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From National Accounts to Inclusive Wealth: A Framework to Bridge Between Market and Accounting Priced Capitals

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DISCUSSION PAPER

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JEL classification: A13, E01, E21, E22, I30, O40, Q51

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Abstract

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Contents

1. Introduction

Following a long history of research and initiatives aimed at better measuring sustainable, inclusive progress – a recent example of which is the Dasgupta Review (Dasgupta, 2021) – there is a clear need for research to develop new, radical, ambitious, inclusive and sustainable measures of economic output, welfare, and wellbeing which go "*Beyond GDP*". This paper investigates two key concepts relevant to the development of inclusive and sustainable measures of economic progress; accounting prices and inclusive wealth. Accounting prices refer to the derivation of 'shadow prices' which reflect marginal social utility; more adequately taking into account the externalities caused by economic transactions compared with market equivalent prices as normally used in National Accounts. Inclusive wealth, sometimes called "comprehensive wealth", refers to the sum total of capital assets held by the nation, including produced, human and natural capital, which can be presented either in market or accounting prices.

This paper outlines a framework adapted from existing economic accounting principles which can capture value in accounting prices – which can in turn be used to calculate inclusive wealth using accounting prices as their measurement of value. To illustrate this framework, a number of case studies have been developed to showcase application in practice, as well as develop our understanding of relevant data sources and gaps.

In future research this framework has the capacity to serve as the core structure for calculating income and wealth statistics for the UK in accounting prices as part of an expanded suite of 'Beyond GDP' indicators. These will both complement and go beyond traditional economic measures such as GDP, acting as alternate value measures to sit beside the market-value based measures 'Gross inclusive Income' and 'Net Inclusive Income', which we have developed in previous papers (Bucknall, Christie, Heys, & Taylor, 2021).

2. Background

Questions on how to tell a more comprehensive story than traditional economic statistics permit have existed almost as long as those metrics themselves. From the earliest integrated models for national accounts, their suitability for use as a wider measure of welfare was always doubted, including famously by Simon Kuznets.

By the time of the 1968 revision of the System of National Accounts, this issue had been noted by leading thinkers, leading to a proposal submitted to the UN Statistical Commission in 1974 to launch a parallel System of Demographic and Social Statistics (SDSS) which would have allowed the creation of wider data which stretched beyond the 'economic'. Due to computational and data challenges this ambitious strand of work was not pursued, even if its fundamental methods were carried through local development in many areas of social statistics as these are measured today.

Nevertheless, the need to think 'Beyond GDP' continued, both in academia and among National Statistics Institutes (NSIs)[1]. The Brundtland Report (World Commission on Environment and Development, 1987) recognised the need to think about wellbeing beyond the economic in three dimensions; in the here and now, in terms of the future, and in terms of the impact of other people elsewhere. This recognition of the need to consider inclusiveness and sustainability drove forward the agenda. In 1993 and 2008, further revisions of the System of National Accounts began to widen the scope of the 1968 document to cover many of the key domains initially described in the SDSS, causing both a blurring between the 'economic' and the 'social', but also adding momentum to the need to ensure consistent, high quality statistics for decision-making which could reveal the trade-offs between economic and wider policy outcomes. Put alongside the publication of the Stiglitz Report (Stiglitz, Sen, & Fitoussi, 2009) and the development of the System of Environmental-Economic Accounts (SEEA), the 2000s and 2010s created a landscape populated by the basic building blocks of a wider and more joined-up analysis of policy and policy trade-offs.

This framework, however, suffered a number of limitations, the first of which was the imposition of a common *numeraire*, in the form of market or market equivalent prices for measuring different forms of activity, stocks and flows of benefits. Whilst allowing consistency and comparison with market outcomes, it failed to fully internalise externalities and allowed economic policy-making to remain focussed on economic outputs to the exclusion of other vital considerations. The second was a general caution about trusting the valuations generated via this common *numeraire* and hence a resistance to aggregating the available data, in part driven by only a few individual countries having access to the resources required to create the full set of required components to implement a principle-driven integrated framework, such as that implemented in ONS (2023) in terms of Gross Inclusive Income and Net Inclusive Income[2]. Whilst this framework utilises market prices it allows one to contrast a wider perspective on welfare with traditional GDP and other national accounts metrics.

[1] While the short history presented here focuses on developments among NSIs, as this is the most relevant context for this research, it's important to note that much development took place within the academic sphere which in turn influenced the discussion among NSIs – for example Nordhaus & Tobin (1973) and Sefton & Weale (2006)

[2] Noting that human capital will shortly be fully integrated, completing this model.

3. Principles and Definitions of the Framework

3.1 Production and Asset boundary

This paper sets out adjustments to economic accounting, building on the national accounts, aimed at generating measures of economic value in accounting prices. Measuring value in this way – in terms of social utility rather than private utility – is a core assumption of the theory underlying the use of inclusive wealth as a measure of intergenerational wellbeing. A simplified mathematical model of this is given in an Annex to this paper, but a more thorough version of this can be found in Dasgupta (Dasgupta, 2021).

Our starting point is the System of National Accounts 2008 (SNA 2008) – unless otherwise stated, concepts, frameworks, and measurement are assumed to be the same as stated in that manual. One key exception is the use of the terms "exchange values"/"exchange prices" in place of the terms "market values"/"market prices" used in SNA 2008 – while the concept is the same, this change of terminology helps avoid confusion and is discussed at greater length in section 4.1.

A broader array of production and consumption activity (relative to SNA 2008) is incorporated through an expansion of the SNA production boundary to include household production and ecosystem services. Closely associated with this, but also necessary for inclusive wealth to encompass all factors of production, the asset boundary is expanded to include human capital[3] and natural capitals not already included in the SNA asset boundary, with consistent SNA treatments applied to capture these within the common framework.

3.2 Defining Externalities

In order to amend exchange prices to accounting prices, the concept of an externality is formally introduced to our economic accounting, along with related concepts:

i. An externality is defined as the occurrence whereby a production activity of one producer unit affects the exchange price of the production activity of a different producer or consumer unit, without a corresponding transaction taking place.
ii. For the purposes of this framework, the only activities considered are production activities which take place within the expanded production boundary.

[3] There are known challenges here which we abstract away from – such as the economic ownership of human capital. If one assumes that the principle of economic ownership is less required when one has expanded the asset and production boundaries as under this approach then this step is legitimate but should not be read that economic ownership of human capital and natural capital now resides in the productive sector.

iii. An externality can affect the exchange price of activity in the same period the externality is produced, in future periods, or both.
iv. The “gross externality” associated with activity x is defined as the sum value of the externalities produced by activity x.
v. The “net externality” associated with activity x is defined as the sum value of the externalities produced by activity x, minus the value of the externalities produced by other activity which affect activity x.

3.3 Accounting Prices

Accounting prices are defined within this framework as equal to exchange prices for an activity, plus the net externality associated with that activity.

To explore how the price of capitals could be calculated in accounting prices, we can start with a simplified model where there are three capitals, which each produce a flow of capital services (part, or all, of which could be an externality):

K: Produced Capital[4], which produces a flow of capital services *k*

H: Human Capital[5], which produces a flow of capital services *h*

N: Natural Capital[6], which produces a flow of capital services *n*

We can describe the exchange price of capital K at time t as a function of the flow of benefits which can be earnt through the ownership of K. In a perfect market setting, this flow of benefits which is earnt through the ownership of K would be equivalent to the value of the flow of capital services which are produced by K, and these would be reflected in the price businesses or consumers would be willing to pay to acquire the asset..

However, if we allow for market imperfections which result in the presence of externalities, then this will no longer necessarily hold. If ownership of K confers on the owner the capacity to derive benefits from another capital, then the market value of K would (other things being equal) rise by an amount equal to the benefits derived from this other capital.

For example, let’s say that capital K is a café (specifically, the building itself), while the other capital is an area of outstanding natural beauty. The area of outstanding natural beauty produces non-excludable cultural services in the form of those who

[4] Produced Capital includes all produced assets within the SNA 2008 asset boundary, but excludes biological resources. Specification of an exact definition is unnecessary for this research, so further discussion beyond this short clarification is left for other research.
[5] Human Capital includes employees, the labour component of the self employed, as well as the unemployed labour force. Specification of an exact definition is unnecessary for this research, so is put to one side. Specification of an exact definition is unnecessary for this research, so further discussion beyond this short clarification is left for other research.
[6] Natural Capital includes cultivated biological assets, as well as other assets associated with ecosystem services such as those defined in the System of Environmental Economic Accounting. Specification of an exact definition is unnecessary for this research, so further discussion beyond this short clarification is left for other research.

observe it finding joy in its beauty. If the café is located close to the area of outstanding natural beauty, then customers of the café may be willing to pay extra for the services of the café in order to be able to enjoy the view via the café window. While the café building directly produces benefits in the form of a place to work and for customers to purchase the café's services – it also enables the café owner to "capture" some of the benefits of area of outstanding natural beauty, in the form of a mark-up on the prices of the café's services and hence an increased rate of return on their capital assets. As the café building enables the owner to capture this benefit through the mark-up, the discounted value of this mark-up on the price of future sales would be reflected in the market (i.e. exchange) price of the café building.

Turning back to the simple, generalised three capital model, we can express this way of describing the exchange price of capital K as follows:

Equation 1

$$Exchange\ price\ value\ of\ K_t = \sum_{z=0}^{T}\left[\frac{k_{t+z}^{K} + h_{t+z}^{K} + n_{t+z}^{K}}{\prod_{\tau=0}^{z}(1 + r_{t+\tau})}\right]$$

Where:

- K_t is produced capital at the end of period t
- T is the service or asset life of **produced capital** K
- k_{t+Z}^{K} is the benefit in time period $t + Z$, caused by **produced capital** (K) and captured by **produced capital** (K)
- h_{t+Z}^{K} is the benefit in time period i, caused by **human capital** (H) and captured by **produced capital** (K)
- n_{t+Z}^{K} is the benefit in time period i, caused by **natural capital** (K) and captured by **produced capital** (K)
- $r_{t+\tau}$ is the discount rate in period $t + \tau$

The exchange price value of human (H) and natural (N) capital could be expressed through similar equations.

The first term of the right-hand side of *equation 1* is the discounted flow of benefits *produced* by capital K which the owner of capital K can also *capture*. So, for example, this would not include any non-excludable benefits which are captured by other economic units. The following two terms ($h_{t+z}^{K} + n_{t+z}^{K}$) reflect the benefits from capitals H and N which the owner of capital K can capture due to their ownership of K – i.e. the externalities from H and N which affect K.

Similar to exchange prices, accounting prices can be described in a similar way as shown by the equation below.

Equation 2

$$Accounting\ price\ value\ of\ K_t = \sum_{z=0}^{T}\left[\frac{k_{t+z}^{K} + k_{t+z}^{H} + k_{t+z}^{N} + k_{t+z}^{F}}{\prod_{\tau=0}^{z}(1 + r_{t+\tau})}\right]$$

Where:

- K_t is produced capital at the end of period t
- T is the service or asset life of **produced capital** K
- k_{t+Z}^{K} is the benefit in time period $t+Z$, caused by **produced capital** K and captured by **produced capital** K
- k_{t+z}^{H} is the benefit in time period $t+Z$, caused by **produced capital** K and captured by **human** capital (H)
- k_{t+z}^{N} is the benefit in time period $t+Z$, caused by **produced capital** K and captured by **natural** capital (N)
- k_{t+z}^{F} is the benefit in time period $t+Z$, caused by **produced capital** K and captured by **final consumption**

That is, the accounting price value of K at the end of time t is equal to the total future flow of benefits which is caused by K, regardless of who captures these benefits. This includes benefits captured as final consumption – i.e. an externality produced by K which forms final consumption for another unit (e.g. households), where there is no corresponding transaction.

3.4 Measuring externalities (theory)

The value of the net externality associated with K at the end of period t, i.e. the difference between the exchange and accounting price K, can be expressed as:

Equation 3

$$E_t^K = \sum_{z=0}^{T}\left[\frac{k_{t+z}^{K}}{\prod_{\tau=0}^{z}(1+r_{t+\tau})}\right] + \sum_{z=0}^{T}\left[\frac{k_{t+z}^{H}}{\prod_{\tau=0}^{z}(1+r_{t+\tau})}\right] + \sum_{z=0}^{T}\left[\frac{k_{t+z}^{N}}{\prod_{\tau=0}^{z}(1+r_{t+\tau})}\right] + \sum_{z=0}^{T}\left[\frac{k_{t+z}^{F}}{\prod_{\tau=0}^{z}(1+r_{t+\tau})}\right] - \left\{\sum_{z=0}^{T}\left[\frac{k_{t+z}^{K}}{\prod_{\tau=0}^{z}(1+r_{t+\tau})}\right] + \sum_{z=0}^{T}\left[\frac{h_{t+z}^{K}}{\prod_{\tau=0}^{z}(1+r_{t+\tau})}\right] + \sum_{z=0}^{T}\left[\frac{n_{t+z}^{K}}{\prod_{\tau=0}^{z}(1+r_{t+\tau})}\right]\right\}$$

$$E_t^K = \sum_{z=0}^{T}\left[\frac{k_{t+z}^{K}}{\prod_{\tau=0}^{z}(1+r_{t+\tau})}\right] + \sum_{z=0}^{T}\left[\frac{k_{t+z}^{H}}{\prod_{\tau=0}^{z}(1+r_{t+\tau})}\right] + \sum_{z=0}^{T}\left[\frac{k_{t+z}^{F}}{\prod_{\tau=0}^{z}(1+r_{t+\tau})}\right] - \left\{\sum_{z=0}^{T}\left[\frac{h_{t+z}^{K}}{\prod_{\tau=0}^{z}(1+r_{t+\tau})}\right] + \sum_{z=0}^{T}\left[\frac{n_{t+z}^{K}}{\prod_{\tau=0}^{z}(1+r_{t+\tau})}\right]\right\}$$

Equation 3 can be interpreted as stating that the value of the net externality associated with K (i.e. the externality caused by K, minus the externalities impacting upon K) is equal to the future discounted value of the flow of benefits (i.e. capital services) which are produced by K but captured by units other than the owner of K, minus the discounted value of the flow of benefits which are produced by other capitals but are captured by the owner of K.

Measurement of this net externality could be achieved through a methodology similar to the Perpetual Inventory Method (PIM) used to measure capital stocks – where the value of a stock of capital is modelled based on past data on investment. In our case, the change in the value of the externality associated with K between time t-1 and time t can be shown to be equal to the externality associated with new investment in K at time t, plus the externalities associated with changes in other prices and volumes minus the externality associated with capital services of K at time t which can be expressed as:

Equation 4

$$E_t^K - E_{t-1}^K = E_{t-1}^{K,\ I} + E_{t-1}^{K,OPV} - E_{t-1}^{K,CS}$$

Where:

- E_t^K = Externality associated with capital K in period t
- E_{t-1}^K = Externality associated with capital K in period t-1
- $E_{t-1}^{K,\ I}$ = Externality associated with investment in capital K in period t-1
- $E_{t-1}^{K,OPV}$ = Externality associated with other changes in price and volumes in capital K in period t-1
- $E_{t-1}^{K,CS}$ = Externality associated with capital consumption of capital K in period t-1

4. Conceptual clarifications

4.1 Imperfections in this conceptualisation of accounting prices

The conceptualisation of accounting prices described in section 3 is a simplification, summarising the difference between accounting prices and exchange prices as being defined as the value of externalities – and conversely, defining accounting prices as exchange prices plus the net value of externalities.

Accounting prices can be conceptualised as the marginal social utility of a product at the level of quantity where supply and private demand meet. Exchange prices in contrast are defined by marginal private utility at the point at which supply and private demand meet. Private demand might deviate away from social demand due to several factors, for example:

- Incomplete markets (i.e. externalities)
- Frictions (e.g. taxes and regulations)

The framework being proposed simplifies the difference between exchange prices and accounting prices as being only due to incomplete markets (i.e. externalities) – it does not take account of frictions, for example. Therefore, while the measure of accounting prices here could be said to be closer to marginal social utility than the exchange price, to the extent that it will still deviate away from the value of marginal social utility it remains imperfect.

It is also worth noting that the framework proposed here, due to its focus on facilitating accounting price of inclusive wealth and production using capitals, does not consider externalities associated purely with consumption (for example, the externality of second-hand smoke associated with someone consuming cigarettes).

4.2 Measuring accounting prices for actual outcomes versus measuring accounting prices for socially optimal outcomes

Some papers, particularly those seeking to measure a shadow/accounting price for the purpose of market regulation, sometimes define the accounting price as the marginal social utility *at the point at which supply equals social demand*[7]. The quantity of the product which would be supplied at this price is often different from that which is supplied at the point at which supply equals *private* demand – indeed, the point of regulation based on this research is often to try to adjust the amount of product supply to its socially optimum amount.

In contrast to this, our framework defines accounting prices as being equal to marginal social utility *at the actual level of supply at a given time*. To the extent to which the social demand curve is not flat, this will also mean the accounting price defined this way will differ to an accounting price which was defined *at the socially optimal level of supply*.

This is because this is a framework which builds upon national accounting, which records the value of economic flows and stocks which actually occurred at a particular point in time (or over a particular period). Our objective is not to measure the *optimum* value and volume of particular flows and stocks, but to measure the *actual* value and volume in a system.

Both approaches (actual and optimum levels of supply) are valid, for differing purposes. The purpose of the framework presented here is to measure economic welfare attributable to different activities, and how this has changed over time. Analysts may want to use this data to ask the question of to what extent actual economic welfare deviates from the optimum, maximum possible welfare in that period and we would encourage this as a domain for further research. As such, we look to measure the (social) value of activities according to their actual supply, rather than their optimal supply.

4.3 The relationship between actually existing prices, prices in the national accounts, and accounting prices

It is also worth highlighting the extent to which the framework for measuring externalities which this paper puts forward is an exercise of measuring the difference

[7] As an example of this in the case of estimating a shadow price for carbon, see the discussion of the Cost-Benefit Approach to measuring the social cost of carbon in Clarkson & Deyes (2002)

between exchange prices *as defined for national accounts* and accounting prices, rather than *prices as they exist in real world markets* and accounting prices. Although this may seem like a subtle difference, it has an important implication for the practical differences between measuring capitals in exchange prices vs. measuring capitals in accounting prices.

If there are complete, frictionless markets for all phenomena which affect utility, then exchange prices and accounting prices are equal, as the private and social demand curves are identical. In practice, many markets for products are incomplete and contain externalities.

Where imperfect markets exist, but prices are still “economically significant (i.e. they affect supply and demand) the national accounts record the actually-existing prices for products. This means that the “exchange prices” used in national accounts will deviate from those which would prevail in “perfect” markets. It is for this reason that the term “exchange price” has been used in this article to refer to these national-accounts-recorded prices rather than “market price” – so as not to confuse between the prices used in national accounts and the prices which would prevail in a perfect market. A relevant example would be the regulated tuition fee for higher education used as the ‘exchange value’ in National Accounts. No-one would allege this value (£9,250 at the present time) would be the market price if market forces were left to operate without government intervention.

In addition, there are instances where national accounts do not use actually-existing prices. The national accounts, for example, include several non-market economic activities. For example, medical services by charities are included – these services may charge a small nominal fee for administrative reasons, but the fee is completely unrelated to the production costs of the service or to the level of demand for the service, and so is “economically insignificant”. In these cases, these economic activities are not measured according to the actual prices used, but are instead measured by estimating the prices which would prevail if there were a market. Similarly, other accounting systems (such as SEEA) seek to measure non-market activities according to the prices which would prevail if a market existed.

So, two points have been established; (1) that accounting prices and exchange prices are equal when full, perfect markets without frictions are present, and (2) many non-market services with economically insignificant prices have their price in economic accounting systems measured according to the price which would occur if a market existed for that service.

This leads to the conclusion that exchange prices for non-market activities, when estimated by modelling what price would prevail for a full perfect market for the product, are conceptually the same as measuring the same activity in accounting prices. This is because where markets (in the largest sense, aligned to our widened asset and production boundary) are complete and frictionless, the exchange price would equal the accounting price.

This has two important implications. The first is that the difference between exchange price and accounting price measurements of non-market phenomenon may only depend on the assumptions that go into defining the counterfactual “market” that’s assumed to exist when calculating exchange prices – and at a limit, there may be no difference at all.

The second important implication is that externalities measured in this framework should be limited only to those externalities not already included in the national accounts.

4.4 ‘New’ value vs. ‘Re-allocated’ value

One of the implications of the framework as set out in sections 3 is that the transition from

> *the measurement of economic value in exchange prices within the boundaries of the national accounts*

to

> *the measurement of value in accounting prices within the boundaries of inclusive wealth*

can be decomposed into three conceptual changes:

1. The expansion of the production boundary to include household production and additional ecosystem services
2. The expansion of the asset boundary to include:
    a. Additional produced capitals (e.g. Household capital, expanded intellectual property products)
    b. Human capital
    c. Additional natural capitals
3. Measurement in accounting prices rather than exchange prices

Only the first of these conceptual changes – the expansion of the production boundary – results in additional economic output and additional economic value added. As was discussed earlier in this section, for these non-market services which do not have economically significant prices, there is practically no difference in whether this value is measured in market-equivalent exchange prices or in accounting prices.

The second change – the expansion of the asset boundary – involves the reallocation of value; the recording of value in different areas of accounts, attributing it to different capitals, or shifting the time period in which the value is recorded. So, for example, while investment in these capitals will now be recorded (as it is reclassified from intermediate consumption to investment), so will off-setting consumption of capital. Over time, these two adjustments are perfectly offsetting, so that the inclusion of these capitals in our framework can be thought of as reallocating the time period in which value is recorded (towards the period in which investment happens and away from the period in which capitals are consumed) rather than adding new value.

The third change – the move from exchange prices to accounting prices – also results only in the reallocation of value. This is because, as defined in section 3.2, the difference between exchange prices and accounting prices are net externalities, which (at an aggregate level, and looking across time periods) cancel out.

This decomposition is useful in highlighting the specific effect of measurement using accounting prices, abstracting this from the effect of expanding the production boundary which often accompanies it. Many programmes, frameworks, and research seek to extend the production and asset boundaries of the SNA while still using exchange prices. Examples include the System of Environmental Economic Accounting and the UNECE guidance on human capital measurement (United Nations Economic Commission For Europe, 2016). This decomposition highlights that these frameworks, and research done using these frameworks, can still inform measurement of inclusive income and wealth in accounting prices. They can inform the first two steps of the decomposition, while the final step (moving from exchange to accounting prices) can be treated as a separate process. As this final process only involves a reallocation of value, it also implies that measurements of wealth – provided their asset and production boundaries are consistent – could, in practice, be similar or even equal at an aggregate level regardless of whether they are measured in exchange or accounting prices.

5. Accounting framework

Constructing a PIM-like model for measuring the externalities embodied in fixed, human, and natural capital requires measuring the externalities resulting from the investment in capitals (covered in section 4.1), as well as the externalities involved in the consumption of capitals (covered in section 4.2)

5.1 Externalities associated with investment

Following the same logic as used in section 3.4 to define the externalities associated with a capital *stock*, the externalities associated with *investment* in a capital (in the equation that follows, produced capital K is used as an example) can be expressed as:

Equation 5

$$\left[\left(\sum_{i=t}^{\infty}\Delta k_i^H+\sum_{i=t}^{\infty}\Delta k_i^N+\sum_{i=t}^{\infty}\Delta k_i^F\right)-\left(\sum_{i=t}^{\infty}\Delta h_i^K+\sum_{i=t}^{\infty}\Delta n_i^K\right)\right]$$

i.e. as the change (due to the investment) in the flow of benefits produced by K but captured by the owners of other capitals (H and N) and as final consumption, minus the flow of benefits produced by other capitals but capture by the owner(s) of K.

To calculate this in a consistent way for investment in produced, human, and natural capital, the following table could be constructed from which the necessary components could be drawn – as well as being of analytical use in its own right:

Figure 1: Simplified accounting table for externalities associated with investment

		Captured By:				
		Produced Capital K	Human Capital H	Natural Capital N	Final Consumption F	**Total**
Produced By	Produced Capital K	$\sum_{i=t}^{\infty} \Delta k_i^K$	$\sum_{i=t}^{\infty} \Delta k_i^H$	$\sum_{i=t}^{\infty} \Delta k_i^N$	$\sum_{i=t}^{\infty} \Delta k_i^F$	$\sum_{i=t}^{\infty} \Delta k_i$
	Human Capital H	$\sum_{i=t}^{\infty} \Delta h_i^K$	$\sum_{i=t}^{\infty} \Delta h_i^H$	$\sum_{i=t}^{\infty} \Delta h_i^N$	$\sum_{i=t}^{\infty} \Delta h_i^F$	$\sum_{i=t}^{\infty} \Delta h_i$
	Natural Capital N	$\sum_{i=t}^{\infty} \Delta n_i^K$	$\sum_{i=t}^{\infty} \Delta n_i^H$	$\sum_{i=t}^{\infty} \Delta n_i^N$	$\sum_{i=t}^{\infty} \Delta n_i^F$	$\sum_{i=t}^{\infty} \Delta n_i$
	Total	$\sum_{i=t}^{\infty} I_i^K$	$\sum_{i=t}^{\infty} I_i^H$	$\sum_{i=t}^{\infty} I_i^N$	$\sum_{i=t}^{\infty} I_i^F$	$\sum_{i=t}^{\infty} I_i$

Where:

- Δk denotes a benefit caused by investment in produced capital (K)
- Δh denotes a benefit caused by investment in human capital (H)
- Δn denotes a benefit caused by investment in natural capital (N)
- As an example, Δk_i^H is the benefit in time period i, caused by investment in **produced capital** (K) and captured by **human** capital (H), so that $\sum_{i=t}^{\infty} \Delta k_i^H$ is the sum of all future benefits caused by investment in produced capital in period t, which are captured by the owners of human capital
- I_i^H denotes total Investment in period I which is captured by human capital (H)
- F is used to capture externalities which are captured directly (i.e. without transaction) as final consumption (i.e. the benefit is captured by consumers rather than the owners of produced, human, or natural capital).

So, as an example, Δn_i^F denotes the benefit caused by natural capital which is capture directly (i.e. without transaction) as final consumption.

The rows of this table record the discounted sum of benefits associated with investment (in time period t) in produced, human, and natural capital respectively. The columns of the table record the units who would "capture" these benefits – or put another way, will be able to secure income corresponding to these benefits. So, for example, investment in natural capital which will create an externality consisting of future services (e.g. cleaner air) which will improve people's health may be "captured" by human capital, in the form of higher wages in the future (e.g. due to higher labour productivity or a longer expected working life).

One way of thinking about who the benefits are "captured by", as above, is who the income (positive or negative) associated with the production (including production of externalities) is captured by. So, if natural capital produced a service (say, a view of outstanding natural beauty) which is captured by produced capital (e.g. by a restaurant owner who charges higher prices so customers can eat near the view), then the service is produced by natural capital but 'captured by' produced capital, as produced capital will receive an income stream.

In addition to having a column for each capital, there is a column for "final consumption". While externalities between capitals result purely in the reallocation of value between capitals – so that, absent discounting, the future flow of benefits associated with all three capitals would be equal regardless of whether this is measured in market or accounting prices – there is also the possibility that an externality is "captured by" final consumption. For example, natural capital may produce a service (say, a view of outstanding natural beauty) which is directly consumed (i.e. by a tourist who views the natural beauty for free). In this case there is an externality, but no owner of either of the three capitals "captures" the value of the service produced, instead the value is directly consumed by the consumer. Another way to think about this would be to say there is an imputed income from the natural capital to the consumer, which is then used to consume the service.

A completed version of the table could look something like this (numbers are purely illustrative):

<u>Figure 2: Example accounting table for externalities associated with investment</u>

			Captured By:				
			Produced Capital K	Human Capital H	Natural Capital N	Final Consumption F	**Total**
Produced By	Produced Capital	K	70	15	5	0	90
	Human Capital	H	10	150	5	0	165
	Natural Capital	N	20	35	40	150	245
	Total		100	200	50	150	500

5.2 Externalities associated with capital consumption (= output)

Following a similar logic again to section 3.4 and 5.1, the externalities associated with consumption (i.e. depreciation) of a capital (in the equation that follows, Produced Capital K is used as an example) can be expressed as:

$$(k_t^H + k_t^N) - (h_i^K + n_i^K)$$

i.e. as benefits produced by K in time period t which were captured by the owners of other capitals (H and N), minus the benefits produced by other capitals but captured by the owner(s) of K in time period t.

To calculate this in a consistent way for capital consumption of produced, human, and natural capital, the following table could be constructed from which the necessary components could be drawn – as well as being of analytical use in its own right:

<u>Figure 3: Simplified accounting table for externalities associated with capital consumption</u>

			Captured By:				
			Produced Capital	Human Capital	Natural Capital	Final Consumption	**Total**
			K	H	N	F	
Produced By	Produced Capital	K	k_t^K	k_t^H	k_t^N	k_t^F	k_t
	Human Capital	H	h_t^K	h_t^H	h_t^N	h_t^F	h_t
	Natural Capital	N	n_t^K	n_t^H	n_t^N	n_t^F	n_t
	Total		Y_t^K	Y_t^H	Y_t^N	Y_t^F	Y_t

Where:

- As an illustrative example, k_t^H is the subset of the benefit(s) produced by produced capital in time t which is "captured" by the owner(s) of Human capital (H)
- K is used to denote produced capital, H is used to denote human capital, and N is used to denote natural capital
- *k* is used to denote the benefits produced by produced capital, *h* is used to denote the benefits produced by human capital, and *n* is used to denote the benefits produced by natural capital
- F is used to denote final consumption – which is used to demonstrate where a benefit/externality is consumed directly by consumers without first being "captured" by the owners of capital. More information on this is available in section 4.1

One important feature of this table to note is that, as set out in section 3.2, all factors of production are capitals – produced, human, and natural capital – due to the capitalisation of labour into human capital. Therefore, total capital consumption for all three capitals is equivalent to total output. As a result, the sum total of capital consumption in the bottom right corner is equivalent to total output in period t, and so is denoted as Y_t.

5.3 Other changes in volume and revaluation

While the model set out in sections 5.1 and 5.2 would allow for the calculation of externalities associated with capital stocks in a world of perfect information and foresight, in practice the volume of capital stocks change due to unforeseen events, and revaluations can take place due to unforeseen changes in the market. For capitals valued at exchange prices, these are measured in national accounts within the other changes in volume of assets accounts, and the revaluation accounts respectively. Similarly, the value of externalities associated with capitals would need to be adjusted each time period for their other changes in volume and revaluations.

In the case of a natural asset, for example, an unexpected natural disaster could cause the net externality between it and human capital to change substantially. Such a change would be recorded in this framework similarly to any other change in the volume of assets – affecting the value of the externality associated with the asset, but not associated with investment in or consumption of the asset. Similarly, an unexpected and substantial shift in the profitability for employers of firm specific training could cause the value of the externality between human capital and produced capital to change – despite there having been no change in the volume of training. This would be treated similarly to a revaluation – leaving the volume of the externality unchanged, with no effect on the externality associated with investment or capital consumption, but changing the value of the externality.

6. Case Studies

To demonstrate how this framework could be used in practice, three case studies are presented for a selection of capitals, showcasing how the conceptual framework would be applied as well as demonstrating how, where available, data could be used to construct accounting price estimates of capital stocks. In line with the framework, this is done through identifying where externalities are produced and received and how the values of these externalities could be calculated.

The case studies also serve to demonstrate where required data are currently unavailable, and what kinds of research is required to fully populate this framework. So, while these case studies are not intended as final, or even initial, estimates of capital stocks in accounting prices, they demonstrate the direction for the next phase of research needed to construct those estimates.

6.1 Produced Capital: Open Source Software

According to the Linux Foundation (2017), Open Source Software (OSS) is software distributed under a license that meets certain criteria:

1. It is available in source code form (without charge or at cost)
2. Open Source may be modified and redistributed without additional permission
3. Finally, other criteria may apply to its use and redistribution.

There may be substantial externalities associated with investment in, and consumption of, open source software. For example, in a 2021 study by the European Commission, they predict “an increase of 10% in contributions to Open Source Software code would annually generate an additional 0.4% to 0.6% GDP” (European Commission, 2021).

To set out an initial map of where these externalities may occur, Figure 4 outlines a simplified version of the framework, focussed only on the production and use of OSS. The rows detail the capitals which may bestow value on OSS via externalities, while the columns detail which capital may receive value from OSS via externalities.

Figure 4a: Externalities associated with investment in OSS

Supplied By	Received By: Produced Capital							Human Capital			Natural Capital	Final Consumption	**Total**
	Machinery and equipment		Dwellings	Intellectual Property Products			Other						
				Software									
	ICT equipment	Other		OSS	Other Software	Other		Software engineers	Enthusiasts	Other			
Produced Capital – Machinery and equipment – ICT equipment				X									
Produced Capital – Machinery and equipment – Other													
Produced Capital – Intellectual Property Products – Software – OSS				X									
Produced Capital – Intellectual Property Products – Software – Other software													
Produced Capital – Intellectual Property Products – Other													
Produced Capital – Other													
Human Capital – Software engineers				X									
Human Capital – Enthusiasts				X									
Human Capital – Other													
Natural Capital													
Total				X									

Figure 4b: Externalities associated with consumption of OSS

Supplied By	Received By: Produced Capital						Human Capital			Natural Capital	Final Consumption	**Total**
	Machinery and equipment		Intellectual Property Products			Other						
			Software									
	ICT equipment	Other	OSS	Other Software	Other		Software engineers	Enthusiasts	Other			
Produced Capital – Machinery and equipment – ICT equipment												
Produced Capital – Machinery and equipment – Other												
Produced Capital – Intellectual Property Products – Software – OSS	X		X				X				X	X
Produced Capital – Intellectual Property Products – Software – Other software												
Produced Capital – Intellectual Property Products – Other												
Produced Capital – Other												
Human Capital – Software engineers												
Human Capital – Enthusiasts												
Human Capital – Other												
Natural Capital												
Total												

Figure 4a outlines the capitals which supply externalities to OSS – i.e. confer value on OSS, without a transaction taking place. This comprises the people who create OSS, including both people who are paid by an organisation to do so as well as "enthusiasts" who do so by choice without payment. It also includes other software (not OSS) and the ICT hardware owned by the companies employing software engineers, with which they develop OSS. Essentially, these are the capitals used in the production of OSS – and while some are compensated for their contribution to the production of OSS (as is the case with paid software engineers and the owners of ICT), due to the open source nature of OSS it is unlikely, in all cases, this private compensation received will be equal to the full social value of their contribution.

This is because the compensation will, under market circumstances, be based on the return to their specific institutional unit – e.g. to the company in which the capital is employed. However, the contribution made may also benefit other institutional units – e.g. other companies. For open source software which does charge, this may mean that, for a specific contribution made to the OSS, the accounting price for the OSS may increase by more than the compensation received for the contribution. Within our framework, that constitutes an externality being supplied by the capitals used in the OSS production process (paid software engineers, unpaid volunteers, ICT machinery, and perhaps others) and being received by the OSS itself as a capital.

The capitals which receive value via externalities when OSS is consumed are outlined in Figure 4b. This include owners of produced capital who may use OSS (at a zero cost or at economically insignificant prices) but still experience a benefit through higher productivity of their produced capital and higher profits as a result. People who utilise OSS may have gains to their own human capital through the skills developed. Enthusiasts may also be able to achieve higher earnings as OSS repositories such as GitHub can be used as a portfolio of work, which can be used as an example or towards a curriculum vitae when looking for a job related to software engineering, potentially leading to higher earnings. Finally, some OSS may be consumed (at zero cost, or at economically insignificant prices) as final consumption by households, who enjoy the use of the OSS (e.g. open source video game software).

Figure 4 suggests that OSS is an essentially reciprocal relationship of externalities – there are similar groups who contribute to the value of OSS via externalities as those who benefit from OSS via externalities.

Future research would need to establish the values for these various externalities, and key to this would be understanding the extent to which OSS is used across the economy and estimate its effect on profits and wages as initially investigated above.

6.2 Natural Capital: Peatlands

Peatlands are wetland landscapes that consist of decomposed plants and animal remains. The waterlogged conditions in which they lay prevent plant material from fully decomposing. This results in a net accumulation of peat as the accretion of organic matter occurs at a faster pace than its decomposition.

The process of peat accumulation causes peatlands to be 'carbon sinks' which act to reduce the rate of growth of atmospheric carbon. However, when drained, peatlands emit a large amount of carbon dioxide. Within the accounting framework proposed in this paper, this could be considered as an externality associated with the capital consumption of peatlands (one form of natural capital) which affects the atmosphere (which could be considered a natural capital). This is likely to be the largest externality associated with peatlands which are not currently covered by the exchange price-based estimates currently included in the Natural Capital Accounts.

The focus of this case study is this externality of the peatlands (one natural capital) on the atmosphere (another natural capital), specifically via carbon emissions. There may be other externalities associated with peatlands, but by focussing on this specific externality and this specific mechanism, we wish to demonstrate how the of value of the externalities of this framework can be estimated.

One possible approach to calculating the size of this carbon sequestration externality is by calculating the carbon emissions of peatlands and then calculating a social cost of carbon associated with these emissions. This is because the value of the atmosphere as an asset, when valued in accounting prices, could be considered equal to the discounted value of some capital services (let's call them "atmospheric services") which allow day-to-day economic activity to take place. The effect of carbon emissions on the atmosphere is, via climate change, to reduce the value of these atmospheric services. This reduction in atmospheric services can be estimated as the reduction in economic activity associated with the carbon emissions – i.e., as a social cost of carbon.

Due to the different emissions patterns of different kinds of peatlands, a first step to estimating emissions associated with capital consumption of UK peatlands as a whole is to breakdown the area of peatland in the UK by its type and calculate emissions associated with each type. By multiplying the area (in hectares) of each type of peatland in the UK by the carbon emissions each type of peatland emits (per hectare), total carbon emissions for UK peatlands can be derived. These volumes of emissions can then be multiplied by a value of the damage caused to the atmosphere for each unit of carbon.

Data on the volume of carbon emitted for different kinds of peatland are available from the study Evans et al. (2017), while an estimate of the damage of carbon to the atmosphere (varying by year) is available from Bucknall, Christie, Heys, & Taylor (2021).

Using these two sources, the value of the externality associated with carbon emissions from different kinds of peatlands can be estimated for the year 2013, as shown in Table 1.

Table 1: The value of externalities associated with different kinds of peatland, UK, 2013

Land Cover	UK Value of Peatland Carbon Emissions
Forest	£68,227,270.47
Cropland_horticulture	£0.00
Cropland_arable	£122,417,290.75
Drained Eroded Modified Bog	£6,511,510.28
Undrained Eroded Modified Bog	£14,090,857.27
Drained Heather Dominated Modified Bog	£10,047,070.58
Undrained Heather Dominated Modified Bog	£17,271,074.94
Drained Grass Dominated Modified Bog	£3,599,385.76
Undrained Grass Dominated Modified Bog	£5,555,013.87
Extensive grassland	£12,973,936.79
Intensive grassland	£74,893,878.77
Near Natural Bog	£102,549.46
Near Natural Fen	-£26,388.26
Extracted Domestic (fuel peat)	£17,495,053.99
Extracted Industrial (horticultural)	£1,798,594.73
Rewetted Bog	£378,071.56
Rewetted Fen	£2,554,158.33
Total	**£357,889,329.29**

One of the caveats to this piece of work stems from the data availability of peatland coverage in the UK. The year the data were collected varies for each country. The data for England is from 2013, Scotland 1990, Wales 1990, and Northern Ireland 2007. This is due to the complicated and resource-heavy process in collecting this data, meaning that it is unable to be updated on a regular basis. To more accurately calculate the size of the externality that peatlands cause upon the atmosphere, we would need consistent and up-to-date data across all four countries. Satellite imagery may be one mechanism to access this.

6.3 Human Capital

Human capital is defined as the knowledge, skills and attributes embodied within people that enables them to facilitate the creation of economic and social well-being (United Nations Economic Commission For Europe, 2016). A range of factors can constitute the stock of human capital including individuals' educational attainment, knowledge, skills and health.

One activity associated with externalities upon human capital is the investment by firms in training their staff. The effect of training upon human capital, and who receives the returns for such training, has a long and well established literature (e.g. Becker (1993)). This case study draws upon these well established insights from the literature, and demonstrates how they can be conceptualised and reflected within this paper’s framework.

First, it is helpful to divide training into firm-specific training and non-firm-specific training.

Non-firm specific training refers to training provided by an institutional unit (a firm or public sector education provider) to a worker which enables the worker to develop ‘transferrable’ skills. A ‘transferrable’ skill in this context refers to a skill that an individual can utilise (or derive benefits from utilising) across multiple potential employers. As this skill can be used elsewhere, the ‘ownership’ of this skill lies with the individual rather than the firm.

An example of a transferrable skill would be gaining a degree, learning how to code in an open-source programming language (such as Python or Java) or learning First Aid. These types of skills can be used by an individual either within the firm which provided the training, at other firms or in the individual’s personal life. The effect of this training on the firm is likely to take the form of increased output due to having a more skilled and productive worker.

However, while the output of the firm may increase as a result of training increasing workers’ productivity, the increase in output may not translate into increased profit. A newly-trained programmer in Python will have increased their marginal labour productivity not just in the firm providing the training, but in all firms that utilise Python programming. Once the employee is trained, the firm will need to increase the wage rate paid to the worker to retain them. In a fully competitive labour market, and assuming the productivity increase in the skills is completely transferable, this increase in the wage rate will need to fully reflect the increased labour productivity of the worker. In other words, some substantial part of the increase in firm output would go to higher pay rather than higher profit. Any pay rise less than this would leave an incentive for other firms to hire the worker for marginally higher pay and profit as a result.

The externality from investing in and providing non-firm-specific training in this scenario is the increase in human capital (i.e. the increase in the worker’s future earning potential) from the training. Although the cost of training is incurred by the firm, it is not able to capture all the benefits as the increase in human capital accrues to the individual, who is able to exploit this economic ownership of this asset to extract rents in the form of higher wages.

Despite this, it can still be logical for firms to offer non-firm-specific training, as employees can be seen to make decisions on labour supply based on both the formal wage which is offered, as well as the value of the externality (i.e. the non-firm specific training). Provided employees make labour supply decisions based on discounted life time earnings rather than earnings in the single period at hand, then they will be willing to supply their labour for a wage below their labour productivity even in a competitive labour market – because the externality they receive to their human capital (i.e. their discounted expected future earnings) outweighs the value of the below-productivity wage. Apprenticeships serve as a strong example of this – a period of work in which salaried compensation is often lower, but this is made up for with high levels of training forming part of the “compensation” package. So long as the money saved in reduced salaries in the initial period is equal to or greater than the cost of the training, it can still be a profit-maximising decision for the employer to offer the non-firm specific training.

In such a case, exchange-price measures of value underestimate the compensation of labour received in the initial period (as they exclude the value of the externality received, i.e. the training) as well as underestimate the resultant value of the increase in the human capital stock. Within our framework, an externality would be recorded during the initial training period, from the owner of the firm’s produced capital to the owner of the human capital (i.e. the employee), equal to the discounted value of the employee’s increased expected future earnings (i.e. the increase in their human capital) as a result of the training.

Training which is specific to one firm behaves differently and is reflected differently within the framework. Firm-specific training corresponds to the knowledge and skills that are not transferrable between firms. For example, training that provides the knowledge and skills needed to use a company’s bespoke software, which another firm would not be willing to offer a wage premia to attract.

Training a worker in a firm-specific software or application directly benefits the firm as it can realise the increased output resulting from increased labour productivity in the form of higher profits. This is because the training no longer increases the wage that the worker could command at alternate companies. As a result, there is no incentive for a higher wage to be offered to ensure employee retention. All benefits from investing in firm-specific training can be captured by the firm in the form of higher profits and therefore no externality arises as economic ownership continues to rest with the firm.

For this reason (i.e. the firm is able to realise the benefit of firm-specific training in the form of higher profits), within the expanded asset boundary firm-specific training is regarded as an intangible asset (a produced non-financial asset, albeit one which is currently uncapitalised in the National Accounts framework) owned by the firm rather than human capital, where the economic ownership rests with the individual.

Future research in this area would require estimates of the value of firm specific training which accrues to firms (estimates of which have already been produced by ONS (Office for National Statistics, 2022)), and separately the value of training which results in higher life-time earnings for workers. These could then be used to estimate the appropriate net externalities, and adjust the exchange-price based firm-specific training capital and human capital numbers calculated by ONS into accounting price estimates.

7. Conclusions

This paper has aimed to demonstrate a mechanism to re-allocate prices between an expanded set of capital assets to reflect the sources of value creation, internalising externalities as perceived by the existing National Accounts production and asset boundaries and how, when undertaken, this produces measures of wellbeing that can be used to derive a sustainable path into the future. It accompanies this with a number of case studies to illustrate the types of adjustments which need to be considered to make this model a reality.

This paper sits within a family of research articles under the banner of improved economic measurement, which aim to deliver a more complete narrative that can work to complement traditional measures such as GDP and the National Accounts. It does this by applying recognised methods and extending these either to include a widened asset and production boundary to reflect the flows of goods and services, which can initially be undertaken in market or exchange prices. Whilst this deliver metrics which are directly comparable to the National Accounts, as this paper shows, further metrics can be developed which further enhance our understanding by re-allocating value creation through the use of accounting prices. Whether one then analyses the economy in terms of flows or stocks, the fundamental underlying narratives remain clear and it becomes easy to see where GDP over or understates the true performance of economic activity and the benefits which people accrue from it.

Obviously, this remains a strategy focussed on the domestic perspective, whilst in the 21st century, with climate change and environmental issues such as the atmosphere and stocks such as fish which migrate across borders increasingly an issue, a wholly national measure in an international world can only do so much, but this paper shows that even within this national perspective we have the opportunity to better understand the economic world around us and better inform decision-making. We hope the research roadmap outlined in this paper will spur others into participating in this vital strand of work.

8. Annex: Underlying Framework

The framework presented here is intended to present a way to undertake economic accounting aligned to the concept of “intergenerational well-being” which can be defined as “…the (possibly discounted) sum of the well-beings of all who are here today and all who will ever be born” (Dasgupta, 2021, p254). The framework builds upon already existing economic accounting principles from the System of National Accounts, and would be built upon the national accounts themselves (possibly as a “enhanced account”). The key measures which result from this framework are inclusive income and inclusive wealth in accounting prices rather than market prices. While the research in this article is primarily conceptual, concurrent research is being undertaken to calculate initial measures of these with market/exchange prices being used in the first instance (Office for National Statistics, 2022).

Interest in Inclusive Wealth, when measured in accounting prices, derives from the theoretical result that (given certain assumptions) well-being is maximised when Inclusive Wealth (measured in accounting prices) is maximised (e.g. Dasgupta 2021, p43). A simplified version of this result can be shown as follows. Assuming that humanity survives indefinitely and well-being is synonymous with utility; intergenerational wellbeing can be defined as

Equation A1

$$V_t = \sum_{Z=0}^{\infty} \left[\frac{N_{t+Z} \cdot u_{t+Z}}{\prod_{\tau=0}^{Z}(1 + r_{t+\tau})} \right]$$

Where:

$V_t = intergenerational\ wellbeing\ in\ period\ t$

$N_{t+Z} = population\ size\ in\ period\ t+Z$

$u_{t+Z} = average\ utility\ in\ period\ t+Z$

$r_{t+\tau} = discount\ rate\ in\ period\ t+\tau$

Equation A1 can be read as stating that current intergenerational wellbeing is equal to the discounted value of the utility of the population from now onwards.

If we assume that total utility, U, is equal to the population size (*N*) multiplied by average utility (*u*), then Equation A1 becomes:

Equation A2

$$V_t = \sum_{z=0}^{\infty} \left[\frac{U_{t+z}}{\prod_{\tau=0}^{Z}(1 + r_{t+\tau})} \right]$$

Adding the assumption that utility is equivalent to the value final consumption (*C*), and defining final consumption as output[8] minus investment, it's possible to rewrite the above equation for intergenerational well-being as:

<u>*Equation A3*</u>

$$V_t = \sum_{Z=0}^{\infty} \left[\frac{C_{t+Z}}{\prod_{\tau=0}^{z}(1 + r_{t+\tau})} \right]$$

<u>*Equation A4*</u>

$$V_t = \sum_{Z=0}^{\infty} \left[\frac{Y_{t+Z} - I_{t+z} + D_{t+z}}{\prod_{\tau=0}^{z}(1 + r_{t+\tau})} \right]$$

As such, we firstly define the value of inclusive wealth as the discounted value of its future capital services:

<u>*Equation A5*</u>

$$W_t = \sum_{Z=0}^{\infty} \left[\frac{S_{t+Z}}{\prod_{\tau=0}^{z}(1 + r_{t+\tau})} \right]$$

Where:

$_t = Inclusive\ wealth\ in\ period\ t$

[8] For simplicity, this model assumes that outputs consist only of final products, i.e. there is no intermediate consumption – although it would be possible to relax this assumption

$S_{t+z} = Inclusive\ wealth\ capital\ services\ in\ period\ t + z$

Capital services can be derived from Inclusive wealth, and used for the purpose of final output or investment:

Equation A6

$$S_t = S_t^I + S_t^Y$$

Where:

$S_t^Y = Inclusive\ wealth\ capital\ services\ used\ for\ final\ output\ in\ period\ t$

$S_t^I = Inclusive\ wealth\ capital\ services\ used\ for\ investment\ in\ period\ t$

The value of final output in any period are then equal, by definition (as inclusive wealth is the only factor of production), to the value of capital services employed for that purpose:

Equation A7

$$Y_t = S_t^Y$$

Similarly, the value of investment in inclusive wealth is equal to the value of inclusive wealth capital services employed for that purpose. This adds to the stock of inclusive wealth in the next period, and replenishes (to some extent) the stock of inclusive wealth used up in production in the current period. This can be summarised as:

Equation A8

$$I_t = S_t^I = (W_{t+1} - W_t) + \frac{S_t}{1 + r_t}$$

With the model now defined, we can show that the value of intergenerational wellbeing is equal to the value of inclusive wealth – so, for the social planner, maximising inclusive wealth is equivalent to maximising intergenerational wellbeing. To do this, we can combine Equations A5, A6, and A8 to define the value of inclusive wealth at time t as:

Equation A9

$$IW_t = \sum_{Z=0}^{\infty} \left[\frac{S_{t+Z}^Y + (W_{t+Z+1} - W_{t+Z}) + \frac{S_{t+Z}}{1 + r_{t+Z}}}{\prod_{\tau=0}^{Z}(1 + r_{t+\tau})} \right]$$

We can expand this by plugging the definition of inclusive wealth in Equation A6 back into the terms in the curved brackets of the numerator in Equation A9:

Equation A10

$$IW_t = \sum_{Z=0}^{\infty} \left[\frac{S_{t+Z}^Y - \left(\sum_{X=1}^{\infty} \left[\frac{S_{t+X}}{\prod_{\tau=0}^{X}(1 + r_{X+\tau})} \right] - \sum_{X=0}^{\infty} \left[\frac{S_{t+X}}{\prod_{\tau=0}^{X}(1 + r_{X+\tau})} \right] \right) - \frac{S_{t+Z}}{1 + r_{t+Z}}}{\prod_{\tau=0}^{Z}(1 + r_{t+\tau})} \right]$$

The terms in the brackets now largely cancel out, So Equation A10 can be simplified to:

Equation A11

$$W_t = \sum_{Z=0}^{\infty} \left[\frac{S_{t+Z}^{Y} + \left(\frac{S_{t+Z}}{1 + r_{t+Z}} \right) - \frac{S_{t+Z}}{1 + r_{t+Z}}}{\prod_{\tau=0}^{Z} (1 + r_{t+\tau})} \right]$$

The second and third terms in the numerator of Equation A11 also cancel out, so that:

Equation A12

$$W_t = \sum_{Z=0}^{\infty} \left[\frac{S_{t+Z}^{Y}}{\prod_{\tau=0}^{Z} (1 + r_{t+\tau})} \right] = \sum_{Z=0}^{\infty} \left[\frac{Y_{t+Z}}{\prod_{\tau=0}^{Z} (1 + r_{t+\tau})} \right]$$

A similar process can be carried out for the definition of intergenerational wellbeing from Equation A4, using equations A6 and A8 to expand it:

Equation A13

$$V_t = \sum_{Z=0}^{\infty} \left[\frac{S_{t+Z}^{Y} - \left(\sum_{X=1}^{\infty} \left[\frac{S_{t+X}}{\prod_{\tau=0}^{X} (1 + r_{X+\tau})} \right] - \sum_{X=0}^{\infty} \left[\frac{S_{t+X}}{\prod_{\tau=0}^{X} (1 + r_{X+\tau})} \right] \right) - \frac{S_{t+Z}}{1 + r_{t+Z}}}{\prod_{\tau=0}^{Z} (1 + r_{t+\tau})} \right]$$

Followed by a similar process of cancelling out, so that:

Equation A14

$$V_t = \sum_{Z=0}^{\infty} \left[\frac{S_{t+Z}^{Y}}{\prod_{\tau=0}^{Z}(1 + r_{t+\tau})} \right] = \sum_{Z=0}^{\infty} \left[\frac{Y_{t+Z}}{\prod_{\tau=0}^{Z}(1 + r_{t+\tau})} \right] = W_t$$

So intergenerational well-being is equal to the discounted value of all future output, which from Equation A12 we know is also equal to inclusive wealth – therefore inclusive wealth is equal to intergenerational well-being.

It's also worth noting that, from Equation A3, intergenerational well-being (and therefore inclusive wealth) is also equal to the discounted value of all future final consumption. The intuition for this result can be seen by considering the equality of final consumption with final output minus investment and plus depreciation. Over an infinite time horizon, the (discounted) value of investment is equal to the (discounted) value of investment, so the two terms cancel out – meaning the discounted value of all future output is equal to the discounted value of future consumption.

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