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COMMENTARY

Pluralistic discounting recognizing different capital contributions: An example estimating the net present value of global ecosystem services

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ABSTRACT

Discounting the future is essential to inform long-term decisions, but the future of humanity is being put in jeopardy by using the same discount rate for all capital types. Different types of capital assets (built, human, social, natural) have inherently different characteristics and contribute differently to the production of all goods and services. They will behave and depreciate differently and will thus require different discount rates and different approaches to discounting. Here, we estimate the net present value (NPV) of global ES recognizing that ecosystem services are the product of the interaction of the four different types of capital that each have different characteristics. We combine a range of different discount rates for each of the 4 types of capital according to their relative contributions to the production and value of each of 17 global ecosystem services. We estimate that the NPV of global ES ranges from \$5.7 to \$9.1 $\times$ 10^{15} (quadrillion 2011\$USD). For comparison, the NPV of global GDP estimated in the same way would be about \$2.9 to \$4.8 $\times$ 10^{15}. This more nuanced approach to discounting can improve information for long-term project appraisal and decision making and help build a more sustainable and desirable future.

1. Introduction

Making decisions about the consequences of development extending into the future is critical and ubiquitous. These choices are unavoidable at the individual, community, national, and global scales, yet they are fraught with uncertainty. We cannot predict the future with any degree of certainty, but we cannot avoid making decisions today that have uncertain future consequences.

One popular method to deal with these decisions is to compare expected costs and benefits over time, making intertemporal comparisons after first 'discounting' the future. The practical implications of discounting are that the further in the future the consequences of a change are, the less weight they are given in current decision-making. This has long been the standard method for economists to deal with future costs and benefits (Frederick et al., 2002) but it has also long been the subject of controversy (Parfit, 1983). Notably, it has been recognised that the discount rates associated with individual/private (market) investment decisions are likely to exceed social and environmental discount rates with consequent sub-optimal social and environmental outcomes (Baumgärtner et al., 2015; Marglin, 1963). The fact that individuals have different time preferences for similar goods/services, means that they "*provide no clue as to how to construct a social discount rate*" (Pope and Perry, 1989). Responses to questions about what is preferred for individual welfare/wellbeing, differ from responses to questions about preferences for social welfare/wellbeing (Arias-Arévalo et al., 2018). Altruism, care about future generations, and other prosocial behaviours (manifested in the non-independence of individual utility functions) make it impossible to derive social preferences through the simple aggregation of individual preferences (Grainger and Stoeckl, 2019; Howarth and Norgaard, 1990).

One of the most controversial applications of the standard approach to discounting the future is the one used by Nordhaus in his modelling of the future impacts of climate change (Nordhaus, 2010, 2017; Nordhaus and Boyer, 2000). Nordhaus used a constant discount rate in a function giving exponentially decreasing weight to consequences that occur further in the future. Nordhaus argued for modest policies to address climate change since, with his relatively higher discount rate, the projected damages in the future would be weighted less. Nicolas Stern, in his work on the economics of climate change (Stern, 2007), also used constant, exponentially decreasing weighting of the future, but with a

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smaller discount rate that gave much more weight to the future. This, in turn, led Stern to argue for much more aggressive policies to address climate change since the projected damages would be weighted more with his lower discount rate. The policy prescriptions varied tremendously with only small differences in the discount rate between the two studies, highlighting the importance of this process and the discount rate in decision-making.

Here, we first briefly review the standard approach to discounting and some variations that have been proposed along with the justification for discounting at all. We then discuss why different discount rates and approaches may be necessary to account for the different characteristics of different types of capital. We call this "pluralistic discounting". Finally, we develop an example using pluralistic discounting to assess the net present value of future global ecosystem services and GDP.

2. The standard approach to discounting

Discounting allows for the estimation of the "net present value" (NPV) of a stream of consequences into the future.

The general form for calculating the NPV is:

$$\mathrm{NPV} = \sum_{t=0}^{n} V_t W_t \tag{1}$$

Where:V_t = the value of the consequence at time t (this could be a positive (benefit) or a negative (cost)W_t = the weight used to discount the service at time tn = the number of time periods into the future.For standard exponential discounting, W_t is exponentially decreasing into the future at the discount rate, r.

$$W_t = \left(\frac{1}{1+r}\right)^t \tag{2}$$

n can be a set time in the future or it can be set to infinity

$$\mathrm{NPV} = \sum_{t=0}^{\infty} \frac{V_t}{(1+r)^t} \tag{3}$$

Note that for a positive discount rate, the value of $(1+r)^t$ is growing exponentially and consequences that occur far in the future soon approach zero and become insignificant. For example for a discount rate of 5%, the value of (1 + 0.05) at 100 time units (say years) in the future would be 131.5. and V_t would be less than 1/131th of its value at time 1. The NPV in this case ultimately converges as t goes to infinity.

If V_t is a constant stream of net benefits (or costs) into the indefinite future, Eq. (3) reduces to simply:

$$\mathrm{NPV} = \frac{V_t}{r} \tag{4}$$

For example, if the stream of benefits (V_t) is a constant \$100 per year into the indefinite future and the discount rate is 5%.

$$\mathrm{NPV} = \$100/0.05 = \$2000 \tag{5}$$

One can clearly see from this version that the higher the discount rate the lower the NPV and as the discount rate goes to 0% the NPV would be go to infinity.

For a 0% discount rate, Eq. (3) is more appropriate but one needs to set a time limit (n) on the summation.

After this quick review of the "standard" approach to discounting, using a constant discount rate applied to all aspects of the project resulting in exponentially decreasing value of future costs and benefits, we now explore some of the alternatives.

2.1. Non-constant discount rates

A constant discount rate (r) assumes 'exponential' discounting, however, 'hyperbolic', 'decreasing', 'logistic', 'intergenerational,' and other forms of discounting have also been proposed (Azar and Sterner, 1996; Newell and Pizer, 2003, 2004; Sumaila and Walters, 2005; Weitzman, 1998).

One general approach to discounting argues that discount rates themselves should not be constant but should decline over time. This is sometimes called time-dependent or variable discount rates, or in some cases 'hyperbolic' discounting. There are two lines of argument supporting this conclusion. The first, due to Weitzman (1998) and Newell and Pizer (2003) argues that discount rates themselves are uncertain and because of this, their average value should decline over time. As Newell and Pizer (2003, pp. 55) put it: "future rates decline in our model because of dynamic uncertainty about future events, not static disagreement over the correct rate, nor an underlying belief or preference for deterministic declines in the discount rate." A similar outcome for declining discount rates is obtained when there is uncertainty over changes in consumption, or where there are different groups of decision makers with differing rates of time preference (Gollier, 2018; Gollier and Weitzman, 2010). A second line of reasoning for declining rates is due to Azar and Sterner (1996), who decompose the discount rate into a "pure time preference" component and an "economic growth" component, a concept first introduced by Ramsey (1928). They argue that, in terms of social policy, the pure time preference component should be set to 0%. The economic growth component is then set equal to the overall rate of growth of the economy, with the assumption that in more rapidly growing economies, there will be more resources in the future and impact on welfare will be marginally less due to the assumption of decreasing marginal returns to income in a wealthier future society. If the economy is assumed to be growing at a constant rate into the indefinite future, this reduces to the standard approach to discounting, using the growth rate for 'r'. If, however, one assumes that there are fundamental limits to economic growth (Costanza et al., 2014a; Daly, 1996), or if one simply wishes to incorporate uncertainty and be more conservative about this assumption, one can also allow the assumed growth rate (and discount rate) to be flat or decline in the future, as Weitzman (1998) and Newell and Pizer (2004) recommend.

Finally, overlapping generational models and a technique called 'intergenerational discounting,' (Howarth and Norgaard, 1990; Sumaila and Walters, 2005), should be mentioned. This approach includes conventional exponential discounting for the current and future generation, but future generations can then be assigned separate discount rates that may differ from those assumed for the current generation. For the simplest case where the discount rates for current and future generations are the same, this reduces to the following formula to (Sumaila and Walters, 2005) (pp. 139):

$$W_t = d^t + \frac{d^* t^* d^{t-1}}{G} \tag{6}$$

Where:

$$d = \frac{1}{1+r} \tag{7}$$

G = the generation time in years (25 is often used here).

This method leads to significantly larger estimates of NPV than standard constant exponential discounting, especially at lower discount rates. At 1% the NPV's are 5 times as high, while at 3% they are more than double.

2.2. Justification for discounting

There are two popular rationales for discounting, one based on consumption, the other based on investment (Arrow and Kruz, 2013; Lind et al., 2013), as outlined below:

1) Consumption (C). Economists generally assume both

- rising consumption over time (C_t) – so that future generations are wealthier than existing generations ($C_{t+1} > C_t$)

  and

- diminishing marginal utility (U) from consumption $\left(\partial U/_{\partial C}\right)$, so that:

  $\partial U/_{\partial C_{t+1}} < \partial U/_{\partial C_t}$

  The value of additional consumption today will thus exceed the value of additional consumption tomorrow – hence the need to discount future consumption.

2) Investment. Economists generally assume a positive return on investments, so a dollar invested today, yields (or is 'worth') more than a dollar invested tomorrow. The corollary is that future investment is 'worth' less than current investment, again underscoring the need to discount future investment.

Under certain conditions (perfect information, perfect competition, etc.) the discount rate required to allow for declining values in consumption would match that required to appropriately capture declining values in investment.

It is not clear that the same discount rate should be applied to all costs and benefits – unless all are dependent upon a similar capital base which generates a similar flow of investment (or benefits) over time <u>or unless</u> all capitals generate a similar flow of investment (or benefits) over time.

2.3. Pluralistic discount rates and approaches

The idea that one can apply the same discount rate to all aspects of a complex project "…stems from the faulty assumption that the varied considerations that are relevant in intertemporal choices apply equally to different choices and thus that they can all be sensibly represented by a single discount rate" (Frederick et al., 2002) (pp. 352).

A few authors have argued that, in particular, the environmental costs and benefits of projects should be discounted differently than built infrastructure (Baumgärtner et al., 2015; Drupp, 2018; Hasselmann et al., 1997; Horowitz, 2002; Kubiszewski et al., 2013b; Kula and Evans, 2011; Plambeck et al., 1997; Price, 1993; Yang, 2003). For example, Kula and Evans (2011) note that "…the growth rate of income based parameters in the social time preference rate should not apply to environmental benefits of investment projects, if any, because these are in a different category of attributes as compared with conventional ones which are actually undermined by the economic growth" (pp. 180).

It is clear that the choice of discount rate, approach, and application make a huge difference to the results of benefit/cost analysis and other decisions about the future. For example, in a sensitivity analysis of Benefit/Cost Analysis (BCA) scenarios for dams on the Lower Mekong River, the results using constant 10%, 3%, and 1% exponential discount rates were compared along with using different discount rates for costs/benefits associated with natural and built capital to show the range of results that this change can produce (Kubiszewski et al., 2013b). As expected, while a 10% discount rate for both natural and built capital showed a positive NPV for the dam projects, a different and lower discount rate for natural capital flips this result to a strongly negative NPV.

So, when different capitals are required to create ecosystem services (ES), the associated benefit functions and thus discount rates will be complex. If the capitals that are required to produce different ES depreciate at different rates, then both their absolute and relative contribution to wellbeing over time must change. It is thus appropriate to discount each type of capital differently. We are not suggesting that individuals partition a single good/service according to the relative capital contributions, and discount each partition differently. We treat goods/services in their entirety (e.g. discounting all provisioning services, or all recreational services, at the same rate). But we recognize that ecosystem services are the *product* of the interaction of the four different types of capital (Costanza et al., 2014b). The services flows themselves are ephemeral and short-term, while the capital stocks that produce them go on into the future. Capital lasts, goods and services are consumed or utilized. It thus makes more sense to focus on the long-lasting capitals that produce the services in the future when discounting the future.The partitioning simply helps describe fundamental differences that underpin the production of different types of goods/services – which helps guide the selection of an appropriate range of discount rates for the capitals.

We are unaware of any research that has estimated production functions for all ES in a consistent and comparable manner. Actual production processes are complex, but we illustrate our argument using the simplest of examples: we assume there are only two capitals (built, K; and natural, N), only two different consumer goods (C_1 and C_2) that are each produced using K and N in different proportions ($k_{1)}$ k_2; $n_1 < n_2$), and a Cobb-Douglas production technology. Such production functions can be written as:

$$C_1 = K^{k_1} N^{n_1}$$

$$C_2 = K^{k_2} N^{n_2}$$

If K grows more rapidly than N, then with $k_1 > k_2$ and $n_1 < n_2$, C_1 will grow more rapidly than C_2. The rates of change in consumption opportunities, and thus in marginal utilities, will thus differ across goods, which justifies the need to use different discount rates.

Our core justification for adopting a pluralistic approach is thus that different ES are likely to grow at different rates. This argument is not new. It is in accordance with early insights of Ramsey (1928), discussed above. It is also in accordance with the 1960/70 insights of Krutilla, Fisher (Fisher and Krutilla, 1975; Fisher et al., 1972) and others and the more recent work of Traeger (2011) who demonstrate that it is not optimal to use the same discount rate for all classes of goods if they grow (or fall) at different rates over time.... a *"result that may be interpreted as different effective discount rates applied to the benefit streams from alternative uses of natural environments does emerge from our analysis"* (Fisher and Krutilla, 1975, p 359).[1] And it is consistent with the empirical findings of Li and Löfgren (2000) and Baumgärtner et al. (2015) who found different discount rates for different types of ecosystem services, while acknowledging that variable discount rates add a level of complexity (Freeman and Groom, 2016).

The contribution of our paper is thus a pragmatic one: we suggest a practical way for thinking about which discount rate/approach to use in different settings, namely by taking a closer look at the characteristics of the capitals used and at the proportions of each capital required to 'produce' different ES.

There is no clear and unambiguous reason for choosing one of the methods described above over the others, for choosing a particular discount rate, or for choosing the same method or discount rate for all the elements of a complex project. For example, Newell and Pizer (2003) argue for the use of a 4% discount rate, declining to approximately 0% in 300 years, based on historical data. Baumgärtner et al. (2015) argue that a good (or service)-specific discount rate is necessary to account for changing relative scarcities; while Li and Löfgren (2000) focus on the case where different individuals (in their case a utilitarian and a conservationist representing, respectively, the present and the future) have different time preferences, finding that this leads to discount rates that optimally decline over time.

Our view is that for some types of ecosystem services – particularly those that are less reliant on built capital (e.g., regulating services and

[1] See also: Krutilla, 1967, and Fisher et al., 1972.

Table 1
Four basic types of capital assets and their investment, depreciation and discounting characteristics.

	Built	Human	Social	Natural
Description	Buildings, machinery, transportation infrastructure, and all other human artefacts and services that fulfil basic human needs such as shelter, subsistence, mobility, and communications.	Human beings and their attributes, including physical and mental health, knowledge, and other capacities that enable people to be productive members of society. This involves the balanced use of time to meet basic human needs such as fulfilling employment, spirituality, understanding, skills development, creativity, and freedom.	The web of interpersonal connections, social networks, cultural heritage, traditional knowledge, trust, and the institutional arrangements, rules, norms, and values that facilitate human interactions and cooperation between people. These contribute to social cohesion to strong, vibrant, and secure communities, and to good governance, and help fulfil basic human needs such as participation, affection, and a sense of belonging.	The natural environment and its biodiversity, which, in combination with the other three types of capital, provide ecosystem goods and services: the benefits humans derive from ecosystems. These goods and services are essential to basic needs such as survival, climate regulation, habitat for other species, water supply, food, fiber, fuel, recreation, cultural amenities, and the raw materials required for all economic production.
Types of investment required	Conventional economic production	Education, health care, etc.	Building communities, good government, cultural events, equity, justice, etc.	Self-maintaining, powered by Net Primary Production (NPP), but can be managed
Depreciation	Physical decay with use – maintenance can prolong life of capital but value will inevitably fall to zero	An individual's human capital decays through ageing, disease, etc., but at least some can be recorded, and retained for use by others (as when books, are used for education).	Decay through crime, corruption, inequality, and other social ills (etc)	Can be self-maintaining (although some culture – e.g. Indigenous Australian's – note the need to *care for country*)
Rivalness and Excludability	Rival and Excludable	Rival and Excludable	Non-rival and Excludable	Non-rival and Non-excludable
Discounting	Conventional exponential discounting	Ethically complex social discount rate that recognizes finite human lifetimes	Social discount rate that recognizes ongoing future generations and culture	Protection of future benefits
Discount rate	Fixed rate proportional to depreciation rate or interest rate	Low	Near 0	Near 0 or negative

certain types of cultural services) the starting rate should be much lower. With the observed increases in marginal values associated with natural capital, one could also argue for the use of a negative discount rate for goods/services that rely almost entirely on natural capital, although we acknowledge that even a zero discount rate may, in some cases, relatively harm the current generation when market rates of interest are positive or when savings rates in the current generation must consequently increase to benefit the future (Heal, 1998; Pearce et al., 2003).

2.4. *The case for different discount rates for goods and services that are derived from the interaction of different types of capital*

Sustaining and enhancing human well-being requires a balanced portfolio of all of our assets—individual people, society, the built economy, and ecosystems. These four basic types of capital assets (human, social, built, and natural) all have distinctly different characteristics that affect expected 'returns' on investments, conceptualised here as relating to the stream of benefits that are expected from a given 'investment' in those capitals. Goods and services created from different combinations of these capitals should therefore be analysed, managed, and discounted differently. Table 1 highlights these differences and their implications for discounting.

It is clear from Table 1 that conventional approaches to discounting (and many of the alternatives described above) apply mainly to goods and services that are strongly dependent upon built capital, where a dollar invested today, will return more than a dollar invested tomorrow, justifying the need to discount. But human, social, and natural capital are distinctly different from built capital in terms of: (1) their fundamental characteristics (including rival-ness and excludability); and (2) the kinds of investments that are needed to sustain them (and what that implies for their future behaviour). As such, one expects the future benefit possibilities that are associated with each capital and thus the marginal benefits – which underpins justifications for discounting – to differ (Fig. 1). Therefore, goods and services that are differentially associated with these capitals, need to be differentially discounted.

For example, human capital requires investment in education and health care. These investments yield results that extend and improve over time as individuals learn more, at least up to the point when health begins to deteriorate. While returns to investment in built capital will fall over time, returns to investment in human capital may rise. How to estimate the present value of those investments is complicated by interacting ethical and economic arguments. Should we use the "value of a statistical life" or "lifetime earnings" to value human capital, or a more complex assessment that incorporates quality of life and longevity? At any rate, ethical consideration for the wellbeing of future generations implies at least a very low, if not zero discount rate.

Social capital is even more complex since it is the aggregate of individuals in complex networks and cultures. How do we value those networks of trust and community? Social capital is difficult and time consuming to build, but can be quickly depleted. We know that social capital depends on equity and trust and correlates with a host of social benefits and problems (Putnam, 2000; Wilkinson and Pickett, 2010). But it is not constructed or depleted in the same way as built capital and, if anything, is cumulative and increasing in value over time. This implies at least a very low, if not a zero discount rate.

Finally, natural capital – the free gifts of nature – does not require investment by humans to continue to provide the huge and valuable array of services that support human wellbeing (Costanza and Daly, 1992), but the relationship is complex. Ecosystems cannot provide any benefits to people without the presence of people (human capital), their communities (social capital), and their built environment (built capital) (Costanza et al., 2014b). Investment in natural capital implies conservation and restoration of their self-maintaining capabilities and, if anything, the future value of those capabilities should be increasing with time, not depreciating. This is in line with the argument of Krutilla (1967) that the socially optimal allocation of natural resources/

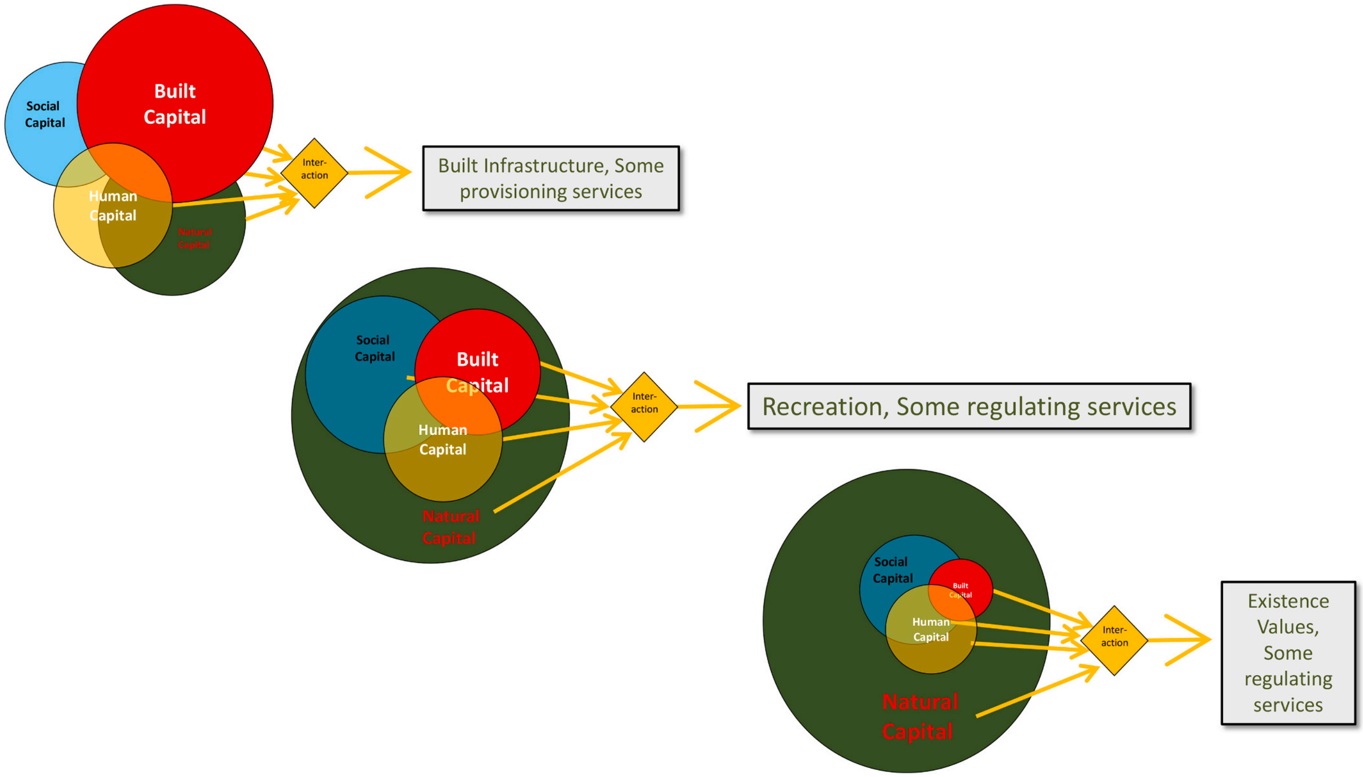

Fig. 1. The relative contribution of each of the four types of capital varies depending on the ecosystem service (after (Costanza et al., 2014b).

Table 2
Net Present Value (NPV) for 17 Ecosystem Services (ES) from Costanza et al. (2014b) using a range of standard exponential discount rates and a hyperbolic rate for 80 years into the future (i.e. to 2100). For the hyperbolic rate the discount rate starts at 5% but decreases by a tenth of a percent per year.

	Ann Flow	Net present value with each discount rate for 80 years into the future (i.e. to 2100)						
	$2007/yr e9	$2007 e9						
Ecosystem service	in 2011	10%	5%	3%	1%	0%	-1%	5% Hyper
Gas regulation	55	552	1082	1667	3031	4417	6816	1782
Climate regulation	6637	66,336	130,059	200,438	364,285	530,948	819,333	215,050
Disturbance regulation	1423	14,222	27,883	42,972	78,098	113,829	175,656	46,104
Water regulation	1871	18,701	36,666	56,507	102,699	149,684	230,985	60,627
Water supply	2083	20,822	40,823	62,914	114,342	166,655	257,174	67,500
Erosion control	16,249	162,411	318,424	490,735	891,883	1,299,926	2,005,983	526,509
Soil formation	955	9548	18,720	28,850	52,434	76,423	117,932	30,954
Nutrient cycling	11,056	110,507	216,661	333,903	606,850	884,489	1,364,900	358,244
Waste treatment	22,625	226,142	443,374	683,299	1,241,858	1,810,018	2,793,132	733,111
Pollination	227	2265	4441	6844	12,438	18,129	27,976	7343
Biological control	1341	13,407	26,285	40,509	73,622	107,305	165,588	43,462
Habitat/refugia	10,876	108,710	213,136	328,471	596,978	870,101	1,342,697	352,417
Food production	14,843	148,360	290,874	448,276	814,717	1,187,456	1,832,424	480,955
Raw materials	2226	22,253	43,629	67,237	122,200	178,108	274,847	72,139
Genetic resources	10,225	102,203	200,379	308,812	561,248	818,023	1,262,333	331,324
Recreation	20,573	205,631	403,161	621,324	1,129,223	1,645,851	2,539,797	666,619
Cultural	1489	14,879	29,173	44,959	81,711	119,094	183,780	48,237
Total ES	124,756	1,246,948	2,444,770	3,767,718	6,847,617	9,980,457	15,401,354	4,042,375
GDP	75,000	749,634	1,469,735	2265,057	4,116,615	6,000,000	9,258,907	2,430,179

environment are likely to increase over time. This too implies at least a very low, if not zero or even negative discount rate.

As an example of this pluralistic approach to discounting we have tried to estimate these relative contributions for the 17 ecosystem services used in Costanza et al. (1997) and Costanza et al. (2014b). We first estimated the NPV of each of the 17 services based on their 2011 annual global flow values from Costanza et al. (2014b), using a range of standard exponential discount rates (10%, 5%, 3%, 1%, 0%, −1%), and one hyperbolic rate starting at 5% for 80 years into the future. These results are shown in Table 2.

Here we assume that these annual flows continue at the same rate for the next 80 years at least. This is obviously a simplifying assumption since we know that there are a broad range of future scenarios that would involve different flows of both ecosystem services and other contributors to wellbeing (Kubiszewski et al., 2017). More comprehensive and sophisticated integrated dynamic models would be needed to fully explore this range of possibilities (Boumans et al., 2002; Costanza et al., 2007). The example presented here is merely to show how discounting affects the NPV without these additional complications, but the approach could easily be applied to more elaborate scenario or

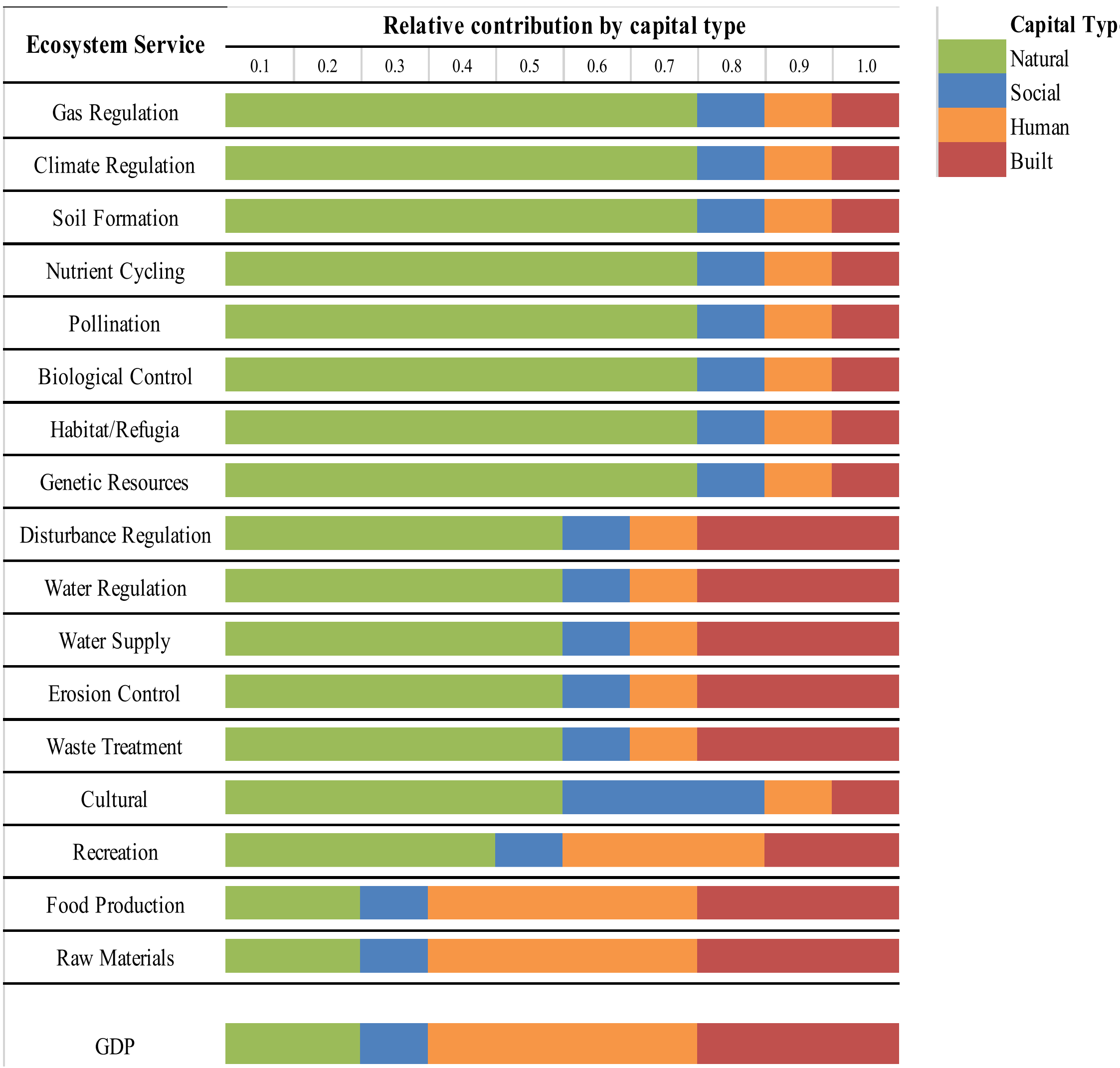

Fig. 2. Estimated relative contribution of the 17 ecosystem services included in Costanza et al. (1997) and Costanza et al. (2014b), (along with GDP) arranged in decreasing percentage of natural capital contribution. For example, climate regulation was estimated to involve 70% natural, and 10% each of social, human, and built capital, while GDP was estimated to involve 20% natural, 10% social, 40% human, and 30% built capital.

Table 3
Options for discount rates for each capital type.

Capital Type	Discount Rate Option 1	2	3
Natural	0%	-1%	-1%
Social	0%	0%	0%
Human	3%	1%	1%
Built	10%	5%	5% hyper

modelling exercises.

Next, we estimated the relative contributions of each of the four capital types to each of the 17 ecosystem services and GDP as shown in Fig. 2. These are, or course, just estimates based on our personal (but expert) opinions. For example, we know that the "labour share" of GDP is often estimated to be about 60% with the "capital share" at about 40% in developed countries. But this excludes natural and social capital. We estimated natural capital's contribution to GDP at about 20%, social capital at 10%, human capital at 40% and built capital at 30%. We estimated these same ratios for food production and raw materials. At the other extreme, we estimated that climate regulation and other regulating services at 70% natural capital and 10% for the other 3 categories. These initial crude estimates could obviously be improved with additional research, but they suffice for the purpose of this example.

We then combined Table 2 and Fig. 2 to estimate variations of the total NPV for each of the 17 ecosystem services using different combinations of discount rates shown in Table 3 for each capital type, weighted by the percentages that each capital type contributes as shown in Fig. 2.

Table 4 shows that the total NPV of global ES estimated in this way is in the range of \$3.8 - \$5.0 Quadrillion (x10^{15}). This is roughly 2 times the NPV of GDP estimated in the same way.[2]

3. Conclusions

We have made the case that discounting the future in the

[2] These estimates are in 2007 US dollars estimated for 2011. Obviously things have changed since then, but this does not change the thrust of our arguments or conclusions.

Table 4
Total NPV for each ES type based on the weighted contribution of each capital type in Fig. 2 and the discount rate options shown in Table 3. All values are in Billions (e9) 2007 USD based on estimates for ES and GDP for 2011.

	Discount rate option		
Ecosystem service	1	2	3
Gas regulation	3756	5624	5694
Climate regulation	451,436	676,062	684,561
Soil formation	64,978	97,310	98,534
Nutrient cycling	752,032	1,126,230	1,140,388
Pollination	15,414	23,084	23,374
Biological control	91,236	136,633	138,351
Habitat/refugia	739,799	1,107,910	1,121,838
Genetic resources	695,520	1,041,598	1,054,693
Disturbance regulation	76,861	115,385	120,852
Water regulation	101,072	151,731	158,919
Water supply	112,531	168,934	176,937
Erosion control	877,753	1,317,700	1,380,125
Waste treatment	1,222,183	1,834,766	1,921,687
Cultural	101,259	138,707	140,613
Recreation	1,050,449	1,599,903	1,652,594
Food production	580,055	1,017,125	1,074,149
Raw materials	87,003	152,560	161,113
Total ECOSERVICES	5,751,135	8,806,034	9,125,244
Total GDP	2,930,913	4,539,348	4,827,481

conventional way using either fixed or varying discount rates may be fine for the flow of costs/benefits that rely predominantly on built capital assets and marketed goods and services, but human, social, and natural capital assets are fundamentally different and goods/services whose production relies more hevily upon these other capitals should at least be discounted at different rates and perhaps in different ways. We conclude that projects that impact goods/services which are differentially reliant upon these four types of assets should differentiate those impacts and discount them differently. This can radically change the results of benefit/cost analyses, compared to using the same discount rate or approach for all goods/services (c.f. (Kubiszewski et al., 2013b). If our goals are to improve the sustainable wellbeing of humans, and not merely the growth of built capital and GDP (Kubiszewski et al., 2013a), then we can no longer ignore the contributions of human, social, and natural capital and must incorporate their current and future contributions in appropriate ways. Because of their characteristics, this will imply much lower discount rates for goods/services that rely on these types of assets. We have estimated the NPV of 17 global ecosystem services in this way, acknowledging the relative contributions of natural, social, human, and built capital in their production and with various alternatives on the discount rate for each type of capital. Results show values in the range of 5.7 to 9.1 quadrillion 2007$US for an 80 year time horizon, compared with 2.9 to 4.8 quadrillion 2007$US for GDP for the same time period using the same methods. Taken together we can estimate the NVP of our planet's ES at around 8 to 14 quadrillion 2007$US – assuming the variable discount rates we used for the different ES types and a constant flow of services for 80 years into the future. Of course these are severe simplifying assumptions and we can't claim any degree of precision for this estimate, nor could we claim any real practical use for it (unless aliens from another planet were in the market for a new one and needed an appraisal in order to get a loan!).

What we wanted to show with this example is the range of possibilities for discounting in a pluralistic way. Pluralistic discounting of the type we describe has tremendous possibilities for project appraisal and benefit/cost analysis across a broad range of projects. For example Kubiszewski et al. (2013b) used pluralistic discounting of hydropower dam benefit/cost analysis in the lower Mekong river to show that with only moderate changes to the discount rate for ecosystem services that were mostly reliant upon natural capital relative to goods/services derived from built infrastructure the NPV flipped from positive to negative. There are a huge number of project assessments performed every year that could benefit from a more nuanced approach to discounting of the type we have described. One of the most important of these project assessments is the choice between continuing to use fossil fuels at the rates we do, or to quickly reduce their use and instead rapidly increase renewable energy. Our approach to pluralistic discounting would favour the later policy, and hopefully we have made the case to more seriously consider it.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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