dasgupta-Maler definition.

What theory shows is that there is a fundamental link between measuring sustainability and national accounting, in particular the measure of net saving adjusted for resource depletion in extractive economies. While this theoretical work progressed, there was a parallel stream of work on what might be termed ‘practical wealth accounting’: national accounts have been extended by including experimental stock and flow accounts for a variety of natural resources. Ahmad *et al.* (1989) is an early introduction to this literature. This work has been supported by the efforts of the United Nations Statistical Commission to develop concepts, classifications and methodology to underpin resource and environmental accounting. The culmination of this work by official statisticians is the UN *System of Environmental-Economic Accounts 2012: Central Framework* (SEEA 2012).

The adoption of the SEEA is a landmark because it establishes a UN statistical standard for resource accounting that has the same authority and weight as the System of National Accounts (SNA). The expectation is that countries will develop resource and environmental accounts to complement the SNA. The SEEA establishes two new national accounting aggregates – depletion-adjusted net saving, and depletion-adjusted national income.

The body of economic theory suggests that depletion-adjusted net saving could be used to guide real-world policies for sustainable development, by implementing the Hartwick Rule and its generalizations. This would be particularly important in developing countries with large extractive industry sectors – in these countries resource depletion can equal 10-50% or more of GDP.

In practice, the statistical standards of the SEEA have been developed with little reference to the body of economic theory on sustainable development.[3] Accounting practices may diverge from what theory suggests. And there is, of course, the

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[3] The only academic paper referenced in SEEA 2012 is Frank Ramsey’s 1928 classic on a mathematical theory of saving.

necessary divergence between real-world economies and the optimal, or at least efficient, economies on which much of the theory is based.

This paper focuses on the SEEA's treatment of exhaustible resources and assesses whether accounting aggregates such as 'depletion-adjusted net saving' defined in the SEEA can serve as indicators of sustainability. We explore the application of SEEA principles to a Dasgupta-Heal-Solow (DHS) economy, since this boils the question of sustainability down to its essentials. We find that, under fairly weak conditions, the generalized Hartwick Rule holds in a non-optimal DHS economy where resource depletion is measured using SEEA methods.

Section 2 develops the basic framework for a non-optimal economy with an 'allocation mechanism,' based on Dasgupta and Maler (2000), and shows that the measure of depletion suggested in an earlier edition of the SEEA (SEEA 2003) would necessarily lead to declining wellbeing if the Hartwick Rule were based upon this measure. Section 3 establishes the main result, showing that the generalized Hartwick Rule holds, subject to two basic conditions, when the SEEA's suggested methodology for valuing depletion is applied. Section 4 examines the dynamics of the unit value of depletion in the SEEA, and gives some empirical insight into the measure. The final section concludes.

2. Defining the allocation mechanism and an example application

Our goal in this section is to flesh out the concept of an allocation mechanism for a non-optimal Dasgupta-Heal-Solow (DHS) economy, and then to measure wellbeing over time under a particular savings rule: set saving equal to the change in total resource wealth.

The DHS economy is the canonical example of a simple economy where unsustainability is a potential development outcome. The economy is closed to trade (and therefore domestic saving equals domestic investment), it exploits a finite stock of a natural resource that is essential for production, resource extraction is costless, and there is no technical progress. Dasgupta and Heal (1979) famously show that the optimal policy for this economy – the policy that maximizes social welfare – leads to a path for consumption that falls asymptotically to zero. The optimal policy is unsustainable.

The economy has production function $F(K,R)$ which satisfies the usual neoclassical conditions,

$$F_K > 0,\ F_R > 0,\ F_{KK} < 0,\ F_{RR} < 0,\ F_{KR} > 0,\ F_{RK} > 0 \qquad (1)$$

All variables are assumed to be functions of time, unless otherwise specified. Production of a homogeneous good is either consumed or invested,

$$F(K,R) = C + \dot{K} \qquad (2)$$

Utility is a function of consumption only, so $U = U(C)$. The pure rate of time preference ρ is constant. Extraction of the resource decreases the size of the resource stock S,

$$\dot{S} = -R \tag{3}$$

The *allocation mechanism* α for this economy has the following characteristics:

(i) There is an extraction rule that determines the path $\{R\}$ for resource extraction.
(ii) There is an investment rule that defines the path for investment $\{\dot{K}\}$, and therefore implicitly defines the path for consumption $\{C\}$ as well.
(iii) The economy is efficient to the extent that,

$$S(t) = \int_t^\infty R(z)dz \tag{4}$$

F_R is the price for units of the resource R
F_K is the interest rate for the economy

(iv) The development path defined by α is feasible, so that $K > 0, S > 0\ \forall t$.

With these definitions in hand, we define social welfare V as,

$$V = \int_t^\infty U\big(C(z)\big)e^{-\rho(z-t)}dz \tag{5}$$

Because the pure rate of time preference is constant, integrating by parts yields,

$$\dot{V} = \int_t^\infty \dot{U} \cdot e^{-\rho(z-t)}dz = \int_t^\infty U_C\dot{C}(z) \cdot e^{-\rho(z-t)}dz \tag{6}$$

The change in social welfare equals the discounted integral of the marginal utility of consumption times the instantaneous change in consumption.

An example saving rule as an allocation mechanism

We now present a non-optimal infinite horizon economy where the saving rule is to set investment equal to the change in total resource wealth which results from resource extraction. The motivation for this saving rule is that the earlier draft UN standard for environmental accounting, SEEA 2003[4], suggested that the value of depletion of an exhaustible resource should equal the resource rent on extraction minus the return on the value of the resource stock. As shown below, this is equal to the change in total resource wealth if the resource stock is valued as the present value of resource rents.

We modify expression (2) to allow for costly extraction, $f(R) > 0$:

$$F(K,R) = C + \dot{K} + f(R) \tag{7}$$

and the value of the resource equals the present value of total rents,

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[4] Unless otherwise specified, all references to ‘the SEEA’ refer to SEEA 2012, the new UN statistical standard.

$$N = \int_t^\infty \left(F_R(z)R(z) - f\big(R(z)\big)\right) \cdot e^{-\int_t^z F_K(\tau)d\tau} dz \qquad (8)$$

It follows that the total change in the value of the resource stock (as a result of extraction) is equal to the return on the resource asset minus the resource rents on extraction,

$$\dot{N} = F_K N - (F_R R - f(R))$$

We define the allocation rules for extraction and investment constituting α to be:

$$\dot{R} < 0 \; \forall t \qquad (9)$$
$$\dot{K} = -\dot{N} \; \forall t \qquad (10)$$

Over the infinite horizon, expression (4) for efficient extraction can hold only if the quantity depleted R is non-decreasing over finite periods of time – expression (9) ensures that this holds true. It is straightforward to show that $\dot{N} < 0$ when quantity R is extracted, hence the sign in expression (10). However, total rents on extraction must not grow more quickly than the discount rate F_K in order to ensure the value of the resource stock is finite. The instantaneous change in investment is given by,

$$\ddot{K} = -\ddot{N} = -\frac{d}{dt}\big(F_K N - F_R R + f(R)\big) = -(\dot{F}_K N - F_K \dot{K} - \dot{F}_R R - F_R \dot{R} + f'\dot{R})$$

The change in consumption is therefore given by,

$$\dot{C} = F_K \dot{K} + F_R \dot{R} - f'\dot{R} - \ddot{K} = \dot{F}_K N - \dot{F}_R R \qquad (11)$$

Since $\dot{F}_K = F_{KK}\dot{K} + F_{KR}\dot{R}$ and $\dot{F}_R = F_{RR}\dot{R} + F_{RK}\dot{K}$, it follows from expression (1) and the allocation rules (9) and (10) that $\dot{C} < 0 \; \forall t$. From expression (6) it follows that social welfare is declining at each point in time. Investing an amount equal to the total change in the value of the resource stock $(-\dot{N})$ is a policy rule for unsustainability in this non-optimal economy.

This result is important because, as Hamilton and Ruta (2009) argue, much of the literature on 'green accounting' for exhaustible resources prior to the adoption of the SEEA 2012 assumed that the correct value of resource depletion is the change in the total value of the resource stock. This was the recommendation of the earlier draft UN standard (SEEA 2003, Box 7.3). A naïve application of the Hartwick Rule – set investment in produced capital equal to the value of resource depletion measured on this basis – would actually lead to unsustainability.[5]

3. The Generalized Hartwick Rule and the SEEA

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[5] El Serafy (1989) made an important contribution by showing that the total rent on resource extraction can be partitioned into an income component and a capital consumption component. This builds on notions of Hicksian income and the Permanent Income Hypothesis. However, his formula for valuing resource depletion is equivalent to measuring the change in the total value of the resource stock.

We now turn to our central question: can depletion adjusted net saving, as defined in the SEEA, underpin a policy rule for sustainability in a non-optimal economy? To explore this we need to define a saving rule and an extraction rule in the non-optimal DHS economy.

As theory suggests, the SEEA assumes that the value of the exhaustible resource stock S is equal to the present value of total resource rents on extraction, N. The SEEA then defines the unit value of the resource in the ground as p, where

$$p \equiv \frac{N}{S}$$

This is the average asset value per unit of resource. For resource extraction is R, expression (3) defines the change in the resource stock, $\dot{S} = -R$. The value of resource depletion is then defined in the SEEA to be,

Depletion $= -pR$

Here the SEEA makes a conceptual leap by assuming that the unit asset value p is the appropriate way to value depletion. This is potentially at odds with economic theory, where depletion is measured as the *marginal* rent on extraction times the quantity extracted. For example, Hamilton and Hartwick (2005) define 'genuine saving' to be $G \equiv \dot{K} - F_R R$ in the DHS economy with no extraction costs. This is a measure of net saving, accounting for resource depletion measured as $F_R R$. Genuine saving is the analogue of 'depletion-adjusted net saving' in the SEEA.

Hamilton and Hartwick (2005) show that a generalization of the Hartwick Rule for sustainability holds in the optimal DHS economy. To derive this result they do not require full optimization of the economy – they simply require efficient pricing of the resource, i.e. the Hotelling Rule. Hamilton and Hartwick derive the following basic relationship between genuine saving and changes in consumption:

$$\dot{C} = F_K G - \dot{G} \qquad (13)$$

The standard Hartwick Rule follows by assuming that $G = 0$ at each point in time in expression (13) – this results in a constant level of consumption over time. But a more general rule for sustainability can be derived by choosing $G > 0$ and $\frac{\dot{G}}{G} < F_K$. If this rule is applied at each point in time, consumption will be everywhere increasing in the DHS economy.

The central result that we wish to establish is that expression (13) can be derived in a non-optimal DHS economy with costly extraction $f(R)$ where:

$F(K, R) = C + \dot{K} + f(R)$, and

(i) the extraction cost function exhibits constant marginal cost, $f(R) = \gamma R$, for constant γ

(ii) genuine saving is measured as $G = \dot{K} - pR$, with $p \equiv \frac{N}{S}$ per the SEEA methodology, and

(iii) the extraction rule is $\frac{R}{S} = \phi$ for constant $\phi < 1$.

Over an infinite extraction horizon starting at time t the efficient value for ϕ is obviously $\phi = \frac{R(t)}{S(t)}$, since this will satisfy the exhaustion criterion, expression (4).

The extraction rule implies that $\frac{\dot{S}}{S} = \frac{\dot{R}}{R} = -\phi$, and that $G = \dot{K} - \phi N$.

The value of the resource asset is the present value of total rents over the infinite horizon,

$$N = \int_t^{\infty} (F_R(z) - \gamma) \cdot R(z) \cdot e^{-\int_t^z F_K(\tau)d\tau} dz$$

Now,

$$\ddot{K} = \dot{F} - \dot{C} - f'\dot{R} = F_K\dot{K} + (F_R - \gamma)\dot{R} - \dot{C} \tag{14}$$

$$\dot{G} = \ddot{K} - \phi\dot{N} = F_K\dot{K} + (F_R - \gamma)\dot{R} - \dot{C} - F_K\phi N + \phi(F_R - \gamma)R$$

and therefore,

$$F_K G - \dot{G} = \dot{C} - (F_R - \gamma)\dot{R} - \phi(F_R - \gamma)R = \dot{C} \tag{15}$$

If genuine saving G is measured using the SEEA methodology to value resource depletion, marginal extraction costs are constant, and resource extraction R is a constant fraction of the resource stock S, then as long as $G > 0$ and G is growing more slowly than the interest rate, consumption will be rising. If this saving rule applies at each point in time, then from expression (6) it follows that social welfare is everywhere rising. The economy is sustainable.

If marginal extraction costs are an increasing function of R, then the average rent per unit of resource $F_R - \frac{f(R)}{R}$ will exceed the marginal rent per unit of resource $F_R - f'$, and expression (15) becomes,

$$F_K G - \dot{G} = \dot{C} - \phi(f'R - f(R)) \tag{15a}$$

The standard Hartwick Rule leads to rising consumption in this instance.

The bad news in expression (15a) compared to expression (15) is that it is no longer sufficient for negative genuine saving to imply declining consumption – saving must be sufficiently negative to offset the final positive term. To be precise, suppose that genuine saving is set to equal a constant $\bar{G} < 0$. Then expression (15a) becomes,

$$\dot{C} = F_K\bar{G} + \phi(f'R - f(R))$$

Consumption therefore declines only if $|\bar{G}| > \frac{\phi}{F_K}(f'R - f(R))$. If $F_K = \phi$ then the absolute value of $\bar{G}$ must exceed the infra-marginal rents on extraction.

To summarize, we have established that depletion-adjusted net saving, measured in a DHS economy using SEEA definitions, will support the generalized Hartwick Rule if (i) resource extraction declines at a constant rate, and (ii) marginal extraction costs are constant.

This result is derived for an infinite horizon problem, but it transfers directly to an economy where the resource is exhausted over a finite period $T - t$. Obviously resources cannot be an essential input to production in such an economy, and the allocation rules for the economy must have two phases – one for the period of resource production, which will mirror what we just presented, and one for the remaining period. To ensure resource exhaustion over the finite period, the main parameters of the extraction program must satisfy,

$$S(t) = \int_t^{T-t} R^*(t) \cdot e^{-\phi(z-t)} dz \tag{16}$$

Here, if $R(t)$ is the currently observed quantity of resource extracted, we can choose $\phi = \frac{R(t)}{S(t)}$ and $T - t = \frac{1}{\phi}$, for example. Then $R^*(t)$ can be chosen to satisfy expression (16).

4. Level and dynamics of the unit value of depletion in the SEEA

Finally, to deepen our understanding of applying the SEEA methodology in the DHS economy, we examine two further issues: what is the rate of change of the unit value of depletion p, and is the value of depletion generally less than total rents on extraction?

Since we know that marginal rents rise at the rate of interest in the optimal DHS economy, it is worth exploring how the unit value of depletion p behaves in the non-optimal economy. Since $p = \frac{N}{S}$, we can derive the following when resource extraction falls at rate ϕ:

$$\frac{\dot{p}}{p} = \frac{N}{N} - \frac{S}{S} = \phi + \frac{F_K N - (F_R - \gamma)R}{N} = F_K + \phi\left(1 - \frac{(F_R - \gamma)S}{N}\right) \tag{17}$$

We know from the theory of the mine that the value of the mine, N, is maximized when the marginal rental rate $F_R - \gamma$ grows at the rate of interest – this is just the Hotelling Rule. In this instance the maximum value of the mine is given by $(F_R - \gamma)S$, because the growth rate and the discount rate cancel. The value of the non-optimal mine N is necessarily less than $(F_R - \gamma)S$, and so the term in parentheses is negative, implying that the growth rate of the unit value of depletion is less than the interest rate.

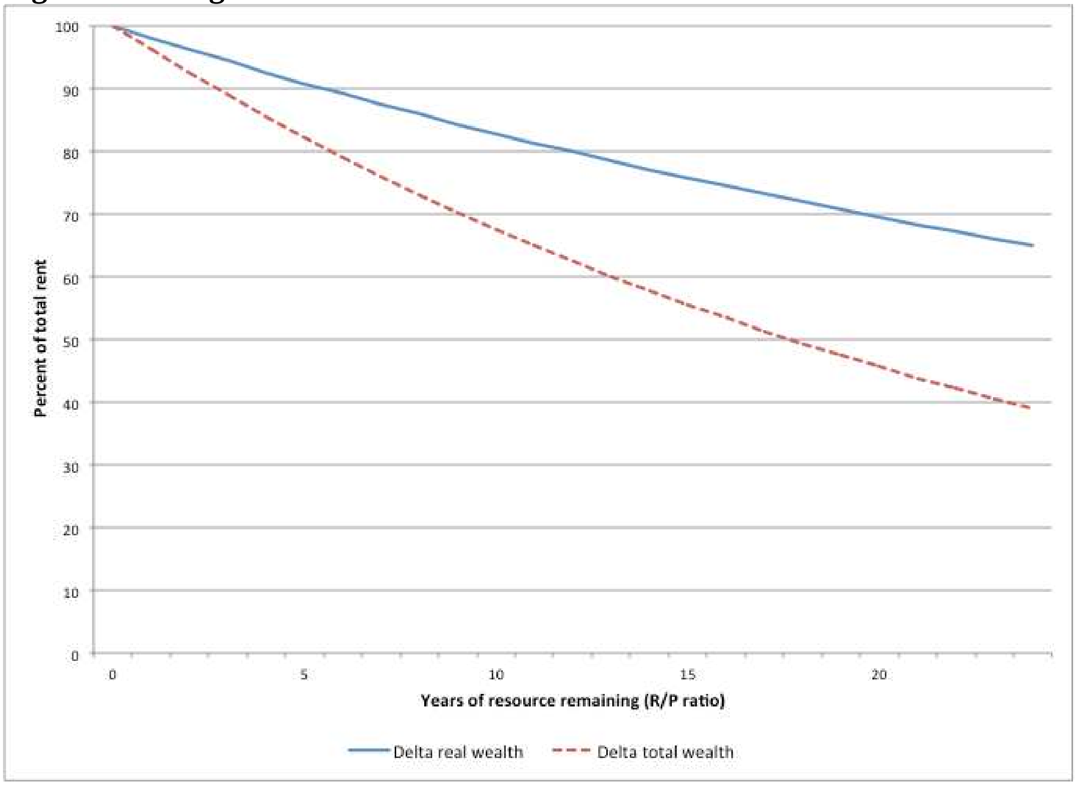
For a finite extraction program where resource deposits have lifetimes up to 25 years, Figure 1 plots the unit value of depletion (the change in real wealth using the SEEA methodology) and the change in total wealth as a percent of total rent on extraction. The curves plotted assume a constant unit rent (average rent per unit of resource) and a constant quantity extracted in each period. The assumed discount rate is 4%. The two curves are defined as:

Delta real wealth = $-p\dot{S} = p\bar{R}$

Delta total wealth = $-(p\dot{S} + \dot{p}S)$

The difference between the two curves in Figure 1 is therefore equal to the capital gains ($\dot{p}S$) when quantity $\bar{R}$ is extracted, expressed as a share of total rent on extraction. The difference increases as the resource deposit size increases. At 25 years of reserves, the change in real wealth when the resource is extracted is equal to 65% of total rents – this compares with the change in total wealth, amounting to 39% of total rent. As we saw in section 2 of this paper, setting investment equal to the change in total resource wealth results in declining social welfare.

Figure 1. Changes in total and real wealth as a function of resource lifetime



Source: author’s calculations; discount rate is 4%

With regard to the level of resource depletion compared to the total rents on extraction, Figure 1 shows that depletion is always less than total rent under the assumption of constant unit rents and constant extraction. More generally, going back to the optimal mine, we know that N is maximized if marginal rents follow the Hotelling Rule. As argued above, this implies that $N = (F_R - \gamma)S$ for optimal extraction. In general, N will be lower than this in the non-optimal economy, implying that,

$$pR = \frac{N}{S}R < (F_R - \gamma)R$$

The right-hand side of this expression equals the total rent on extraction. In general, therefore, the value of resource depletion will be less than total rent in the non-optimal economy. The SEEA formula for valuing depletion effectively partitions the total rent on extraction into a depletion component and a residual rent. Since only the depletion component has an impact on wellbeing, by implication the residual rent is in fact income that can be consumed without affecting wellbeing.

5. Conclusions

This analysis of non-optimal DHS economies suggests that the valuation of depletion in the SEEA 2012 is quite robust. The findings on the DHS economy show that the generalized Hartwick Rule for sustainability will apply under two assumptions – that marginal extraction costs are constant, and that extraction declines at a fixed rate.

The analysis in section 2 frames the allocation rule for a simple non-optimal extractive economy. In addition to feasibility constraints, two basic (and interacting) rules determine the path of the economy – an extraction rule which determines the quantity of resource extracted at each point in time, and a saving rule which determines both how much wealth is created and how much consumption the economy will enjoy at each point. Within this framework the variant of the Hartwick Rule traditionally assumed in the resource accounting literature – set gross investment to equal to the change in the total value of the resource as a result of extraction – results in an economy with declining social welfare if this saving rule is followed over time.

Section 3 derives the correct policy rule for sustainability – set gross investment to be greater or equal to the value of resource depletion as measured in the SEEA. That is, depletion-adjusted net saving should be greater or equal to 0. The assumptions required to derive this result are not overly stringent. Declining production from a fixed stock of resources is a fairly standard assumption for extractive activities, reflecting declining resource quality as the stock is depleted. Constant marginal extraction cost, implying a fixed proportionality between the quantity extracted and the cost of extraction, is at least a plausible description of the extractive process, and it is capable of refutation if extraction cost functions can be estimated. If there are increasing marginal costs of extraction then the analysis shows that setting depletion-adjusted net saving equal to 0 will produce increases in wellbeing – but this comes at the cost of there being no simple relationship between negative net saving and declines in wellbeing.

We show that the unit resource rent p in the non-optimal DHS economy grows at a rate less than the rate of interest. The value of depletion will be less than the total rents on extraction, which implies that total rents are partitioned between a capital consumption component and an income component that can be consumed without affecting sustainability. This partitioning can support fiscal rules for extractive economies, guiding governments on how much resource rent can be consumed without affecting real wealth, and how much needs to be reinvested in other assets so that social welfare can be sustained.

Overall, these results provide welcome reassurance that practical wealth accounting in a world with multiple imperfections can say something quantitative about whether current policies, pursued into the future, will lead to rising social welfare and sustainability. SEEA 2012 is an important step forward.

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