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Types of Capital and Their Measurement

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Abstract
Capital is notoriously heterogeneous, and this heterogeneity can make measurement very difficult. One way that this issue has been addressed in the literature is to measure capital as the sum of past investments depreciated, with depreciation rates differing across types of capital. In this paper we explore multiple other methods for measuring capital and discuss which method best measures which types of capital.

Key words: Measurement, capital, investment, depreciation, intangibles, natural capital

JEL codes: **C43, C51, C82, O4**

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1. Introduction

Capital plays an important role in many economic models and theories, including those relating to economic growth, investment, and welfare. Given capital's theoretical importance, much time has been spent by economists and economic statisticians on measuring it. The measurement of capital has a long and, at times, fraught history. It has been described as the "one of the nastiest jobs" in economic measurement (Hicks 1981). Despite this, or perhaps because of it, much progress has been made. From the Cambridge capital controversy of the 1950s and 60s, to the seminal work of Dale Jorgenson and co-authors in the 1970s and 80s, to the increased recognition of natural capital and intangible capital in more recent decades, capital measurement has come a long way.

However, the measurement of capital is far from resolved, and takes on renewed importance in the light of various developments in the 21st century. First, and most importantly, the environmental crisis demands consideration of sustainability in economics and economic measurement. Capital, by its nature of being durable, is at the heart of sustainability issues. Second, the slowdown in economic growth and productivity growth since at least the 2008 global financial crisis, and perhaps before, is still not fully understood. The sources of growth before and after this slowdown, including capital in its various forms, continue to warrant attention. Third, the rising availability of large datasets together with the rising ability to analyze data with artificial intelligence raises the prospect of new measurements becoming feasible. Fourth, economic measurement continues to progress in other areas, and capital measurement must keep pace. The focus on "Beyond GDP" and "inclusive wealth" demonstrate an interest in thinking about welfare and wealth, not only production and income, which necessitates consideration of capital. Relatedly, the revision to the System of National Accounts (SNA), due in 2025, will make several changes to the coverage and concepts of capital in the national accounts.

Given these demands, this paper aims to move the economic measurement community towards a deeper understanding of the myriad forms of capital, and how they might best be measured. We do not seek to re-open old debates but build on the depth of thinking of the past. This paper focuses on the conceptual underpinnings of the measurement of capital – we do not delve too deeply into specific data issues, but rather consider what measurement approaches might best be used in different circumstances. We also seek to encompass a broad range of capital, not only those types treated as such in business accounting or the national accounts at present. As such, we believe our contribution is principally for thinkers on economic measurement – in national statistical institutes around the world, and allied researchers and organizations.

This initial research is focused on the current value and nominal measurement of capital as a first step in our understanding. We ask the question: what is this piece of capital worth today? There are three valuation methods, which economic theory tells us will give the same value under restrictive conditions: 1) the purchase price in a market transaction; 2) the cumulated value of past investments, less depreciation; 3) the discounted value of future benefit flows. We recap these three valuation methods and the conditions under which they are applicable. We then suggest when they might best be used, and for which types of capital.

What is capital? We begin from the perspective that capital is any asset which is expected to provide value in a future period – in other words capital stores resources from one period to another. Capital assets constitute all the productive resources of the economy other than labor

and intermediate inputs. The scope of capital considered in this paper is intended to be broad, perhaps as broad as one might reasonably go. We consider tangible, intangible, human, and natural capital. We also include long-lived items which are not fixed assets, such as inventories, valuables, consumer durables, and licenses. To be clear, we go beyond the scope of capital that is currently included in the national accounts.

To bring some structure to this wide array of capitals, we propose five "dimensions" of capital: a) tangible or intangible, b) produced or non-produced, c) standardized or non-standardized, d) exclusive or non-exclusive capital services, and e) fixed or non-fixed. Each dimension has implications for measurement methods, reflecting the characteristics of capital. Cross-tabulating the dimensions reveals that some 'types' of capital are more common than others and provides novel insights into the nature of capital and why measurement challenges arise.

To set the scene, we present here three initial examples – many more are discussed later in the paper, and the ideas and descriptors are elaborated.

First, consider a piece of equipment such as a truck. It is tangible, produced, standardized, exclusive, and fixed. If it has been sold recently, its value can be observed directly. And even if it has not been sold, the current market value of the truck may well be ascertained as a price fetched by similar trucks on the used truck market. The used truck market price, if available, is a simple and transparent means of obtaining the current value. It may also have a current reproduction cost on the new truck market, less depreciation. And as its capital services accrue exclusively to its owner, its discounted future return may be calculable. Thus, this sort of capital is relatively easy to value.

Second, consider an intangible asset such as a pharmaceutical drug patent. It is intangible, produced, non-standardized, exclusive, and fixed. Just like with a truck, if it has been sold recently, its value can be observed directly. But because it is non-standardized, it is very unlikely that a similar patent even exists let alone has been sold recently enough to give a relevant price on the used patent market. Based on current sales and expected future prices and sales, the discounted future return may be calculable; these values would be reflected in the stock market or private equity value of the owning firm. The research and development cost of the specific drug is unlikely to be a good estimate of the value of the drug, because these investments are highly risky with a skewed, long-tail distribution. However, with free entry, it is possible that the value of all pharmaceutical drugs may approximate their total cost of research and development less depreciation.[2] It is arguably not the intangible nature of the asset that makes valuation difficult, but the non-standardized nature.

Third, consider an intangible asset such as the research underlying a pharmaceutical drug whose patent has expired. It is intangible, produced, non-standardized, non-exclusive, and fixed. The exclusive value of the patent is zero. The generic version of the drug can be sold for a substantially lower price than it was pre-patent expiration. However, the non-exclusive value of the drug is higher than ever, if we consider this to be the discounted future consumer surplus arising from the intangible asset. Measuring consumer surplus is naturally very difficult and so this asset is challenging to value, largely due to the non-exclusivity of its

[2] An interesting question is whether federal and non-profit outlays for research and development should be included here.

capital services. However the consumer surplus has, in theory, a lower bound at the exclusive value of the (economic) profits from drug sales before the patent expired.

The paper proceeds as follows. Section 2 provides a brief history of capital measurement and overview of the literature, including for some key categories of capital. Section 3 describes the three valuation methods, and their conditions. Section 4 describes our capital dimensions and what they mean for measurement. Section 5 presents an extensive list of capital types, allocated to the aforementioned dimensions, with associated notes. Section 6 presents cross-tabulations of the dimensions with associated examples, and notes on valuation and measurement, as well as some issues that arise. Section 7 concludes with discussion on the insights of the previous sections, drawing conclusions for capital measurement, and outlining a research agenda.

2. Literature

This section offers a brief history of capital measurement and overview of the literature. It is not our intention to give a comprehensive review, and beyond the scope of the present paper to do so. Many such reviews exist, including Kendrick (1961), Usher (1980) and Corrado et al. (2005). Instead, we hope to ground the discussion of later sections in what has gone before, and what current practice looks like.

There is an enormous literature that could be cited on the measurement of capital, going back at least to John Stuart Mill (1848) and David Ricardo (1817). Keynes (1936) has played a central role in the development of the theory as has Solow (1956). Jorgenson and Griliches (1969) explain how the development of neoclassical theory can be brought to bear in economic measurement, including of capital.

National accountants have recently been considering including more assets in the category ‘capital’, including intangible capital (Nakamura 2003 and Corrado et al. 2005), human capital (Jorgenson and Fraumeni 1989), and natural capital (SEEA 2012). Guidance for national accountants on measuring capital is in OECD (2009a). Hence, the enormous existing literature may now be applied to more assets.

John Kendrick (1961) takes as his basic definition of capital, Irving Fisher’s idea that capital is the stock of all kinds of wealth that exists at a point of time. He distinguishes human and nonhuman wealth, non-produced land and produced capital, consumer durables, inventory, social capital, intangible assets. And he views as means of measurement: i) the cumulated value of past investments, less depreciation, and ii) the discounted value of future revenue flows.

Dan Usher (1980) begins his survey by noting that there are different purposes of measurement. These include the needs of: i) the investment function, where investment is a function of the existing capital stock, ii) the consumption function, where consumption depends on wealth, and iii) the production function, in which capital and labor are the inputs. As practical means of measurement, Usher discusses the cumulated value of past investment less depreciation, book values, and fire insurance estimates. He compares two valuation bases, supply side valuation—the cost of production (Young and Musgrove 1980) – versus demand side valuation – the usefulness of the capital good in production (Gordon 1980). The difference is that if there is a costless improvement in quality, Young and Musgrove would not include that in the good’s real price, while Gordon argues for hedonic methods to price

quality. As mentioned earlier, our paper focuses on nominal values and therefore does not concern itself with calculating quality-adjusted price indexes.

Ultimately, Usher notes that the long run value of capital, K, may differ from its short run production value, y=f(K,L). However, these can be reconciled by including the value of the capital stock in the next period in the short run production function. The consumption forgone is the current cost, *a la* Young and Musgrove, but the usefulness of the good in production generates the long run value of production. This is of value in its own right. In particular, optimal intertemporal decision-making rests on equating current costs and future returns.

In short, as Hulten (1991) shows, in a model of investment capital with perfect foresight and competition and without frictions, capital investment will be socially optimal. Under those circumstances, the cumulated value of past investment, less depreciation, equals the discounted value of future net revenues. When marginal revenue is curved due to monopoly power, capital investment will be less than socially optimal. Under those circumstances, the monopolist will equate the marginal unit of capital investment with its discounted future revenue stream. The monopolist can earn economic profits equal to the difference between the average discounted future revenue stream and the average cumulated value of past investment less depreciation. Similarly, where marginal costs are curved due to monopsony power, capital investment will also be less than socially optimal. Human capital is an important example in which the investor is a monopolist, may not be fully rational, and has financing constraints.

Intangible capital

Intangible capital, sometimes also known as knowledge capital or knowledge-based assets, refers to capital which is non-physical in nature. It often relates to innovative ideas and is often digital. Human capital, albeit largely intangible, is usually treated separately, and we discuss that below. From the beginning, the intangible assets of mineral exploration and architectural drawings were implicitly included in structures investment and therefore treated as fixed capital assets in the national accounts. Significant measurement work on other intangibles did not begin until the late 1990s. Important papers in the measurement work include Parker and Grimm (2000), Nakamura (2003), and the seminal Corrado et al. (2005). Software, research and development (R&D), mineral exploration and entertainment, literary and artistic originals are currently treated as fixed capital assets in the national accounts. OECD (2009b) gives measurement guidance for these assets, which are known as intellectual property products in SNA 2008.

Corrado et al. (2022) points out the difficulties in the measurement of intangible capital. To start out, intangible capital is frequently created and transferred in-house rather than sold in a market transaction. Crouzet et al. (2022) discuss the importance of the in-house nature of intangible in the corporate form and growth of firms. Martin (2024) describes the challenges of collecting data from firms on intangible assets through surveys of businesses. Furthermore, there is a literature that has long suggested that the returns to intangible investment are riskier and more fat-tailed than returns to tangible investment. Thus the current value of a particular capital asset may be far different from the depreciated value of past investment in that particular capital asset, as Scherer (1999) points out.

Intangible capital is central to endogenous growth theory. In endogenous growth models, such as the Schumpeterian growth model presented in Aghion and Howitt (2009), it may also be the case that with perfect foresight and free entry that the optimal investment in research

equals the discounted present value of the future revenues. In this model and ones like it, there is free entry and competition in the longer run, so there are no long-run monopoly rents. In these cases, Hall (2000) argues that capital investment will still equal assets. But if entry is restricted, this is unlikely to hold, capital investment will be less than optimal and expected economic profits may be positive. A separate estimate of intangible capital was constructed by Prescott and McGrattan (2000). These constructions look to stock market valuations as an alternative means to measure the combined value of total intangible and tangible capital assets. They look back to Tobin (1969) and his measure of "q", as updated by Hayashi (1982) and Abel and Blanchard (1986). In these cases, measures of intangible capital are useful in understanding macroeconomic dynamics.

Human capital

Human capital is sometimes considered a type of intangible asset, but is usually treated separately due to its uniqueness and ubiquity. Its intangible component relates principally to the knowledge of humans, acquired through education or experience, but can also relate to other human characteristics including personality traits. Investment in education, that is, the creation of intangible human capital, is an important source of differences in lifetime earnings per capita, as has been known since Mincer (1974) and indeed since Smith (1776).

There are at least two tangible components of human capital which are part of investment but whose theoretical treatment is insufficiently developed for this paper to pursue further. One is location wealth (Bilal and Rossi-Hansberg 2022). This wealth arises because the rent paid at a household's geographic location contributes to the future income stream of household members. A second is human health. Health care and personal care (such as exercise) contribute to human capital and future streams of well-being. How these two sets of expenditures related to human capital measurement is a topic for future research.

In seminal measurement work, Jorgenson and Fraumeni (1989) estimate the value of human capital by forecasting both the future stream of earnings from market work and the future value of non-market time and discounting these streams to the present (the income method). In principle, this should be equal to the cumulated cost of this investment less depreciation. Deming (2022) points out that investment in education accounts for a large proportion of income differences across countries, and that this investment has high economic returns.

The future discounted value typically provides a substantially higher value of human capital than the cumulated cost less depreciation method. Abraham and Mallatt (2022) point out the large discrepancy between the income method as calculated by Jorgenson and Fraumeni and the cost method as they calculate it based on assumptions generally adopted in the literature. They show that it is possible to narrow the discrepancy, depending on changing assumptions about the value of an additional year's education and on the discount rate assumed. A high subjective discount rate may account for the exceptionally high rate of return to education.[3] The choice of whether to use the income method or the cost method will tend depend on what economic facts we wish to explain and what data are available.

Natural capital

Natural capital, also known as environmental capital or environmental assets, relates to the value of natural environment of the world. The term "natural capital" is attributed to

[3] The coronavirus pandemic revealed another possible explanation for large discrepancy. The cost method that Abraham and Mallatt calculate focuses on out-of-pocket costs and ignores the large of cost of disease transmission that may be associated with in-person education (Chung et al. 2023).

Schumacher (1973), though the importance of land, one type of natural capital, has been acknowledged for much longer.

Modern measurement of natural capital is guided by the System of Environmental Economic Accounting (SEEA). This contains complementary guidance to SNA 2008, and indeed will be even more closely integrated with SNA 2025. The key environmental assets considered by SEEA and SNA are land (with soil separately identified in SEEA), water resources, aquatic and other biological resources, mineral and energy resources, and timber. In SNA, these are all treated as non-produced assets and included only where there is a clear economic owner who stands to benefit from the natural asset. All natural capital in the economic territory is included in SEEA, irrespective of ownership or benefit.

The SEEA Ecosystem Accounting guidance considers combinations of environmental assets which make up ecosystems, from which ecosystem services are derived. Ecosystems are typically valued by adding up the value of the ecosystem services, including provisioning services (products from nature, e.g. energy or fish), regulating services (environmental services, e.g. carbon sequestration), and cultural services (non-physical benefits of nature, e.g. from recreational use). Environmental assets can also have value from non-use, for example from wanting future generations to benefit from nature.

Government capital

The measurement of government capital suffers difficulties unique to the government sector as well as the measurement difficulties described earlier. Most important, many government assets, such as military research or environmentally significant areas, are rarely sold in market transactions, and therefore no market price for them can be observed. In addition, policymakers consider goals beyond profit maximization when planning capital purchases or capital creation. Finally, governments use very different financing mechanisms than exclusive entities do – and therefore may discount future capital services very differently. As a result of these measurement difficulties, the standard formulas for calculating capital values do not necessarily apply.

One might think that the measurement difficulties described earlier could be avoided by using the depreciated value of past investment to value government assets. In fact, past investment can be surprisingly difficult to measure. Governments often use eminent domain to acquire tangible assets at an out-of-pocket cost lower than the previous owner's desired sale price. Further in the past, governments frequently used either war or the threat of war to acquire land and other natural resources at a zero out-of-pocket cost. Finally, modern governments use regulatory mandates to acquire tax data (Soloveichik 2023) and other intangible assets at a very low out-of-pocket cost. In theory, the difference between the actual value of acquired assets and the out-of-pocket cost could be tracked as a type of in-kind taxation. In practice, measuring that difference reliably would be a very formidable empirical problem.

3. Three capital valuation methods

Economic theory suggests that there are three core ways of valuing capital which, under restrictive conditions which we will elaborate below, will give the same valuation. These are:

1. **Expenditure method** – Purchase price in a market transaction
2. **(Re-)Production method** – Cumulated value of past investments, less depreciation
3. **Income method** – Discounted current value of future benefit flows

This section briefly sets out these methods, and the conditions under which they are appropriate. Section 5 considers how they interact with the dimensions of capital, which we propose in section 4.

Valuation 1: Expenditure method – Purchase price in a market transaction
The most obvious and transparent method to value a capital asset at time *t*, is the price paid by the purchaser (investor) for that asset at time *t*. Call this purchase price P_t.

Clearly the purchase price, as revealed through a transaction, is a valuation agreed upon by the buyer and seller. This will give an accurate assessment of value assuming perfect competition, complete information, and short-term profit-maximization by both the buyer and seller.[4] While those conditions are rarely met completely in practice, this may nonetheless be a valid method when such data are available.

However, market transactions which satisfy the above assumptions may occur too rarely or too secretly for national accountants to calculate a reliable valuation. In some cases, national accountants can use market transactions which do not satisfy the above assumptions to calculate a reasonable valuation. But when valuation of many assets is required (e.g. all the assets of a particular type owned by an industry, or by the whole economy), as is usually the case in the national accounts, the purchase method may be infeasible.

An extension of the method is imputed valuation from purchase prices of similar or identical assets. For instance, while it would be highly unlikely that every truck in the economy is transacted each year, if some are transacted then the valuation of the rest could be inferred from the valuation of the few. Similarly, even though transactions may be rare for individual homes, neighborhood transactions provide information about the value of nearby similar homes. And the same may be true for works of art. Hedonic methods – which control for observable and quantifiable differences between similar products (assets) – take this a step further, allowing for imputed valuation even if the transacted assets are not so similar to the non-transacted assets.

A further extension is stock market transactions, as suggested in the "q" literature (Tobin 1969, Hayashi 1982) and in the literature on intangibles (Prescott and McGrattan 2000, Hall 2000). These literatures argue that market valuations[5] of companies should reflect the valuation of all the capital owned by the company, and so purchases of companies can reveal the value of the associated capital assets. When some assets are not included on the balance sheet, such as many intangible assets, the value of the missing intangibles can be inferred as the difference between the companies' value and the balance sheet capital assets.

Valuation 2: (Re-)Production method – Cumulated value of past investments, less depreciation
The second method is to cumulate past investment flows, and deduct depreciation[6], to give the current value of a capital asset. This method is also known as the perpetual inventory

[4] Pre-existing relationships are a common reason for one party to forego short-term profit maximization. For example, an altruistic parent might "sell" an asset to their child for well below the market price. Transactions without such a relationship are sometimes called "arm's-length transactions". But even unrelated parties might sometimes forego short-term profit maximization. For example, there may be tax advantages from underpricing.
[5] Market valuations for a company include both the value of stock and the value of bonds.
[6] SNA 2008 (section 12.46-47) recommends that catastrophic losses and other unexpected events be recorded as "other changes in volume of assets" rather than "depreciation". To simplify the discussion, this paper uses the

method (PIM). With appropriately quality-adjusted price deflators, and assuming the depreciation adjustment is correct, this gives the value in terms of units of current vintage assets (i.e. it converts investment in historic assets into current-period-equivalent units of capital). It thus gives the value of the (re-)production cost of the asset at time *t*, even if the investment occurs before time *t*. This can be applied for a cohort or group of assets, or an individual asset (in which case there is only one past investment value, rather than an investment series). The perpetual inventory method gives us the economic cost of capital, as it is based on the production cost of capital.

Formally, the current stock of capital K_t is based on past capital K_{t-1} that is subject to depreciation d_t, and if investment I_t provides the augmentation of the asset, then $K_t = I_t + d_t K_{t-1}$. National accountants frequently simplify their calculations by assuming that the depreciation factor, d_t, is a constant d. We can then iterate backwards to derive:

$$K_t = \sum_{j=0}^{T-1} d^i \, I_{t-j} + \, d^T K_{t-T}$$

The perpetual inventory method is often the main practicable option for national accounts and is widely used. While the data demands are not insignificant, the necessary data do normally exist in the national accounts and assumptions can be readily made. Specifically, the method requires data on past investment flows, appropriate quality-adjusted price deflators, an assumption on the level of the capital stock preceding the start of the investment data,[7] and an assumption on the rate and pattern of depreciation. The depreciation pattern should reflect both physical wear and tear, and anticipated obsolescence.

For an individual asset the data demands are smaller: just a single past investment value, along with a suitable price deflator and depreciation schedule. For instance, say a truck was purchased for $50,000 in the year 2010, and we wish to value it in 2020. Say the quality-adjusted price of new trucks has risen 30 percent over those 10 years, such that an equivalent truck today would cost $65,000. But our 10-year-old truck is no longer new – with depreciation of, say, 8 percent of its original value per year, it is now worth only 20 percent of its original value.[8] Then the current value of the truck, in current period prices, is 20 percent of $65,000, which is $13,000. It would thus cost $13,000 today to produce a truck of equivalent quality and condition.

Despite being widely used, this method has several limitations. First, empirical estimates on depreciation rates are scarce, and even more so on how they might have changed over time. Second, it can only be applied to assets for which there is a past investment flow and corresponding investment price index – it therefore is not applicable for non-produced assets. Third, re-production cost is often difficult to measure for capital that is all or partly created on own account, which is highly prevalent for intangible assets (Martin 2024), since the production technology then is unclear. In addition, the perpetual inventory method requires national accountants to measure the market value for older capital assets relative to otherwise similar new capital assets; this is done using past measured depreciation rates.

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term "depreciation" to refer to all value changes. This treatment is consistent with previous research showing that expected catastrophes can be included in a broad measure of depreciation (Sliker and Nakamura 2023).

[7] If the investment series is long enough, the current stock is not sensitive to the assumed starting stock.

[8] This example abstracts from the pattern of the age-price schedule and uses straight-line depreciation for simplicity. A geometric rate of 8%, cumulated over 10 years, would leave 43% of the original value.

Valuation 3: Income method – Discounted current value of future benefit flows

The final valuation method is the current value of benefits that the owner expects to receive from the capital asset. That is, the net present value of (expected) future benefit flows from the asset.

Formally, the current value of an asset V_t depends on the benefit flow in the current period s_t, and the discounted value of the asset in the next period b_tV_{t+1}, which is the product of the discount factor b_t and the asset value in the next period V_{t+1}. Thus $V_t = s_t + b_tV_{t+1}$. Assuming that the discount factor is a constant *b,* we can iterate forward to obtain:

$$V_t = \sum_{j=0}^{T} b^{t+j} s_{t+j}$$

That is, the value today is the sum of the sequence of expected benefits from the asset, discounted to the present.

The discounted value of future benefits is theoretically appealing but often very difficult in practice. First, the method relies on the discount factor. This discount factor is difficult to measure given that the real rate of interest varies, both in the short run due to cyclical changes (Abel and Blanchard 1986) and in the long run due to trend changes (Mian et al. 2021, Rogoff et al., 2024). Second, the method also needs data on expected future benefit flows, which are often unknown. National accountants often extrapolate actual benefit flows to proxy for expected benefit flows, which adds another level of complexity.

For assets which are rarely transacted and for which valuation by (re-)production cost is not feasible, valuation by future benefits is often the only practicable option. Thus, this method is used often for natural capital, human capital, and public capital. For instance, public goods such as highways and parks, can be valued using survey methods to obtain valuations of their services from users, which can then be capitalized using discounted future value. There are other methods that are highlighted in the System of Environmental-Economic Accounts.

For some types of capital, current market prices, where they exist, are related to future discounted values. For instance, stock market valuations of companies are related to the current value of expected benefits from the assets owned by the company. Because of this relationship, economic agents must make estimates of the expected benefit flows (which might be revenue or income flows in the case of companies), and current and expected discount factor. Therefore, data are sometimes available to national accountants on what these discount factors are likely to be.

The valuation by future expected benefits reveals that an asset can have positive value while delivering negative benefit flows in the current period. If the asset appreciates in value sufficiently in some period to offset the discount factor, the fact that it doesn't provide current services does not mean its current value is negative. Conversely, an asset may provide positive services in the present, but have a negative value, if its services are sufficiently

negative in some future periods. For example, a shut-down nuclear bomb factory could be surrounded by dangerous nuclear waste that must be stored until it can be remediated.[9]

Contrasting the methods: valuation and economic theory

How do these three valuation methods compare? In a competitive equilibrium with constant returns to scale and instantly flexible capital (Pasinetti 1962, Kaldor 1966, Tobin and Brainard 1977), the three valuation methods give the same result. These are, of course, highly restrictive assumptions which are rarely met in practice.

The reproduction cost of capital may not provide the same value as the other two methods if we relax the assumptions of constant returns to scale and instantly flexible capital supply. In these cases, if C_t is the cost of production of an asset with purchase price of P_t, then for economic rationality $C_t \leq P_t$. And reproduction cost may be a conceptually sub-optimal method for many important capital categories, particularly where producers have monopoly power in some market. Furthermore, reproduction cost is not even relevant to cases where capital supply is not flexible enough to match demand. For example, the cost of building a lifeboat using the normal production method is not relevant to the passengers on a sinking ship who need a lifeboat right now. As reproduction costs underlie the perpetual inventory method, this is worth some attention.

In endogenous growth models, such as the Schumpeterian growth model in Aghion and Howitt (2009) it may also be the case that with perfect foresight and free entry the optimal investment in research may equal the discounted present value of the future revenues. But if entry is restricted, this is unlikely to hold, capital investment will be less than optimal and net expected profits may be positive. This is particularly true since intellectual property law provides monopoly rights to the holder. This makes it optimal for incumbent monopolists to buy up small competitors to ensure the maintenance of their monopoly beyond their patent rights. That appears to be the world that we are in, at least in the US where inventors are increasingly employed by large firms that are slow to implement innovations (Akcigit and Goldschlag 2023, Arora et al. 2023).

4. Capital dimensions

We shape our discussion around a few dimensions of capital, which we do not think have been assembled in this way before. While many of these dimensions, or "dichotomies", have received considerable attention, we cross-classify these dimensions in ways that we hope bring new insight to existing challenges. The dimensions we consider are:

a. Tangible or intangible (section 4.1)
b. Produced or non-produced (section 4.2)
c. Standardized or non-standardized (section 4.3)
d. Capital services exclusivity or non-exclusivity (section 4.4)
e. Fixed or non-fixed (section 4.5)

4.1. Tangible or intangible

We define tangible capital as: "Forms of capital that can be touched and must have a physical location in the real world to exist. In other words, capital that has a physical embodiment."

[9] This asset class is described in the international guidelines for national accounting, System of National Accounts 2008, as 'terminal costs' (section 10.161).

We define intangible capital as: "Forms of capital that are idea-based, knowledge-based, or theoretical." The issue of intangible capital has gained significant interest in recent years, driven notably by the seminal work of Corrado et al. (2005).

We use "intangible" here as a dimension or concept, rather than a pre-determined set of assets. Seemingly similar items can be tangible in one circumstance and intangible in another. For example, a notebook filled with signatures from famous people could be a tangible collectible asset while a notebook filled with names and addresses of customers could be an intangible customer data asset. We include intangible assets tracked in the national accounts as intellectual property products, intangible assets that are tracked in the national accounts as a component of tangible assets (e.g. architectural drawings embodied in buildings and so on), intangible assets that are not currently tracked in the national accounts but whose tracking has been discussed in the existing literature (Corrado et al., 2005), and more speculative intangible assets such as licenses or laws.

"Intangible" is a relevant dimension for measurement because of its implications for all three measurement approaches.

First, regarding re-production costs, intangible assets are (usually) highly scalable (Haskel and Westlake, 2017) – they can be reproduced at near zero marginal cost given their non-physical characteristics. As such, costs of production can be a poor conceptual measure of intangible assets, since the nature of (re-)production is quite different for tangible and intangible assets.

Second, regarding transaction prices, transactions in intangible assets are often harder to observe given the lack of physical embodiment. For instance, a transaction in a tangible piece of machinery requires that it is physically created, transported, received, and installed, and this is likely to result in measurements at several points. Its physical presence also makes it salient for data collectors. By contrast, intangible assets can proliferate with limited human intervention, and can be transacted without leaving much of a trace.[10]

Intangible assets are also often produced on own account (by the ultimate user), which causes similar issues. However, while common with intangibles, this is not a property unique to their intangibility. For example, Byrne et al. (2021) estimated that cloud computing centers in the U.S. did $58 billion in own account investment in servers in 2015.

Third, regarding the net present value of future income flows, intangible assets often display synergies and spillovers with other assets. This is also possible for tangible assets but far more common with intangibles. This makes it difficult to clearly identify future income flows for that asset specifically, rather than the system in which the intangible asset exists. That is, the valuation of intangible assets is highly state dependent.

4.2. Produced or non-produced

Produced assets are those resulting from a production process that is controlled by humans. Earlier literature considered all capital to be "produced" and thus could be represented as

[10] However, small tangible assets like gemstones can also proliferate without much official intervention and are often used for transactions by entities that do not want to be traced.

"dated labour". Indeed, that was considered one of the key challenges of capital measurement in the past.[11]

SNA 2008 defines produced assets as "non-financial assets that have come into existence as outputs from production processes that fall within the production boundary of the SNA" and non-produced assets as "non-financial assets that have come into existence in ways other than through processes of production" (United Nations, 2008, section 10.9.a.). Even extending the SNA production boundary in various ways (such as including intangible goodwill that is produced through marketing and consumer durables that are produced by households), some capital assets are produced by humans in some way, and some capital assets are not.

We include within non-produced assets anything naturally occurring in the Earth's environment, in the universe (i.e. uncultivated and not created by humans, including scientific properties of the universe) or in humans (i.e. naturally biologically occurring). Unlike SNA 2008, we do not consider contracts to be non-produced non-financial assets. Rather, we view contracts as being a bundle of two separate capital types. The wording of the contract is a produced intangible asset. Where relevant, the difference between the contracted price and the market price for a particular item represents a financial asset that is positive for one party and negative for another with zero net value.

The dimension of non-produced is relevant for measurement since it rules out the possibility of valuing the asset by re-production cost, since it is by definition not produced. This does not rule out the possibility that the non-produced asset could be extremely similar to a produced asset. For instance, a forest could be either uncultivated and thus non-produced, or it could be cultivated and thus produced. But these are still two conceptually different assets and thus the value for one might not equal the value for the other. For example, natural diamonds and lab-grown diamonds have different market prices even though they appear almost identical (Cerullo and Lee 2023).

Non-produced assets can be transacted if they are owned by economic agents, so the transaction cost is theoretically feasible. Though in practice, land is the only non-produced asset which is commonly owned by economic agents and transacted frequently enough to measure market prices reliably. In addition, government agencies (such as the Federal Communications Commission in the US) conduct periodic auctions of radio spectra that can be used to measure market prices if sufficient assumptions are made. So, the transaction cost method is rarely feasible for any non-produced asset other than land and radio spectra. The net present value of future income method is thus the only possible option for (most) non-produced assets. We discuss this in section 6.

4.3. Standardized or non-standardized

This dimension is related to the produced or non-produced dimension in section 4.2 but is subtly different. An asset is standardized if there are multiple other assets that share all economically relevant characteristics. Produced assets are typically standardized when there is a (more or less) controlled and known process that allows an entity to reproduce the capital and obtain the same capital services. For example, trucks are produced on an assembly line which is carefully engineered to produce thousands of nearly identical vehicles at once. To be clear, standardized does not necessarily mean perfectly identical. Items with different colors or different options can still share all economically relevant characteristics. Standardization

[11] An issue also related to the term "round-about-ness" from an older literature.

arises from mass production; the economics of mass production, in turn, give rise to the arm's length sale of mass-produced investment goods. Hence, standardized assets are generally produced assets. However, there are also many produced assets which are not standardized.

On the other hand, non-produced assets may be to some extent standardized when natural processes happen to produce multiple assets which are similar enough for practical purposes. For example, all the radio spectra in a particular frequency band may have similar enough transmission capability that broadcasters are indifferent between one radio spectrum and another. There are often good economic reasons for businesses to produce standardized output – but no economic reason why innate properties of the universe should produce standardized natural resources.

Non-standardized assets are either non-produced or produced through a one-time production process. Thus, non-standardized assets are in some way unique – they cannot be replicated. A good example of a produced asset that is non-standardized is an original song. While copies of the song on a medium (CD or digital download) are standardized, song originals are all unique. Furthermore the production process for song originals is sufficiently unpredictable that a musician who tries to imitate a popular song original (without violating copyright) is unlikely to produce another popular song original. As a result, others cannot obtain the same capital services (CD sales, concert revenue, etc.) from another song original

An interesting case study is the re-recording of original songs by Taylor Swift. The original recordings of her songs were owned by a record label under copyright and a contract that determined her earnings from them. Neither Taylor Swift nor anyone else could replicate the original recordings under different arrangements because they were protected by copyright and contract. To get around this, Swift re-recorded the songs using assets that she did own – the composition and the lyrics – creating new original recordings. She now owned a series of new assets (the new original recordings) which were very similar to the previous assets (i.e. sounded similar) but were clearly different assets.

Many, though not all, intangible assets are non-standardized. For instance, every fact about the world is different – so research and other scientific knowledge-based capital are non-standardized. Emotion-based and relation-based capitals are also non-standardized. But intangible copies of an original, such as software copies, are clearly standardized. Further, some entertainment originals can be close to standardized – for example, soap opera scripts that are written by anonymous writers who are paid by the page are much easier to value than great works of literature that are written by known writers who are paid from royalty revenue. And cryptocurrency can be seen as an intangible valuable which is almost perfectly standardized.[12]

Measurement difficulties that other researchers have associated with intangibility are often due to non-standardization. In other words, intangibles that are more standardized are relatively easy to value. Conversely, tangibles which are less standardized can be very hard to value. Thus, great care should be taken to differentiate between standardized and non-standardized intangibles, e.g. between software copies and originals.

[12] The exact national accounting treatment of cryptocurrency is still being debated and may depend on the type of cryptocurrency (IMF 2023).

Tangible assets are generally standardized when new. But older tangible assets are often very non-standardized. For example, consider the case of vehicles. New vehicles of a specific model are almost indistinguishable and therefore are easy for a borrower to drive temporarily – but older vehicles develop their own quirks and may be only drivable by their owners. However, the decrease in standardization with age is not universal. Some biological processes produce variability naturally that can then be reduced with human intervention.

Standardized assets which are sold frequently have a market transaction price that allows both new investment and current stock to be measured. These valuations underlie the "q" theory of investment (Tobin 1969) – the reasoning being that in a competitive market, standardized assets cannot in equilibrium be worth more than their purchase price. When, out of equilibrium, the asset is worth substantially more than its purchase price, competition will result in a higher price for that type of asset, shrinking the gap between purchase price and use price.

The implications of non-standardized capital for measurement are similar to non-produced assets. They rule out measurement by re-production costs, since re-production is not feasible by definition. Non-standardized assets can be transacted, but it is rare for a single asset to be transacted frequently enough for the market price method to be feasible in practice. The unique nature of a non-standardized asset could also make the value dependent on its owner and state of the world. For example, a non-standardized older vehicle would be worth more to someone familiar with its quirks and thus able to benefit from it, than to anyone else – this is also an illustration of a monopoly user: a monopoly based on a unique relationship. The present value of future income is again the only viable option, but the valuation is subject to the current economic situation.

4.4. Exclusive or non-exclusive capital services exclusive

The ownership conditions of an asset, and thus usage of its capital services, may also affect the measurement of its value. In some cases, the legal owner of an asset uses all the capital services associated with that asset – the capital services accrue exclusively to the owner. In other cases, the legal owner of an asset is bound by contracts, laws, or social norms that prevent them from using all the capital services associated with the asset – the capital services do not exclusively accrue to the owner. Exclusive or non-exclusive capital services are related to the idea of excludability versus non-excludability, often applied to public goods; exclusivity results from the exercise of excludability.

This exclusivity of capital services relates to the owner's sector, though the relationship is imperfect. Privately owned assets (i.e. assets owned by units in the private sector) are usually "exclusive" assets, and publicly owned assets (i.e. assets owned by units in the government or nonprofit sector) are usually "non-exclusive" assets. For instance, machinery owned by a private manufacturing firm is an exclusive asset and infrastructure owned by government is a non-exclusive asset.

However, publicly owned assets where the government or non-profit receives all services associated with an asset are, in our view, exclusive assets. For example, the capital services of office equipment owned by government and used by government employees accrue exclusively to government (although government output is of course for wider benefit). Similarly, the capital services of a military base that is protected by a barbed wire fence and guard towers (exclusive, albeit providing non-exclusive defense services). Conversely, some

privately-owned assets are non-exclusive. For example, infrastructure assets owned by regulated private corporations are non-exclusive assets, since households and other businesses benefit from (indeed, depend upon) the capital services of the infrastructure assets.

In truth, this dimension is probably more of a spectrum than a truly dichotomous dimension, though we treat is a dichotomy to make progress. Some examples of some assets that are non-exclusive but only in one regard are: a unfenced residential backyard in which some but not other neighbors have an easement that allows them to walk through at will; a piece of land that is fenced off but encumbered with an easement which allows a utility-providing business (e.g. water supply business) to run pipes through the land and access those pipes whenever the business wants; and culturally sensitive assets like monuments or collectibles, which can be subject to terms like a requirement to allow researchers to study the asset periodically. Of particular importance is non-exclusivity (social ownership) of intellectual property. The exclusive value of intellectual property is subject to the terms under which the property owner is granted sole rights to the property, which may be limited temporally or subject to pre-emptive innovation of entrants. Another important example is human capital, that can be subject to terms such as a marriage contract or a child support order. More generally, contracts and laws place limits on the value of property that may separate it from its unencumbered value.

4.5. Fixed or non-fixed

This dimension follows standard national accounts treatment. SNA defines “fixed assets” as assets which are used “continuously or repeatedly in production”. Gross fixed capital formation (GFCF) is the national accounts term for capital investment, with the “fixed” relating as above to investment in fixed assets. The broader concept of gross capital formation (GCF) includes GFCF plus acquisition less disposal of valuables and changes in inventories. Valuables and inventories are not fixed assets, since they are not used continuously or repeatedly in production. Valuables are not used in production – they are a store of wealth only. Most valuables are tangible items like gold or gemstones – but cryptocurrency can be seen as a new type of intangible valuable. Inventories are not used continuously or repeatedly – they are held until such a time as they used once, which could be as a raw material in production or as a final good sold to a final user.

The exact same asset can be fixed in one context and non-fixed in another context. For example, a dairy cow is a fixed asset while she is milked daily – but a non-fixed asset (a work-in-progress inventory) when she is slaughtered to produce meat once. More generally, produced capital assets often start out as inventory that is held for sale, become fixed assets which are used in production, and then end up as inventory which is set aside for scrap. Measured GFCF is positive when an inventory asset is purchased for use in production and negative when an asset used in production is sold for scrap (SNA 2008, section 14.106), but GCF is not affected by simply reclassifying an asset from fixed to non-fixed.

SNA 2008 focuses on market production processes, and therefore its fixed vs. non-fixed discussion only applies to assets used by units within the SNA 2008 production boundary. But the same general ideas can apply to assets used by households. For example, a ceramic cup is a fixed asset[13] because it is generally washed and reused for years. But a paper cup is a

[13] SNA 2008 allows cheap items like a ceramic cup to be classified as intermediate inputs (United Nations 2008, section 6.225). This allowance is made for measurement simplicity rather than conceptual reasons.

non-fixed asset if held in inventory for a time, because it is generally only used once and then thrown out.

Non-fixed assets are generally produced, standardized and exclusive. Because of those other characteristics, non-fixed assets are typically easy to value. For example, the value of a gold bar (valuable) can be readily calculated from its weight, purity, and the London exchange price of gold. Or the value of eggs in a grocery store cooler (inventory) can be readily calculated from their wholesale cost and similar information. Finally, newer non-fixed assets like cryptocurrency (valuable) are continually sold in extremely public markets and therefore have easy to observe prices. While it is theoretically possible for a non-fixed asset to be either non-produced, non-standardized, or non-exclusive, there are relatively few such examples and so neither the discussion in this paper nor the matrix of capital dimensions in section 6 will include a breakdown of non-fixed assets by the other dimensions.

5. Types of capital

This list of dimensions for capital is intended to assist us in setting forth some principles of measurement for capital that go beyond valuing a capital asset as the sum of past investment depreciated over time (i.e. the perpetual inventory method). In this section we use a series of illustrative examples to explore the three capital valuation measures introduced in section 3, framed by the dimensions described in section 4. Table 1 summarizes the dimensions for each example capital.

Naturally not all dimensions or combinations of dimensions are equally likely. Indeed, some combinations are very rare or unlikely (at least, in our current society) – we summarize this in Table 2. We do not discuss every conceivable type of capital.

Trucks
Trucks are tangible, produced, standardized, exclusive, and fixed. This is an archetype for business equipment, and so many other types of capital could be viewed in the same way. A new truck has a current reproduction cost. Used trucks – the majority of the trucks we must value – have a value that is likely to be related to current reproduction cost less wear and tear. In addition, because they are (relatively) standardized, current transactions are very useful in approximating the value of a particular used truck. As it is owned exclusively, its discounted future return may be calculable. Its original reproduction cost, depreciated to the present day, is also a plausible means of valuation. Thus, this sort of capital is relatively easy to value.[14]

Inventory of packaged food
This is tangible, produced, standardized, exclusive, and non-fixed. When new, its value is its reproduction cost. However, older food often has a lower value than its production cost. For example, the production cost for fresh bread and stale bread is similar – but fresh bread has a much greater market value. Thus, its purchase cost is likely the best measurement method. To be clear, the purchase cost often includes not only the payment to the seller, but also acquisition costs like driving to the store. In other words, the value of food items in a household pantry is likely larger than the value of the same food items in a grocery store. By definition of being non-fixed, it cannot be valued by discounted future returns.

[14] In fact, there are websites which automatically value trucks based on known characteristics like mileage.

Original artwork
For example, a painting in a gallery which sells artwork to the public. It is tangible, produced, non-standardized, exclusive, and non-fixed. As a non-fixed item, the painting does not have a stream of returns whose discounted future value can be calculated. As a non-standardized item, it does not have a reproduction cost that can be measured. Thus, its current value in transaction is the sole means of current valuation or perhaps the current price of similar art works, that is, its appraisal value. Its original production cost or its first transaction price is unlikely to be a good basis for its current valuation but those are conceivable valuations in the absence of others. Important artwork in a museum may be non-exclusive (i.e. have social claims upon it) – the Louvre is not free to dispose of the Mona Lisa, for example.

Public monuments
A public monument is tangible, produced, non-standardized, non-exclusive, and fixed. The comments on original artwork apply, except that there are unlikely to be even comparable transactions values available. Original production cost is a conceivable valuation for some types of monuments. However, unlike most assets which depreciate due to physical deterioration and obsolescence, some public monuments could increase in value (at least, from a social perspective) as they age and take on greater status. Thus, original production cost less depreciation should be evaluated carefully, and may undervalue this sort of asset. The stream of services received by the public might be a means of valuation (based on survey evidence of, e.g., park attendees).

Cryptocurrency
Cryptocurrency is intangible, produced, standardized, exclusive, and non-fixed. It has no stream of returns, although it has a use as source of liquidity. It has a current transaction price that values it accurately.

Protected software original
This is intangible, produced, non-standardized, exclusive, and fixed. Own-account software which is used to produce copies may provide a stream of revenue – in the form of one-time purchases of copies or monthly subscription fees for access to copies – which can be valued using the discounted future value of benefits method. But own-account software which is used to produce in-house services is unlikely to have observable services and therefore the discounted future value of benefits method is difficult in practice. Own-account software does have an initial cost of production, which is the method typically used to value investment in own-account software in the national accounts. But the *re*-production cost is unmeasurable given that it is non-standardized, so unlikely a good guide to the value ex-post. Valuation by original production cost less depreciation is challenging given the difficulty measuring both production costs for own-account assets and depreciation for intangibles (which cannot physically deteriorate). Furthermore, even if the calculated values are reasonable across all software assets in each period, they are still unlikely to be accurate for individual assets.

Software copies sold to business user
Purchased software copies (CD or digital download) are intangible, produced, standardized, exclusive, and fixed. They may be valued from their one-time purchase price, if purchased outright, or from the purchase price inferred from the monthly subscription fees under which they are used. Although they are intangible, they are still straightforward to value since they are standardized.

Opensource software copy
Opensource software copies, such as Apache or R, are intangible, produced, standardized, non-exclusive, and fixed.[15] The capital services provided by opensource software can be very valuable to users, but they are generally non-exclusive since the benefits accrue to non-owners.[16] It may be possible to value the services provided by opensource software by surveying users on their expended benefits or willingness to pay..

New idea still under patent
A patented idea, such as a pharmaceutical drug, is intangible, produced, non-standardized, exclusive, and fixed. Its current market price – the value of the drug patent– might be ascertained if the patent were to be sold alone, though this is unlikely in practice. Its current market price would also be reflected in the stock market or private equity value of the owning firm. Based on current sales and expected future prices and sales, the discounted future return may be calculable. Research and development expenses are often reported in tax filings or corporate reports, so production costs are often observable. However, the research and development cost of the specific drug is unlikely to be a good estimate of the value of the drug, because these investments are highly risky with a skewed, long-tail distribution. However, it is possible that the value of all pharmaceutical drugs may approximate their total cost of research and development. It is arguably not the intangible nature of the asset that makes valuation difficult, but the non-standardized nature.

Older idea after patent expiration
This is intangible, produced, non-standardized, non-exclusive, and fixed. The idea may be used without a license by any party. The exclusive value of the idea is zero because the generic version of the drug can be sold for a substantially lower price than it was pre-patent expiration. However, the non-exclusive value of the idea is higher than ever, if we consider this to be the consumer surplus arising from the intangible asset. Thus, the consumer surplus from the idea provides a stream of non-exclusive returns that may be valued through surveys or the like. The production cost of the idea is another means to value the idea. However, the exclusive depreciation rate on the idea is not the non-exclusive depreciation rate. This asset is challenging to value, largely due to its non-exclusive capital services and because it is freely available. Surveys of valuation are useful here to estimate services, which might then be capitalized.

Knowledge-based human capital
This is intangible, produced, non-standardized, exclusive, and fixed – the same combination as an idea under patent. We view knowledge-based human capital as being produced through education and training, though it may interact with non-produced human characteristics in meaningful ways. Like for patented ideas and R&D, production costs of knowledge-based human capital are likely unsuitable measures at the individual level, though if well calculated may be adequate at an aggregate level. Although the human brain is of course tangible, we view human capital as intangible in a more practical sense. The benefit of the knowledge accrues only to the owner (the human in question) through higher wages if used in the

[15] Amateur software production is likely considered a household service by SNA 2008 (section 6.28), and therefore opensource software which is produced by amateurs would likely be considered a consumer durable rather than a produced fixed asset. This paper extends the production boundary to include household production.
[16] Developers of opensource software sometimes get exclusive benefits as well. For example, an opensource demo version could be a marketing tool that increases purchases of paid software with more features. However, since they aren't the exclusive beneficiary of the capital services, the asset is still non-exclusive, and we cannot value the asset from the exclusive benefits alone.

economy, and the asset can thus be valued by net present value of future benefits (income), which is indeed the standard method. We can set aside the obvious issue with valuation by purchase price.

Petroleum reserves
A petroleum reserve is tangible, non-produced, non-standardized, exclusive, and fixed. Its value is perhaps best constructed from the sale value of the oil in the oil reserve less its cost of extraction: the discounted future stream of capital services. As it is non-produced, it cannot be valued by production or re-production costs. However, one might use production costs for a renewable substitute, such as biodiesel, to proxy for the value of non-produced petroleum reserves. Transaction value is a legitimate valuation method, though unlikely to occur in practice.

Oil exploration
This is intangible, produced, non-standardized, exclusive, and fixed. With free entry, the cost of production should be equal to the expected value of the exclusive returns to the research. However, natural resource owners generally have a secure monopoly on the usage of their property, so free entry is unlikely to hold, and the cost of production may understate the true value. Furthermore, it may be hard to pin down all the components of the cost of production, as is true of many intangible assets since information builds on past research.

Radio spectra rights
This is intangible, non-produced, non-standardized, exclusive, and fixed. Its original value is the price of purchase of the spectra rights, if that has occurred. It is likely that the spectra rights provide returns to the owner (telecommunications companies, for instance) whose discounted value may be calculated. It is also possible that the spectra rights can be resold, or the value inferred from similar spectra rights that are sold. Clearly no production or re-production costs are possible. Note, the costs of ownership transfer of the spectra rights (e.g. the costs of running an auction) is also recorded as fixed capital formation in the national accounts – they can be valued by production costs.

Uncultivated forest
A natural forest composed of old growth trees is tangible, non-produced, non-standardized, non-exclusive, and fixed. Its exclusive market value might be observable if market transactions involving natural forests are common in a particular region, though there will be no perfect comparator. Similarly, its exclusive market value could be calculated from the discounted future value of rents if the forest owner sells output like hunting rights or hiking trail access. However, this exclusive value will not include the non-exclusive value associated with natural services like carbon sequestration or biodiversity. The benefits of natural forests cannot be entirely exclusive since there is no way to exclusively capture the environmental benefits. Thus, they have both exclusive values and non-exclusive values, and the classification probably depends on which value is larger and whether the forest is administered by a profit-maximizer or not. Clearly no production or re-production costs are possible.

Cultivated forest
An exclusive forest cultivated for wood production is tangible, produced, non-standardized, non-exclusive, and fixed. The fact that the forest was cultivated means that the owner receives sufficient exclusive benefits to cover the cultivation cost – but there are still non-exclusive benefits associated with its positive externalities. Under current national accounting

guidelines, however, it could be considered exclusive since the positive externality benefits would not be included in the production boundary. Its exclusive value may be inferred from its stream of revenues, from sales of similar assets, and perhaps from its cost of acquisition. While the cultivated growth is produced, it is effectively bundled with non-produced assets including land, making it hard to value accurately using production costs.

Land
Land is tangible, non-produced, exclusive, and fixed. Land is defined both by its qualities, such as altitude, but also by geographic relationship to other land, whether these be neighborhoods in a city or to oceans, lakes, and rivers. Some land may be relatively homogeneous and therefore almost standardized. But most land is very heterogenous and therefore non-standardized. Thus, rather than considering land as a whole, different types of land might be better viewed as capital types – for example, agricultural land, land beneath dwellings, land with public rights of way, and so forth. Land is often sold together with produced structures that have a positive value and produced pollution that has a negative value, and the valuation of land is made more complex by this bundling.

Atmosphere
The atmosphere for a given territory is tangible, non-produced, non-standardized, non-exclusive, and fixed. It provides services that are evidently of great, possibly infinite, value. Degradation of the atmosphere and its services are one of the great challenges of our times. Yet valuation is very difficult as evidenced by its not being included in the SEEA Central Framework. It is characteristically affected by activities throughout the globe. While clearly immensely valuable, it may not be practicable to value the atmosphere.

6. Capital types and their measurement implications

In this section we set up a nested matrix that allows us to set up a four-by-four matrix of capital dimensions, as a visual way to approach the types. We nest the dimensions of standardization and production along one axis, and the dimensions of tangibility and exclusivity along the other, in Tables 2 and 3. Because examples of non-fixed assets which aren't produced, standardized, and exclusive are so few, the matrix of capital types in Tables 2 and 3 do not include the fixed versus non-fixed dimension. We refer to combinations of dimensions as capital 'types'.

There is an important connection between intangibility and exclusivity of capital services (i.e. 'social' ownership). Intangibles are typically easily replicated at close to no cost, so under exclusive ownership the piece of capital requires either secrecy or government protection for the capital services to accrue exclusively to the owner. Secrecy is hard to maintain for long, so intangibles which are protected by secrecy eventually become non-exclusively owned eventually. Similarly, government protection generally requires that the intangible be made public, in exchange for a temporary monopoly ownership. After the period of monopoly lapses, the intangible becomes free to use and the capital services are no longer exclusive. This relationship is made visible by nesting the two.

Produced and standardized dimensions also naturally fit together, since standardization arises from the human production process. Hence, all standardized assets are produced. As noted in section 5, some non-produced assets are close to standardized, such as near identical land parcels. In Tables 2 and 3 we do not include any examples of assets which are non-produced and standardized.

Table 1 – Capital examples and their allocated dimensions

Asset example	Tangible vs. Intangible	Produced vs. Non-produced	Standardized vs. Non-standardized	Exclusive vs Non-Exclusive	Fixed vs. Non-fixed
Truck	Tangible	Produced	Standardized	Exclusive	Fixed
Inventory of packaged food	Tangible	Produced	Standardized	Exclusive	Non-fixed
Original artwork	Tangible	Produced	Non-standardized	Exclusive*	Non-fixed
Public monuments	Tangible	Produced	Non-standardized	Non-exclusive	Fixed
Cryptocurrency	Intangible	Produced	Standardized	Exclusive	Non-fixed
Protected software original	Intangible	Produced	Non-standardized	Exclusive	Fixed
Software copy sold to user	Intangible	Produced	Standardized	Exclusive	Fixed
Opensource software copy	Intangible	Produced	Standardized	Non-exclusive	Fixed
New idea still under patent	Intangible	Produced	Non-standardized	Exclusive	Fixed
Older idea after patent expiration	Intangible	Produced	Non-standardized	Non-exclusive	Fixed
Knowledge-based human capital	Intangible	Produced	Non-standardized	Exclusive	Fixed
Petroleum reserves	Tangible	Non-produced	Non-standardized	Exclusive*	Fixed
Oil exploration	Intangible	Produced	Non-standardized	Exclusive	Fixed
Radio spectra rights	Intangible	Non-produced	Non-standardized	Exclusive	Fixed
Uncultivated forest	Tangible	Non-produced	Non-standardized	Non-exclusive	Fixed
Cultivated forest	Tangible	Produced	Non-standardized	Non-exclusive*	Fixed
Land	Tangible	Non-produced	Non-standardized*	Exclusive	Fixed
Atmosphere	Tangible	Non-produced	Non-standardized	Non-exclusive	Fixed

Note: Dimensions with an asterisk are not clear cut – see text for discussion.

Table 2 includes an example of each applicable capital type (as defined by the cross-classification of the four dimensions) – many of these are as detailed in section 4, though some are new. It also includes an indication of prevalence of the type, based on our judgement. Prevalence here is not an indication of value, but rather a rough guide to the number of distinct assets which fall within the type. The prevalence indicator is intended to

be a roughly five-point scale: very common, common, uncommon, rare, very rare. This is intended to be indicative only.

Table 2 – Matrix showing nested cross-tabulation of capital dimensions with examples and indication of prevalence

		Produced		Non-produced	
		Standardized	**Non-standardized**	**Standardized**	**Non-standardized**
Tangible	**Exclusive**	Truck *Very common*	Artwork original *Common*	Not Applicable	Petroleum reserves *Uncommon*
	Non-exclusive	Park bench *Common*	Public memorial *Uncommon*	Not Applicable	Uncultivated forest *Uncommon*
Intangible	**Exclusive**	Purchased software *Common*	Software Original *Common*	Not Applicable	Radio spectra rights *Rare*
	Non-exclusive	Opensource software copy *Uncommon*	Opensource software original *Uncommon*	Not Applicable	Outer space *Very rare*

Note: We judge the non-produced and standardized dimensions are incompatible, since standardization arises from the human production process. As such, there are no entries in this column. The prevalence indicator is intended to be a roughly five-point scale: very common, common, uncommon, rare, very rare. This is intended to be indicative only.

Table 3 – Matrix showing nested cross-tabulation of capital dimensions with indication of applicable valuation methods and measurement difficulty

		Produced		Non-produced	
		Standardized	**Non-standardized**	**Standardized**	**Non-standardized**
Tangible	**Exclusive**	Purchase, PIM, NPV *Less Difficult*	Purchase*, PIM, NPV *Difficult*	Not Applicable	Purchase*, NPV *Difficult*
	Non-exclusive	Purchase, PIM, NPV *Difficult*	Purchase*, PIM*, NPV* *Difficult*	Not Applicable	Purchase*, NPV* *Very Difficult*
Intangible	**Exclusive**	Purchase, PIM, NPV *Less Difficult*	Purchase*, PIM*, NPV *Difficult*	Not Applicable	Purchase*, NPV *Difficult*
	Non-exclusive	Purchase*, PIM*, NPV* *Difficult*	Purchase*, PIM*, NPV* *Very Difficult*	Not Applicable	Purchase*, NPV* *Very Difficult*

Note: We judge the non-produced and standardized dimensions are incompatible, since standardization arises from the human production process. As such, there are no entries in this column. “Purchase” refers to valuation by purchase price in a market transaction; “PIM” is short for perpetual inventory method and refers to valuation by cumulated value of past investments, less depreciation; “NPV” is short for net present value and refer to valuation by discounted current value of future benefit flows. Valuation methods with an asterisk are deemed

feasible but difficult in practice in some way. The measurement difficulty scale is intended to be a roughly three-point scale: Less Difficult, Difficult, Very Difficult. This is intended to be indicative only.

Table 3 follows the structure of Table 2 but instead of providing examples, it provides two pieces of information: 1) which of the three valuation methods are likely to be feasible, and 2) an assessment of the measurement difficulty associated with the type. For brevity, the three valuation methods are denoted as follows: “Purchase”, “PIM”, “NPV”. Measurement methods are noted if they are conceptually feasible, though this does not mean they will be straightforward in all cases. We indicate by an asterisk those measurement methods which, though feasible, will likely be difficult in one way or another. The measurement difficulty scale is intended to be a roughly three-point scale: Less Difficult, Difficult, Very Difficult. This is intended to be indicative only.

While the previous sections have presented the classification and valuation of capital as discrete tasks, these tasks are less clear-cut in practice. We briefly set out some issues with applying our framework to the real-world.

Bundling
Capital measurement is even harder if national accountants want to measure each category of capital separately. Many market transactions bundle components from different asset categories with different characteristics together. The distinction of different categories is material since each may have a different associated price index and age-efficiency profile, such that measures of the capital stock are affected by the classification into these different categories. There is also clearly interest in understanding the value and economic contribution of assets of different categories, and so failing to disentangle these categories risks over- or under-stating the value of some assets relative to others. Disentangling the types can be particularly important in cases where national accounting rules require one category of investment to be included in GDP but another category of investment to be excluded from GDP. A very important case of these requirements is real estate, where land is handled very differently to buildings and structures.

Variation over time
Patent expiration plays interesting roles in the valuation of a patent. The total value of a prescription drug idea does not decrease and may well increase immediately after its patent expires. But the exclusive value of that prescription drug idea likely decreases, perhaps very sharply. Of course, the exclusive value of a prescription drug idea does not completely disappear when it goes off patent. The original patent owner still has other intangible assets like a trademark and customer data which may be very valuable. An interesting case is that the original holder of a patent may take advantage of reputational issues to move a drug to non-prescription status, where the brand and manufacturing ability of the patent holder may confer an advantage relative to simply permitting the drug to go off-patent.

Variation over place
Different countries with different laws, rules and norms may lead to different measurement methods and/or valuations for ostensibly the same asset in different places. One example is the exclusive component in important original artworks – similar types of artworks may be exclusively owned in one community, and so able to be valued based on its transaction price, but non-exclusively owned in another community and thus very difficult to value.

7. Conclusion

We have begun a survey of types of assets. This appears a promising way to organize our thinking on the valuation of capital. We have introduced five dimensions of capital in section 4 and linked these to a long list of capital types in section 5. Section 6 presented a cross-classification of these dimensions and linked the valuation methods to the resultant capital types. What can we learn from this?

First, standardization often makes measurement easier. Standardized capital, which is usually produced, can usually be valued by all three valuation methods: transaction price; re-production costs less depreciation (for produced standardized assets); and present value of future benefits. It is also possible to infer a price based on a very similar (standardized) product. In practice, national accountants typically pick whichever valuation method is easiest to implement.

Second, items that are non-exclusively owned cannot be valued based on their market price. The basic problem is simple. Even when market transactions are available, they only reveal the exclusive value of an asset rather than the non-exclusive value. For example, the exclusive value for a very beautiful building which is protected from renovation by a landmark designation may be lower than the exclusive value for an ugly building which can be renovated freely. In these circumstances, economists must use either re-production cost (if possible) or the discounted value of future non-exclusive revenues to value capital.

Finally, non-produced assets cannot be valued by their production cost. The complete elimination of one valuation method is not so serious for non-produced assets which have an easy to observe market value. But many non-produced assets are rarely transacted. Furthermore, most non-produced assets are so non-standardized that the few transactions which do occur yield little useful information about the market value of other non-produced assets. Similarly, non-produced assets are often non-exclusively owned and therefore do not have easy to observe revenues. As a result, values for important natural resources like the atmosphere or biodiversity cannot be measured reliably.

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Appendix – Extended list of examples of capital assets

Produced Capital:

Buildings and structures other than infrastructure (A non-living produced item which is immobile and is used in production repeatedly by its owner)

a) Dwellings: residential homes
b) Buildings other than dwellings: manufacturing plants; retail stores; offices; schools; hospitals, etc.
c) Nonbuilding structures other than infrastructure: artificial beaches; protective walls; etc.
d) Non-dwelling consumer structures: Backyard playhouses

Infrastructure (A non-living produced item which is immobile and is used in production repeatedly by others than its owner)

a) Infrastructure owned by government
b) Infrastructure owned by the private sector

Infrastructure may be non-exclusively owned.
Some infrastructures may be irreplicable (e.g. impossible to rebuild road network).

Equipment (A non-living produced item which is mobile and is used in production repeatedly by its owner)

a) Transport equipment: vehicles; aircraft; boats
b) Computer hardware: laptops, desktops, servers
c) Telecommunications equipment: non-computer audio and video equipment;
d) Other machinery and equipment: measurement devices; large tools (washing machines, lawnmowers, etc.); small tools (dishes, cooking knives, personal care devices, etc.); furniture; carpets and window covers; musical instruments; medical devices;
e) Weapons systems: single-use and dual-use military equipment;
f) Consumer durables: clothing and footwear.
g) Physical embodiments of intangible capital: books, CDs

Comments:

Physical embodiments of intangible capital are included in equipment at their production cost rather than their sales cost. For example, the production cost of a printed book is about 60% of its sales price (Soloveichik 2013) and therefore a book purchase is 60% tangible capital investment and 40% intangible capital investment.

Physical items which are given “free” by marketers or salespeople are valued based on their production cost. For example, a “free” tote bag which is handed out at a convention might be valued based on the normal retail price of tote bags.

Physical items which are listed as “free” by the seller of a bundle are valued based on their production cost rather than their sales cost. For example, a “free” cellphone which is bundled

with a two-year service contract would be valued based on its normal retail price (Aizcorbe, Byrne, and Sichel 2019).

Equipment which is used by a business or government is considered capital – but the exact same item which is used by a household is considered a consumer durable.

Cultivated biological resources (A living produced item which is used in production repeatedly)

a) Cultivated long-lived animals: Dairy cows; breeding livestock; racehorses; farm horses; working dogs or cats (sheepdogs or barn cats which catch mice); zoo animals; semi-wild protected species (bison in Yellowstone).
b) Cultivated long-lived plants: Farm orchards; farm pastures; forest used for hunting or recreation; landscaping trees; lawns; indoor plants owned by businesses or governments.
c) Pets and long-lived consumer plants: nonworking dogs and cats; other pets; horses ridden for pleasure; indoor plants owned by consumers.

Notes:

Cultivated assets which are used by a business or government are considered capital – but the exact same items which are used by a household are considered a consumer durable.

Valuables (A non-living produced item which is held as a store of value)

a) Rare commodities: Gold (monetary and non-monetary); other precious metals; gemstones.
b) Culturally important items: Fine artwork; collectibles; cultural artifacts; monuments.

Notes:

SNA 2008 defines these valuables as capital whether they're owned by businesses, governments or household. In practice, measured GDP and productivity don't change if they're tracked as consumer durables instead.

Software (A set of instructions to be carried out automatically by machine)

a) Computer software originals (own-account, custom, and pre-packaged).
b) Copies of computer software
c) Noncomputer software (heating and cooling cycle for building, punch-tape machine tool; punch-card weaving designs); etc.

Notes:

Software which is used by a business or government is considered capital – but the exact same item which is used by a household is considered a consumer durable.

Exploration and evaluation (Facts about a known natural resource)

a) Mineral exploration and evaluation
b) Non-mineral exploration and evaluation - Exploration which discovers specific facts about individual natural resources other than minerals is not treated as capital in the national accounts (Soloveichik 2022).
c) Surveys for immediate construction. BEA currently tracks this intangible asset as a component of structures.
d) Surveys not for immediate construction. BEA does not currently track this asset.

R&D (Discovered facts about the world)

a) Facts discovered as the result of deliberate experimentation (Frascati-defined R&D) protected under patent or other intellectual property laws.
b) Facts discovered as the result of deliberate experimentation (Frascati-defined R&D) not protected under patent or other intellectual property laws.
c) Physical or biological facts discovered serendipitously during ordinary activities. This is often known as learning-by-doing. For example, a firm might accidentally add the wrong ingredient to a chemical vat and discover a useful product. BEA doesn't currently track this intangible capital asset as R&D.
d) Characteristics of the universe discovered through logic. For example, a mathematical proof or a grand unified theory of physics. I'm not sure if BEA tracks this intangible asset as R&D.

Notes:

The vast majority of R&D is capital that is used for business and government production. But R&D can be a consumer durable if it is created by amateurs and either used by those amateurs themselves or shared without cost. For example, many diet and exercise routines are consumer durables.

Branding (Information emotional ties about consumers and consumer tastes)

a) Market research
b) Brand loyalty: past product experiences by an individual or their social network.

Entertainment, literary and artistic originals (Original creative products)

a) Original theatrical movies, long-lived television programs, books, music, and miscellaneous artwork (including commercials re-used over multiple years), protected under copyright or other intellectual property rights.
b) Original theatrical movies, long-lived television programs, books, music, and miscellaneous artwork (including commercials re-used over multiple years), not protected under copyright or other intellectual property rights.

Design (A set of instructions to be carried out by humans relating to individual products and processes)

a) Product design: Graphic design; company slogans
b) Process design: technical manuals; employee training videos;

c) Architectural designs. BEA currently tracks this intangible asset as a component of structures.

Organizational capital (A set of instructions to be carried out by humans relating to an organization a as whole)

a) Supply chain networks
b) Organizations structures
c) Contracts are included in this category based on their production cost. For example, if a lawyer paid $200 per hour spends 10 hours writing a contract, then it's worth $2,000. To be clear, this production costs includes both out-of-pocket costs for purchased services and imputed costs for own-account services.
d) Filing systems; technical jargon (whether specific to one company or shared within an industry); safety procedures; work schedules; etc.
e) Information and emotional ties held by employees or potential suppliers. For example, a CEO might build loyalty by chatting with employees and listening to their concerns and ideas.

Data (Recorded information not elsewhere classified)

a) Digitalized data
b) Non-digitalized data
c) Personal photographs; personal letters; social media posts; customer reviews; fanfiction; and other artwork owned by individuals are consumer durables.

Knowledge

a) Information held by an individual: topics taught in school; topics taught by parents, other family, or friends; topics learned from books out of school; topics learned from life experience; etc.
b) Information held by others about an individual: Credit score; school transcript; professional certification; social media profile and comments; gossip.

Physical Attributes

a) Health variables: age; weight; muscle mass; immune system function; etc.
b) Appearance variables: hair length; scars; plastic surgery; tattoos; etc.
c) Location: Individual living close to job opportunities, marriage partners, household production opportunities, or other desirable locations have more human capital.

Certification

a) Legal permission to engage in specific activities such as driving, voting, working in licensed occupations, etc.
b) Legal permission to live, work, marry, or engage in household production at a certain location.
c) Citizenship in a particular country or trip.
d) Recognized religious affiliation. To be clear, this is not a measure of an individual's beliefs – but rather of the religion that they are recognized as belonging to.

Social Capital

Laws and customs/Disease control/Social networks

Natural Resources (Both Long-Lived and Short-Lived)

Territory

a) Primary surface usage: right to cultivate land; right to build a house on land; right to invite human guests onto land; right to stay on territory for whatever reason you want whenever you want; right to stay on territory for specific reasons at a specific time.
b) Animal usage: right to have pets on land; right to have farm animals; right for wild animals to come naturally onto a territory; right to artificially place wild animals onto a territory; etc.
c) Mineral usage: right to explore for minerals. If minerals are found, the property owner is required to allow mining in return for a specific royalty payment.
d) Water usage: right to use water that naturally flows through a territory. In wetter climates, property owners are generally allowed to use as much water as they like. But in drier climates, there are often strict limits on usage.
e) Air usage: right to use air that naturally flows through territory. For example, people in warm climates might not want neighbors blocking breezes.
f) Hunting/gathering usage: right to hunt deer; gather truffles; or otherwise benefit from wild or semi-wild living organisms.
g) Surface travel usage: right to cross territory when needed; right to visit property that is stored inside of territory; etc.
h) Air travel usage: right to fly airplanes overhead; right to orbit satellites overhead; right for birds to migrate overhead; etc.
i) Underground travel usage: right to lay pipes or wires slightly underground; right to dig subways or other large structures way underground; etc.
j) Communication usage: right to make audible noises; right to transmit electromagnetic waves through territory; right to signal otherwise (vibration? smoke?).
k) Sunlight/view usage: right to see sky and get natural light; right to see beautiful natural landscapes like oceans or mountains; right to see attractive buildings or landscaping created by neighbors; right to see neighbors on their territory; right to build fences which block view into territory; etc.
l) Pollution usage: right to dump solid waste on own land; right to dump liquid waste on water that flows through land; right to emit airborne waste; right to emit light from territory; right to emit smells from territory; right to bring ritual contamination to land; right to launch rockets into space; etc.
m) Option to change usage.

Characteristics of territory

a) Physical characteristics: elevation; underlying rock type; terrain ruggedness; long-term chemical pollution; etc.
b) Biological characteristics: wild animals naturally living in territory; wild plants naturally growing in territory; long-term microorganism population; etc.
c) Climate characteristics: expected temperatures; expected rainfall; expected wind; expected sunlight; expected ground disturbances. To be clear, climate describes

the full distribution rather than just summaries like mean or standard deviation. For example, a territory which has 12 inches of rainfall in a normal year and 1212 inches once a century is very different from a territory which has a normal distribution of rainfall ranging from 12 to 36 inches per year.

d) Human characteristics: nice neighbors; loud parties; crime; exciting restaurants; desirable friends for children; culturally compatible neighbors; etc.

Inventory

Produced physical items

a) Short-lived items used up in production: wood and nails used to build structures; seeds used to plant crops; bolts used to assemble cars in factory; corn used to feed cattle; ingredients used to cook meal; grapes used to make wine; cement used to make concrete; etc.
b) Long-lived items used up in production (embedded capital): elevators installed in structures; stereos installed in cars; gravel mixed with wet cement; etc.
c) Work-in-progress inventory: half-built structures; unharvested crops; half-assembled cars in the factory; cattle on feedlot; meals that are still being cooked; wine that is being aged; concrete that is curing; etc.
d) Finished inventory (owned by creator): buildings that are waiting for a buyer; grain in silos after harvest; fully assembled cars in the warehouse; whole carcasses at the slaughterhouse; cooked meals in the restaurant freezer; wine in bottles; etc.
e) Ready-to-sell inventory (owned by wholesaler or retailer): flour at the grocery store; fully assembled cars at the dealer; raw steaks at the grocery store; frozen meals at the grocery store; wine at the liquor store; etc.
f) Household inventory (owned by consumers): flour in the pantry; cook steaks on the dining room table; reheated meals in the oven; open bottles on the dining room table; etc.

Produced intangible items

a) Short-lived items used up in production: interview quotes used to make news report; agendas for a meeting tomorrow; etc.
b) Long-lived items used up in production (embedded capital): pre-packaged software that is added to computer while it being assembled; sequel rights that are used to make a new movie; drug patent which is used to make a follow-up drug; etc.
c) Work-in-progress inventory: half-written books; unprocessed footage that will be assembled into a news report; notes from a meeting that will be organized into a memo soon; receipts that need to be entered into the system before a bill can be calculated; lawyer notes that need to be turned into a document; etc.
d) Finished inventory: pre-taped reality shows; television commercials which are exciting at first but bore the public after a few weeks; bills for services that will be paid soon; legal documents for a case that will be filed soon; strategy recommendations for an election next month; etc.
e) Ready-to-sell inventories (owned by wholesaler or retailer): prepackaged video games on CD's; magazines on shelf; newspapers; etc.
f) Household inventory: prepackaged video games on CD's; short-lived apps downloaded on smartphone; magazines on cough; newspapers on breakfast table; etc.

Items produced by natural processes but controlled by humans

a) Desirable non-living items: water in a dam reservoir; soil on farmland; etc.
b) Undesirable non-living items: water in a basement; stones which rise to the surface of farmland; snow on sidewalks; toxic run-off with a short lifespan; etc.
c) Desirable living items: deer in the forest; fish in a lake; endangered species in a wildlife preserve; wildflowers in a prairie; etc.
d) Undesirable living items: ticks in a forest; mosquitos in a lake; lawn grass which needs mowing or weed eradication; mice in a house; germs in the soil