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The Time Value of Carbon and Carbon Storage: Clarifying the terms and the policy implications of the debate.

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This discussion paper contains preliminary research and analysis. It is undergoing limited circulation to stimulate timely discussion and critical feedback and to influence ongoing debate on emerging issues.

I. INTRODUCTION

Consider the question: "Is there any reason to invest in mitigation projects that will capture carbon today and then release an equivalent amount of carbon in 50 years?"

This question asks whether there is any value to the temporary storage of carbon. Note that the question excludes many of the common contexts in which concepts of "temporary storage" or "impermanence" are debated; the question does not address the uncertainty associated with the "risk of reversal" discussion, for instance, because we assume that storage reversal will occur with 100% certainty and correspondingly, that the carbon remains stored for the project duration of 50 years. The question asks whether there is value to storage that is *known* to be temporary; put another way-- does temporary storage of carbon have value in and of itself?

In this discussion paper we will explore the issues and implications associated with temporary carbon storage in an attempt to articulate whether or not temporary carbon storage has a value, what the nature of that value is, and how it can be used to inform policy design in a variety of relevant arenas for greenhouse gas (GHG) accounting and climate policy. Specifically, this paper explores the implications of a positive valuation of temporary storage in three contexts: lifecycle GHG accounting for biofuels, agricultural offsets accounting, and deferred emissions from reduced deforestation and degradation (REDD) mechanisms.

[1] The views expressed are those of the author and should not be attributed to the Economic Research Service or to the USDA.

II: The value of temporary carbon storage: clarifying the terms

Several different authors have argued in favor of a positive value for temporary storage of carbon. The literature has cited reasons such as:

- "buying time" for learning, technological advancement and deployment, or capital turnover (Marland, 2001);
- slowing the rise of temperature and therefore delaying the impacts of climate change (i.e. front-end benefits) (Dornburg et al, 2008);
- altering the path of emissions in other ways—smoothing out the path of emissions and avoiding peaks—that allow us to delay impacts (Dornburg et al, 2008); and
- creating potential for temporary storage to become permanent.

For the moment, we will concern ourselves only with the original question about whether temporary storage has a value in and of itself, so we will eliminate the last reason from discussion and focus instead on the first three.

There is a fundamental distinction between the first reason given above and the next two. Reasons 2 and 3 both refer to the time path of damages incurred by emissions. The argument is that if temporarily withholding a unit of emissions changes the path of emissions in a way that delays impacts, then aggregate damages from emissions will go down: "Temporary sinks slow the rise of temperature during their maintenance, and, thus, shorten the time of climate change impacts. In an analysis that 'treats climate-change impacts in any year as equally important,' the cumulative temperature impact will always be favorable for temporary sinks" (Dornburg et al, 2008).

According to this argument, the value of temporary storage arises through impacts on the value of damages incurred and if you delay those damages, the value of damages in aggregate goes down. In other words, **there is a value to temporary carbon storage if the social cost of carbon declines over time.** The social cost of carbon (SCC) refers to the cost of the damage done through the emission of a unit of carbon dioxide (Tol, 2008). That value is also, analogously, the value or benefit associated with preventing a unit of carbon (dioxide) emission. If the social cost of carbon is declining, it means that a unit of emissions will add less to the aggregate damage done by carbon dioxide emissions if it is postponed (i.e. the value of temporary storage = the value of *delayed* carbon dioxide stock buildup).

The "buying time" argument for temporary storage value addresses the flip side of the carbon challenge— not the benefits of reducing emissions, and how they may change over time with atmospheric stocks and damages inflicted, but the cost of reducing emissions and how it could change over time. This argument makes the point that, given that we know we want to reduce greenhouse gas emissions permanently, it may be less costly in the long run to engage in temporary reductions now, and then make those reductions permanent at lower cost later, when new technology has been developed or when natural capital turnover cycles can be capitalized on. The value of the temporary reductions in those cases derives from the ability to ultimately make permanent reductions more cost-effectively; that value is fundamentally different from the

value described above, where temporary reductions themselves carry a value (i.e. the value of temporary storage = value of delayed investment in permanent storage).

For clarity, we will henceforth refer to the former source of value -- the values arising from delayed carbon stock damages— as the "value of temporary storage," with the assumption that such storage is in fact temporary and ends at the end of the storage project period. In contrast, the latter source of value – the value arising from increased flexibility to cost-effectively achieve permanent reductions over time—will be referred to as "the value of *interim* storage." In the latter case, the implication is that the path of emission reduction will remain unbroken, but that the form of that reduction is likely to change from the interim project to a more permanent reduction in another form at some point. For example carbon sequestered in a forest could be "rented" while a utility waits until it can cost effectively retire a high emitting coal plant near the end of its lifetime and replace it with a renewable energy facility. If the carbon stored in the forest is replaced by a zero emitting alternative such as a solar farm, the aggregate impact on the atmosphere should be the same as if the coal plant had been retired at the beginning of the project period.[2]

Such a distinction is important because the pathways generating the values are completely different, as are the methods used to estimate them. In the following sections we explore in more detail the complexities of measuring the value of temporary storage, the proxies used to represent them in policy, and the policy arenas in which some of these debates are playing out. An in-depth exploration of the value of interim storage is left to the next report.

[2] Clearly regulatory structures would need to be designed to ensure that these systems are properly established and implemented in the context of binding greenhouse gas mitigation policy.

III: The Value of Temporary Storage: The Social Cost of Carbon

Rising atmospheric carbon dioxide levels have been implicated in costly geophysical changes ranging from rising sea level to changing precipitation patterns, including increased frequency of catastrophic weather events such as hurricanes and drought; such evidence supports the general conclusion that the social cost of carbon is positive (e.g. that there is a cost to society associated with the emissions of greenhouse gas). There are therefore potential benefits to be derived from curtailing carbon emissions and from policies that impose or incentivize such constraints.[3] No consensus exists, however, about what the precise value of that social cost figure should be (Tol, 2008). An extensive history of economic analysis on the topic has illuminated the complexities of the issue, but failed to arrive at a consensus value due to the significant levels of uncertainty surrounding the question.

There are many reasons cited for why climate change impacts are expected to change over time. These include but are not limited to:

- future population change (which increases damages by increasing the number of people affected by climate change (Tol, 2008);
- stock- or path- dependent damage functions-- the more stressed systems already are due to the warming impacts, the greater the impacts of additional stress will be (Interagency Working Group, 2010) ; and
- threshold effects and non-zero probabilities of catastrophic ecosystem collapse.

A significant amount of complexity arises due to the dynamics of carbon emissions and impacts in accounting for greenhouse gas impact and content. Carbon's persistence in the atmosphere, for instance, means that evaluating the full impact of current emissions requires an understanding of the current damages associated with an additional unit of carbon in the atmosphere, as well as how those damages will change over time. Similarly, from the perspectives of GHG accounting at the project level, it is often necessary to compare or aggregate carbon emissions over time in determining the net carbon impacts of a given project. This is because the GHG emissions changes associated with a project, especially those involving land-use change, often occur over a long period of time. Aggregating and comparing emissions, or emissions reductions, over time requires an understanding of how the value of the damage caused by a unit of emissions in the future will compare to the value of damage caused by a unit of emissions today.

There are two relevant time horizons in the calculation and use of SCC estimates. The first, the "impact horizon," refers to the period of time over which warming impacts occur when a unit of carbon is emitted, regardless of when that emission occurs. The second relevant time horizon is the "project horizon," or the period of time over which a project or regulation results in changes of emissions and emissions timing (Figure 1).

[3] Throughout this report we refer to the benefits of reducing emissions as an avoidance of incurring the social cost of carbon figure associated with a unit of emissions. This figure does not incorporate any consideration of the cost of curtailing emissions, and should therefore not be considered a net benefit figure. Economic theory tells us that the efficient level of regulation of carbon will be one leading to an emissions level where the marginal cost of a unit of additional abatement is equal to the social cost of carbon (i.e. where marginal costs of reduction = marginal benefits of reduction).

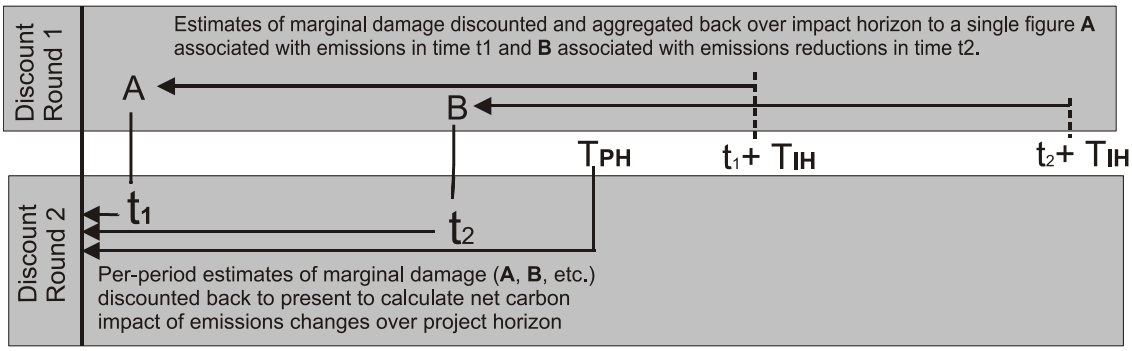

Figure 1: There are two distinct rounds of discounting involved in the calculation and use of social cost of carbon estimates (represented by A and B in the figure above).

Consider first the "impact horizon". The purpose of aggregating over that time horizon is to associate a unit of carbon emissions in a given period with a single measure of damage that reflects the "cost" of that emission over time, or, conversely, the "benefit" of preventing that emission in that time period. There are several variables that affect the path of damage over time that is expected from a unit of emissions. One of these is the rate at which atmospheric carbon decays over time as carbon is re-absorbed into biotic sinks such as forests and oceans. The way in which this decay is represented varies, with some authors using a fixed decay rate applied to atmospheric stocks (Richards, 1997) and others using an exponential decay function that reflects a declining rate of carbon decay over time (Fearnside et al., 2000). In both cases, this variable reflects the purely physical dynamic of the persistence of carbon in the atmosphere over the impact horizon and translates a unit of emissions into an atmospheric carbon stock impact over time.[4]

The second relationship defining the path of damage expected from a unit of emissions is the relationship between carbon stock and the damage expected from that stock. This relationship translates the physical stock dynamic described by the decay function into a measure of the cost implications of that stock response and moves the "impact horizon" into the realm of economics. Although there are many simplifying assumptions used in different analyses of carbon stock damage over time, such as the assumption that marginal damages are not stock-dependent at all or that they are linearly related to stock, the reality of this relationship is likely more complicated than such assumptions suggest. Although such simplifications improve the analytical tractability of the problem, they are difficult to justify for any other reason.

So in any time period, a unit of emissions is associated with a path of expected damages over time that reflects both the impact of that unit on atmospheric carbon stocks over time and the impact of those carbon stocks on damages from climate change over time. Integrating that damage path over the impact horizon produces a single value for the expected costs associated with a unit of emissions in a given time period. Because these impact figures are monetary, a discount term is employed as part of the aggregation to "weight" damages in different time

[4] Although not illustrated here, the impact horizon may also be measured on a rolling basis, rather than relative to a fixed end point. This methodology avoids any truncation bias associated with measuring impacts relative to a fixed end point (see Marshall (2009) for more detail).

periods according to some judgment about how and whether the value of a dollar of damages changes over time.

Once a path of emission damages has been condensed into a single cost number (the social cost of carbon) associated with a unit of emissions (or a single benefit number associated with an avoided ton of emissions) in each time period, a second round of aggregating over time occurs. In the second round, the purpose of the aggregation is to calculate a single total **present value** of all the carbon emission costs and avoided emission benefits that occur over the project horizon. This process compares the value of dollars in different time periods, weights them using a discount rate, and then aggregates them to a single number representing total value expressed in today's dollar (Figure 1). The second round of aggregation is a fairly straightforward process of discounting cost and benefit figures over a finite time horizon using economic discounting. The discount factor selected should be internally consistent with the discount factor used to calculate the social cost of carbon in the first round of discount; some argue that in the case of a constant discount rate the rate should therefore be the same in the two discounting periods (Interagency Working Group, 2010). Internal consistency should, however, also be evaluated in the case of declining or non-constant discount rates.

Clearly, calculation of the social cost of carbon involves a great deal of uncertainty in the form of uncertain future damage functions, atmospheric carbon stock levels, emissions trajectories, etc. Despite this uncertainty, delays in addressing atrmospheric carbon buildup lead to higher levels of risk of catastrophic impacts and damages (Stern, 2007), so climate policy design continues to move forward now to address the unfolding impacts of climate change. Many climate policies, however, rely on some understanding of the magnitude of the SCC, and the underlying assumptions about how marginal damages change over time, to ensure that the policy provides the proper incentives or the proper level of control.

In 2009, a governmental interagency working group was established and assigned the responsibility of calculating SCC estimates to be used in benefit/cost analysis of regulations impacting carbon dioxide emissions. The working group relied on a three integrated assessment models (the FUND, DICE, and PAGE models) to generate estimates of the monetized damages of climate change impacts associated with carbon dioxide emissions in various time periods. Because such values are extremely sensitive to the discount rate chosen to aggregate impacts over the residency period (or "lifetime") of a unit of carbon in the atmosphere, and because there is so much disagreement about selection of an appropriate discount rate under such circumstances, the working group generated SCC estimates for four different discounting scenarios (Table 1).[5]

Table 1: Estimated SCC figures for regulatory analysis ($/ton CO_2)

Discount	5%	3%	2.5%	3%
Year	Average	Average	Average	95th Percentile
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8

[5] A description of the discounting scenarios used, together with an explanation of why they were chosen, is available in the documentation of the working group's efforts and results at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/sem_finalrule_appendix15a.pdf.

2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

Using Regulatory SCC Estimates to Infer Social Value of Temporary Storage

The increasing social cost of carbon over time for all the scenarios arises because "future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climate change" (Interagency Working Group, 2010). Note, however, that these values for SCC are expressed in future-year terms; the value of the SCC in 2050 assuming a 3% discount rate is projected to be 44.9 $/ton of CO2. Expressing those values in "present value" terms requires discounting them back to the present using an appropriate discount rate; the working group argues that "damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency." Using the respective discount rates, then the present value of the social cost of carbon estimates are shown in Table 2.

Table 2: The present value of estimated SCC figures.

Discount	5%	3%	2.50%	3%
Year	Average	Average	Average	95th Percentile
2010	4.7	21.4	35.1	64.9
2015	4.4661	20.5301	33.94	62.7979
2020	4.17461	19.5697	32.576	60.0484
2025	3.94434	18.9991	31.6924	58.0243
2030	3.65583	18.1606	30.5135	55.3676
2035	3.30739	17.1938	29.235	52.3933
2040	2.93849	16.1499	27.8418	49.15
2045	2.57432	14.9616	25.9986	45.418
2050	2.23012	13.7644	24.208	41.753

Note that when expressed in "present value" terms, the value of the SCC is declining over time in all cases. This decline occurs because the rate of growth of social damages (i.e. the rate of increase of the cost to society of carbon emissions over time) is lower than the discount rate used to discount the values back to the present. If the value of damages is growing more slowly than the value of current investments (as reflected in the discount rate used), it is theoretically possible to invest the value of "foregone damages" and have it grow faster than damages. The

result will be an investment that is large enough to compensate for the value of future social damages.

The working group's results can therefore be used to estimate present values for the temporary storage of carbon (foregoing damages early but incurring them later when stored carbon is released). Table 3 shows the estimated per-ton value of storing carbon from 2010 until the release date listed.

Table 3: Estimated per-ton value of storing carbon from the 2010 until the release date listed ($/ton CO_2)

Discount	5%	3%	2.50%	3%
Year of Release	Average	Average	Average	95th Percentile
2010	0.00	0.00	0.00	0.00
2015	0.23	0.87	1.16	2.10
2020	0.53	1.83	2.52	4.85
2025	0.76	2.40	3.41	6.88
2030	1.04	3.24	4.59	9.53
2035	1.39	4.21	5.87	12.51
2040	1.76	5.25	7.26	15.75
2045	2.13	6.44	9.10	19.48
2050	2.47	7.64	10.89	23.15

According to the path of SCC estimates provided by the interagency working group, there is therefore always a positive value to temporary storage of carbon (i.e. the costs to society of storing carbon now and releasing it later are less than the costs associated with not storing the carbon at all). That value increases with the length of storage and is highly sensitive to the discount rate and structure selected. In this scenario, the value of temporary storage declines with the discount rate used; the higher the discount rate, the lower the SCC in any time period, because future damages are more heavily discounted. The more heavily the future is discounted, the less damage carbon emissions are assumed to cause, and the less value there is to delaying those damages.[6]

In the sections that follow we will discuss some of the arenas in which the concept of social cost of carbon plays an important role in policy and regulation design in general, as well as the

[6] This interpretation is specific to this scenario and to this particular relationship between SCC, growth rate of SCC, and discount rate. If the SCC itself is not as sensitive to the discount rate used in the first round of discounting (and is therefore more similar across discount rates), then it might be feasible to see a case where the temporary value of storage increases with the discount rate used. In such a scenario, a high discount rate decreases the perceived impact of later emissions so heavily that it increases the incentive to hold carbon in storage until later when it can be released with what is perceived to be far less damage. [This is one of the reasons that the difference in GWP between different gases is important—can't convert everything into carbon equivalents in advance. The difference in time of impact among gases will make a difference in how this relationship plays out].

implications for those issues of using the new regulatory SCC figures as estimates of the temporary value of carbon under different discounting scenarios.

IV: Relevant Policy Arenas

The importance of the concept of temporary storage, and how relative values of emissions at different points in time compare, plays out across a number of different policy arenas.

- Biofuels GHG accounting: accounting for paths of carbon emissions associated with biofuels production in assigning a single GHG content figure for a gallon of biofuel.
- Reduced emissions from deforestation and degradation: assigning a value to *deferred* deforestation, where deforestation rates are lowered, but permanent protection is not guaranteed.
- Biological offsets (e.g. in agriculture and forestry): defining the equivalence of temporary and permanent offsets in order to determine how/whether they should be tradable within the same market.
- Accounting for long-lived versus short-lived forest products in land-use change or product-based accounting: determining whether/how carbon emission values assigned to long-lived forest products such as timber should differ from shorter term carbon emissions, such as those arising through burning, in determining the carbon impact of a forestry project.
- Allowance banking and borrowing: determining an appropriate rate of trade across time for emissions credits that can be banked or borrowed.

V: Case Study: Biofuels, Life Cycle Analysis, and GHG Accounting

In the United States, biofuels have been promoted as an alternative to petroleum-based fuels. The anticipated benefits include revitalized rural economies, increased energy independence, and reduced greenhouse gas emissions associated with the transport sector. In recent years, however, experts have raised concerns about the magnitude of greenhouse gas (GHG) emissions arising from the land-use change associated with the production of biofuel feedstocks. These concerns raise questions about the claims of GHG benefits associated with biofuel production and use (Searchinger, 2008).

The two major regulations supporting biofuels development—California's "Low Carbon Fuel Standard" and the Federal Renewable Fuels Standards -- therefore require quantification of the GHG content of the biofuel in order to ensure that they satisfy GHG requirements attached to the law. In both cases, GHG "content" is broadly interpreted to mean a life-cycle-based measure of all GHGs emitted throughout the production and transport of the fuel and its major inputs. The carbon dioxide released when biofuels are combusted as fuel is not included in such accounting because it is "short-cycle" carbon that was absorbed from the atmosphere as the biofuel feedstock grew. However, other GHG emissions arise at several stages in the production of biofuels that must be accounted for, including the GHG emissions associated with clearing or

converting land, growing and fertilizing the feedstock, transporting the feedstock, and converting the feedstock into fuel**.**

Until recently, the possibility for significant carbon dioxide emissions associated with land-use conversion for feedstock production was largely neglected. Recent research reports, however, have suggested that the potential magnitude of these emissions is significant (Searchinger, 2008). Such emissions are complicated to quantify, however, in part because carbon emissions from land-use change, and the avoided emissions from substituting biofuels for fossil fuel in transport, are on-going over time and can be difficult to attribute to specific policies. Efforts to quantify the net emissions associated with land-use change and attribute those emissions to current biofuel production or biofuels policy, therefore, must design an accounting methodology that allows them to compare and aggregate such emissions into a single figure that can be compared across fuels and across other policy options for reducing GHG emissions.[7]

For such aggregation, it is necessary to select two important analytical parameters: 1) a time frame for analysis that sets temporal boundaries within which emissions or benefits are counted, and 2) some sort of weighting scheme that allows the analyst to compare one unit of emission (or displaced emission) that occurs today with a similar unit that occurs at variable points in the future. These parameters are familiar in economic analyses. In cost-benefit analysis they are referred to as the "amortization period" and the "discount rate", and they represent critical policy decisions about the relevant time frame for analysis and how much future emissions (or savings) will "matter" relative to those today.

In its proposed rule for calculating the greenhouse gas emissions associated with a gallon of biofuel, as required by the Energy Independence & Security Act's Renewable Fuel Standard, EPA proposed two possible ways to handle time in the aggregation of carbon emissions. In the first scenario, carbon costs (i.e. from land use change) and benefits (i.e. from displaced petroleum use) are estimated for 30 years beyond initiation of a biofuels production project. These figures are then aggregated using a 0% discount rate to determine net carbon impact over the length of the project. The alternative scenario tracks carbon costs and benefits for 100 years from project initiation, and discounts them back to the present for aggregation using a 2% discount rate.

EPA's proposed rule broke from discounting tradition, however, in applying the discount rate directly to physical carbon units and calculating carbon costs and benefits in terms of physical emissions units rather than the economic impact of those emissions. Because discount rates are generally used in the context of investment decision-making to reflect the "time value of money", they are usually applied to monetary units, such as costs or benefits, rather than to physical units such as tons, million metric tons of carbon equivalent (MMTCE), or pounds (lbs) per acre. Although the practice of applying discounting directly to physical units to estimate the "time value of carbon" in assessing carbon mitigation options is becoming more common (Stavins and Richards, 2005), a great deal of disagreement exists about the validity of applying discounting principles to carbon units.

[7] Net emissions are the total emissions associated with producing and using the fuel minus the avoided emissions associated with not producing and using an energy-equivalent amount of fossil fuel.

The purpose of comparing physical carbon emissions in the future to physical carbon emissions in the present through some sort of discounting procedure is essentially to capture how the value of the damage caused by a unit of emissions in the future will compare to the value of the damage caused by a unit of emissions today. The process of applying a discount rate to carbon tonnage is a "short cut" to information about how the value of damages changes over time that skips the series of important steps described above that translates physical impacts into economic impacts (Marshall, 2009).

When transferring the discounting practice over to physical units, it is important to recognize that, despite a failure to include explicit benefit and cost curves in the analysis, the estimated time value of carbon is nevertheless a function of underlying curves that are assumed to drive changing "carbon values" over time. In such studies, the discount rate must therefore capture more than just the "time value of money" dynamic generally associated with discounting practices. An appropriate physical carbon discount function form and rate must *also* reflect very complicated relationships among variables such as the rate of change of the damages produced by atmospheric GHG stocks (which reflects changing assumptions about available mitigation technologies), the persistence rate of GHGs in the atmosphere, initial GHG stock levels, etc (Richards, 1997). Simple extrapolations from default monetary or market discount rates, or even the lower "social rates of time preference" often used in intergenerational analyses, are not appropriate except under very restrictive assumptions about the shape of the marginal damage curve from carbon emissions and its relationship to atmospheric stocks.

Implications of the SCC estimates for selection of a physical carbon discount rate

As described earlier, the implicit purpose of the discount rate when applied to a physical carbon unit is to reflect the relative weights of the value of damage done by emissions in each time period. The social cost of carbon estimates can therefore be used to derive discount rates which, when applied to the physical carbon unit, produce a discounted physical carbon figure that is proportional to the discounted social cost figure. Such a figure can be used to come up with a discounted carbon content figure based on "damage-weighted" carbon emissions figures.

As an example, consider the stream of social cost figures derived in the case of the 2.5% discount rate (Table 4). The second column discounts that SCC back to the present year using a 2.5% discount figure. The third column then calculates an index of the weight of damages in any given year relative to the damages in year 2010. The objective of a physical discount rate in this context is to generate a path of physical unit weights that equals the path of damage weights relative to the year 2010; if a unit of emissions in year 2030 creates ¼ the damages of a unit of emissions in year 2010, then the appropriate discount rate will be one which, when applied to a single unit of emissions in year 2030, produces a discounted unit value of .25 in the year 2010. The fourth column illustrates the path of appropriate physical carbon discount rates for this particular path of social costs of carbon.

Table 4: Calculating a physical carbon discount rate from a stream of social cost of carbon values.

	SCC figure for 2.5% discount rate scenario	NPV of SCC, discounted to present using a 2.5% discount rate	Weight of Damages Relative to year 2010	Physical Discount Rate
2010	35.1	35.10	1.0000	0
2011	35.7	34.83	0.9923	0.007773
2012	36.4	34.65	0.9871	0.00653
2013	37	34.36	0.9789	0.007146
2014	37.7	34.15	0.9731	0.006851
2015	38.4	33.94	0.9670	0.006744
2016	39	33.63	0.9581	0.007158
2017	39.7	33.40	0.9515	0.007125
2018	40.4	33.16	0.9447	0.007139
2019	41	32.83	0.9353	0.007457
2020	41.7	32.58	0.9281	0.007491
2021	42.5	32.39	0.9228	0.007328
2022	43.4	32.27	0.9194	0.007029
2023	44.2	32.06	0.9135	0.006984
2024	45	31.85	0.9073	0.00697
2025	45.9	31.69	0.9029	0.006832
2026	46.7	31.46	0.8962	0.00687
2027	47.5	31.22	0.8894	0.006921
2028	48.4	31.03	0.8841	0.006866
2029	49.2	30.78	0.8768	0.006943
2030	50	30.51	0.8693	0.007026
2031	50.9	30.31	0.8634	0.007019
2032	51.7	30.03	0.8556	0.007115
2033	52.5	29.75	0.8476	0.007214
2034	53.4	29.52	0.8411	0.007235
2035	54.2	29.23	0.8329	0.00734
2036	55	28.94	0.8246	0.007446
2037	55.9	28.70	0.8176	0.007485
2038	56.7	28.40	0.8091	0.007594
2039	57.5	28.10	0.8005	0.007702
2040	58.4	27.84	0.7932	0.007752
2041	59	27.44	0.7818	0.007971
2042	59.7	27.09	0.7718	0.008128
2043	60.4	26.74	0.7618	0.008279
2044	61	26.35	0.7506	0.008473
2045	61.7	26.00	0.7407	0.008613
2046	62.4	25.65	0.7308	0.008748
2047	63	25.27	0.7199	0.008923
2048	63.7	24.92	0.7101	0.00905
2049	64.4	24.58	0.7004	0.009173
2050	65	24.21	0.6897	0.009331

Note that the appropriate physical discount rate is significantly lower than the economic discount rate used in the analysis (which in this case is 2.5%). Furthermore, the schedule of physical discount rates to be applied to emissions in the different years is non-constant and increasing over time. This dynamic arises because the estimated SCC figures increase at a declining rate over time.

To illustrate how such discounting figures might be used, consider the problem of calculating the GHG impact associated with the production of ethanol from an acre of land. A very stylized schedule of production emissions might appear as shown in Table 5. These figures reflect large up-front costs associated with potential carbon emissions from land-use change, followed by a stream of benefits associated with displaced petroleum use from ethanol produced on the land for 30 years after conversion.

According to EPA's recently finalized rules for the calculation of GHG impacts under the Renewable Fuel Standard, such emissions should be aggregated over 30 years using a discount rate of 0%. This analysis suggests that, even with a project period of 30 years, a non-zero discount rate is appropriate if the objective of the aggregation is to generate a "damage-weighted" total of emissions costs and benefits over time. The results in table 5 illustrate that the use of this discount schedule discounts the stream of future benefits sufficiently to narrow the gap between project benefits and costs. As one might expect, this change in weighting could tip the comparison so that costs exceed benefits if the cost and benefit figures are sufficiently close in the un-discounted case (Table 6):

Table 5: Using a physical carbon discount rate, derived from the SCC, to weight carbon units over time.

	costs: emissions	benefits: avoided emissions from petroleum use		schedule of discount rates		discounted costs	discounted benefits
2010	20	0		0	2010	20.0000	0.0000
2011	5	2		0.007773	2011	4.9614	1.9846
2012	4	2		0.00653	2012	3.9483	1.9741
2013	3	2		0.007146	2013	2.9366	1.9577
2014	2	2		0.006851	2014	1.9461	1.9461
2015	1	2		0.006744	2015	0.9670	1.9339
2016	0.1	2		0.007158	2016	0.0958	1.9162
2017	0.1	2		0.007125	2017	0.0952	1.9030
2018	0.1	2		0.007139	2018	0.0945	1.8894
2019	0.1	2		0.007457	2019	0.0935	1.8706
2020	0.1	2		0.007491	2020	0.0928	1.8562
2021	0.1	2		0.007328	2021	0.0923	1.8456
2022	0.1	2		0.007029	2022	0.0919	1.8388
2023	0.1	2		0.006984	2023	0.0913	1.8270
2024	0.1	2		0.00697	2024	0.0907	1.8147
2025	0.1	2		0.006832	2025	0.0903	1.8058
2026	0.1	2		0.00687	2026	0.0896	1.7925
2027	0.1	2		0.006921	2027	0.0889	1.7787
2028	0.1	2		0.006866	2028	0.0884	1.7682

2029	0.1	2	0.006943	2029	0.0877	1.7536
2030	0.1	2	0.007026	2030	0.0869	1.7387
Total	36.5	40			36.1293	37.1955
Net Benefits		3.5				1.0662

Table 6: Example of a scenario where the project is desirable when carbon is not discounted, but where costs exceed benefits when carbon is discounted using a physical carbon discount rate based on the SCC.

	costs: emissions	benefits: avoided emissions from petroleum use	schedule of discount rates		discounted costs	discounted benefits
2010	20	0	0	2010	20.0000	0.0000
2011	5	1.9	0.007773	2011	4.9614	1.8853
2012	4	1.9	0.00653	2012	3.9483	1.8754
2013	3	1.9	0.007146	2013	2.9366	1.8598
2014	2	1.9	0.006851	2014	1.9461	1.8488
2015	1	1.9	0.006744	2015	0.9670	1.8372
2016	0.1	1.9	0.007158	2016	0.0958	1.8204
2017	0.1	1.9	0.007125	2017	0.0952	1.8079
2018	0.1	1.9	0.007139	2018	0.0945	1.7949
2019	0.1	1.9	0.007457	2019	0.0935	1.7771
2020	0.1	1.9	0.007491	2020	0.0928	1.7634
2021	0.1	1.9	0.007328	2021	0.0923	1.7534
2022	0.1	1.9	0.007029	2022	0.0919	1.7468
2023	0.1	1.9	0.006984	2023	0.0913	1.7356
2024	0.1	1.9	0.00697	2024	0.0907	1.7240
2025	0.1	1.9	0.006832	2025	0.0903	1.7155
2026	0.1	1.9	0.00687	2026	0.0896	1.7029
2027	0.1	1.9	0.006921	2027	0.0889	1.6898
2028	0.1	1.9	0.006866	2028	0.0884	1.6798
2029	0.1	1.9	0.006943	2029	0.0877	1.6659
2030	0.1	1.9	0.007026	2030	0.0869	1.6517
Total	36.5	38			36.1293	35.3358
Net benefits		1.5				-0.7936

In this context, the discounted case accounts for the fact that there is a foregone storage benefit associated with the release of large amounts of carbon at the front end of the project through land-use change. Use of the discount rate narrows the margins of benefits for the project relative to the case where the value of storage is not accounted for.

VI: Case Study: Biological Offsets and Temporary Carbon Storage Value

As potential designs for climate legislation are debated in the U.S., one central area of discussion has been about the extent to which the agricultural and forestry sectors can or should be involved as a source of offsets credits for capped sectors under a climate bill. Proponents argue that there are many sources of "low hanging fruit" within agriculture and forestry where emissions sequestration could occur at relatively low cost; such reductions would help keep the costs of

compliance with climate legislation low while providing additional income opportunities for the agricultural and forestry sectors. Some policymakers are particularly enthusiastic about the potential for sequestering carbon in terrestrial ecosystems through an increase in biomass or soil organic carbon (van Kooten, 2008).

Such offsets opportunities, termed "biological offsets," differ fundamentally from other potential offset opportunities within agriculture, however. Offsets generated from use of methane digesters, changes in fertilizer use, etc., represent emissions reductions that are permanent; future changes in practices will not re-emit the carbon reductions achieved through use of the technology. Biological sequestration projects can make no such guarantee; forests grown this year for sequestration purpose could be harvested in 30 years if market timber prices change or could accidentally burn and release stored carbon as a result of natural processes, for instance. Because biological sequestration cannot guarantee permanent storage, it is difficult to define how such biological offsets "stack up" against permanent reductions in meeting emissions reductions goals for climate policy. Such a definition is critical to designing offset markets that allow one to be traded for the other, however.

The "permanence" issue in the biological offsets debate addresses the question of how policy can be designed to ensure that activities that are inherently impermanent can generate offset credits that are considered equivalent, by some definition, to permanent reductions. Proposed institutional design solutions to this problem have included: permanent enforcement, continuous liability rules, credit discounting, ton-year accounting, minimum period for project lifetime, temporary "Certified Emissions Reductions" (CERs), buffers for risk management, and annually rented credits of some kind (Blanco et al, 2000; Fearnside, 2008; Sedjo et al , 2003; Bigsby, 2009).

There are two different approaches to the design of solutions to permanence issues with respect to biological offsets. One approach considers temporary offsets to be simply an interim storage mechanism that is just one part of a permanent sequestration path. According to this approach, the challenge to solving the permanence problem is ensuring that when and if the biological offset project "reverses" and re-emits its stored carbon, the purchaser of the temporary credit takes measures to ensure re-sequestration through either another temporary credit or a permanent reduction elsewhere. Sedjo and Marland (2003) reflect this approach in describing the problem of permanence in the offsets markets as a liability issue. The question is not whether carbon can be stored indefinitely using a particularly technology or practice, but whether liability can be maintained indefinitely, so that reversals must be compensated and the stream of sequestration remains unbroken, though it may take multiple forms.

Institutional solutions such as annually rented credits and permanent liability rules approach the problem from this perspective, and in theory it makes sense. Permanent liability leads to permanent sequestration; you can postpone liability by renting annual credits, but eventually you have to satisfy your liability by investing in permanent reductions. However, in the real world, ensuring permanent liability indefinitely into the future is extremely complex. Companies go out of business, regulations change, and enforcement resources are limited. Additional institutional refinements attempt to deal with these risks through mechanisms such as credit buffer reserves and compliance obligations under climate policy to insure against future losses. Nevertheless, the

fundamental premise of this approach -- that if companies are allowed to hold temporary credits some mechanism needs to be in place to keep an eye on them, possibly indefinitely, to ensure those temporary credits eventually become permanent—may be untenable, and, if you subscribe to the second approach to temporary credit design, unnecessary.

An alternative approach to temporary credits argues that it should be possible to define some measure of "equivalence" between temporary credits and permanent reductions that can be used to determine how temporary credits should be designed and how they compare to permanent reductions, given temporary credits of different lengths, in effectiveness. Equivalence could be defined by a specified duration period, for instance, so that any offset generated by a storage project that lasts 50 years is equivalent to a permanent reduction today. Ton-year accounting is a commonly used accounting method that relies upon determination of an equivalency duration (see text box).

The relative values derived from the ton-year method are highly sensitive to the equivalence duration chosen, however; the longer the equivalence duration, the less value is awarded to temporary storage. There is a great deal of debate about whether the 100-year assumption is appropriate, but it has the advantage of being consistent with the construction of the Global Warming Potential indices that are used to determine equivalence among the impacts of different greenhouse gasses in the atmosphere (Herzog et al, 2003).

Text Box: Ton-Year Accounting

The ton-year accounting method is one method often proposed as a way to compare the value of temporary storage to a permanent reduction or to other storage projects of different lengths. This method relies on an underlying duration equivalence assumption, often 100 years, that essentially asserts that storage of 100 years or longer is permanent and therefore equivalent to a permanent reduction (Herzog et al, 2003; Fearnside, 2002). Storage of less than 100 years is discounted; "The 'discount' for non-permanent storage is based on differences in the integrated atmospheric carbon over the 100 years from a pulse of carbon removed from the atmosphere at time t =0 and re-emitted to the atmosphere at time t=T based on a simulation of a carbon cycle model" (Figure 2).

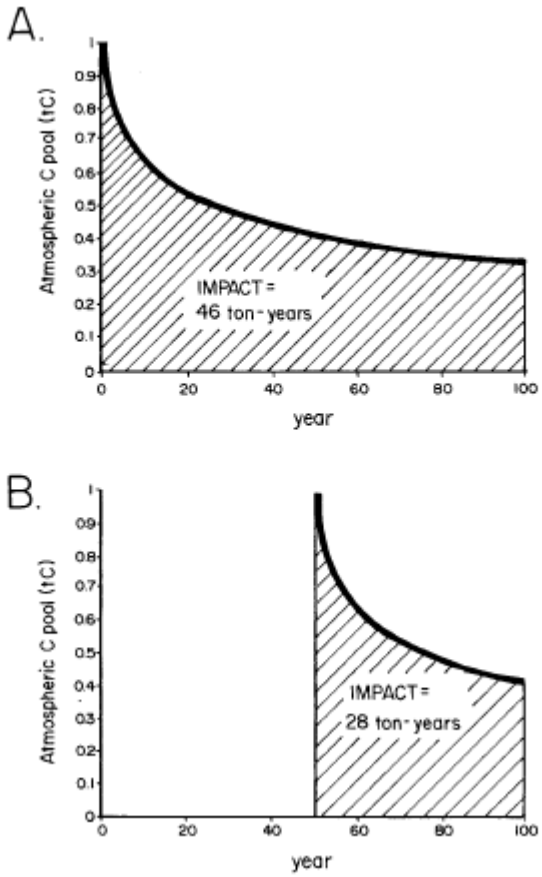

Figure 2. Source: Fearnside, 2000

Note that due to degradation in the atmosphere, a permanent reduction is equivalent to 46 ton-years. In contrast, a ton of carbon stored in a forestry project and released in year 50 has a ton-year benefit equal to the difference between emitting the unit now (46 ton-years) and emitting the unit in year 50 (28 ton-years), or 18 ton-years. Such a project would therefore be credited with 18 ton-years of storage, versus a permanent reduction that is credited with 46 ton-years of storage.

Implications of SCC estimates for equivalence estimates

Like discounting physical carbon in the context of biofuels accounting, the equivalence concept introduced here, though often measured in physical units such as ton-years, is a shortcut for comparing the value of damages done by emissions in different time periods. In the context of temporary credits, a permanent reduction can be said to be equivalent to the number of temporary reductions that provides an equivalent level of damage reduction. Theoretically, if used as a trading ratio between permanent and temporary credits, that ratio should create an equivalence relationship that ensures a comparable impact between permanent reduction and the requisite number of temporary credits, and ensures that the respective market prices reflect the relative impacts of temporary versus permanent storage.

As an example, consider the 5% discount rate scenario shown in table 1 (the NPV of SCC table). (table duplicated below for now)

Discount	5%	3%	2.50%	3%
Year	Average	Average	Average	95th Percentile
2010	4.7	21.4	35.1	64.9
2015	4.4661	20.5301	33.94	62.7979
2020	4.17461	19.5697	32.576	60.0484
2025	3.94434	18.9991	31.6924	58.0243
2030	3.65583	18.1606	30.5135	55.3676
2035	3.30739	17.1938	29.235	52.3933
2040	2.93849	16.1499	27.8418	49.15
2045	2.57432	14.9616	25.9986	45.418
2050	2.23012	13.7644	24.208	41.753

This table suggests that a ton of carbon dioxide emitted in 2010 generates $4.7 worth of damages. Determining an appropriate trading ratio with temporary credits would therefore require calculating for each potential project duration the number of temporary credits required for the NPV of the avoided damages from those temporary credits to be equivalent to $4.7 per ton of carbon dioxide. Consider that a ton of carbon dioxide emitted in 2050 is estimated to generate $2.23 worth of damage. The value of sequestering that ton, in terms of avoided damages, from 2010 to 2050 is therefore $4.7-$2.23 = $2.47 (Table 4). When using a 5% discount rate, a permanent reduction of one ton of carbon in 2010 is therefore equivalent to 4.7/2.47=1.9 temporary credits for storage lasting from 2010 to 2050. In other words, permanently reducing a unit of carbon in 2010 is equivalent, in terms of damages avoided, to temporarily storing 1.9 units of carbon dioxide from 2010 to 2050.

As one would expect, the equivalence ratios for shorter projects are much higher than they are for longer projects. In the case of ten-year storage credits, for instance, the benefit of the storage is only ($4.7- $4.17)= $.53 per ton. One would therefore need to purchase 4.7/.53 = 9.0 temporary, ten-year storage credits in order to avoid the same amount of damage as a permanent

reduction yields. The equivalence trading ratios for each discounting scenario are shown in Table 7.

Table 7: Equivalence trading ratios for temporary credits of different durations and under different discouting scenarios.

Discount	5%	3%	2.50%	3%
Year of temporary credit expiration	Average	Average	Average	95th Percentile
2010	N/A	N/A	N/A	N/A
2015	20.094	24.6002	30.2587	30.8742
2020	8.94574	11.6919	13.9064	13.377
2025	6.21973	8.91337	10.3004	9.43907
2030	4.50117	6.60609	7.65297	6.80834
2035	3.37496	5.08773	5.98462	5.18923
2040	2.66817	4.0761	4.83589	4.12064
2045	2.21106	3.32383	3.85655	3.33128
2050	1.90292	2.80266	3.22255	2.80382

As shown, as the discount rate used decreases, the necessary trading ratio between temporary credits and permanent reductions increases. This is because as the discount rate decreases, damages from future emissions are discounted less. If future emissions have higher relative damages, then the value of temporary storage goes down, as does the value of temporary storage credits relative to permanent reductions.

Temporary Storage and the REDD Debate (text box)

The combined effects of deforestation, degradation, and peatland emissions are estimated to generate 8-20% of global anthropogenic greenhouse gas emissions (van der Werf et al, 2009). Tools for reducing deforestation will therefore be an important part of any strategy to avoid catastrophic climate change. Reducing Emissions from Deforestation and Forest Degradation (REDD) is a proposed market mechanism to encourage reductions in forestry-related emissions by providing a financial incentive for maintaining carbon stored in forests. REDD mechanisms establish a value for carbon currently sequestered in forests (and for the avoided release of that carbon) as well as for additional sequestration, together with a mechanism through which forest owners receive a payment for maintaining their carbon stocks. In addition to the carbon benefits, REDD mechanisms are promoted as a good way to incentivize maintenance of other forest-related ecosystem services such as habitat protection and provision, biodiversity, erosion control, and flood control.

REDD mechanisms are currently being debated at the international level as one potential way for countries to meet their obligations under international climate change agreements. Under such a system, developed countries could offset part of their emission reduction obligations by making payments to provide incentives for reduced deforestation in tropical countries. The mechanism could be structured so that payments are negotiated and transferred at the project level, like a large international offset program, or at the national level, where countries themselves generate tradable carbon credits in exchange for lowering their national deforestation rate below a defined baseline level.

Much of the debate surrounding the legitimacy of the GHG reductions achievable through a REDD mechanism raises questions related to the permanence of reductions achieved through changes in forest management and to the potential "leakage" of emissions associated with changing patterns of land use arising as a result of GHG mitigation projects. The permanence issue arises because, like all other biological sequestration mechanisms, changes in forest management result in sequestration that can ultimately be reversed, either naturally through wildfire, for instance, or through anthropogenic land use change.[8] The incentives provided by a REDD mechanism may therefore defer, but perhaps not ultimately avoid, deforestation and release of stored carbon.

"Leakage" refers to the possibility that increased protection of forests in one area will lead to increased pressure on, and increased deforestation of, forests in another area. With high levels of leakage, carbon credits generated by the initial forest protection program could overestimate actual aggregate reductions in emissions, when in fact emissions have shifted. While permanence is concerned with the extent to which emissions are avoided versus simply displaced in time, leakage is concerned with the extent to which emissions are avoided versus simply displaced in space.

In the case of a project-level REDD mechanism, the implications of the SCC figures for the negotiated contracts between forest owners and international buyers are the same as those described in the section on biological offsets; a trading ratio between the impermanent carbon credits from sequestration and the credits obtained from permanent reductions or avoided emissions can capture the relative difference in magnitude of damages avoided.[9] The length of the contract agreed upon will determine the appropriate trading ratio. Note that a trading ratio as described addresses the permanence issue through a proposed definition of equivalence, but it does not address the issue of leakage.

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[8] Ebeling et al (2008) argue that reducing deforestation rates is as "permanent" as fossil-fuel-use-reductions, which still leave the fuel in the ground for possible later use. If all fossil fuels are ultimately going to be exploited, then any current reduction measure is actually a deferral of use. They argue that the value of such reductions lies in how they impact the timing of emissions: "In fact, a time delay in emissions through temporary abatement measures results in permanent climate benefits because the cumulative atmospheric concentrations of GHGs will be lower at any future point in time." Note the distinction between permanent sequestration and permanent benefits; the argument is that non-permanent sequestration can still provide permanent benefits. The value of temporary storage of carbon reflects those permanent benefits.

[9] Under project-level mechanisms the baseline against which emissions removals are measured over time is the estimated amount of emissions that would have been expected under a "business as usual scenario." Put another way, these are the emissions expected in the absence of the project activity (in this case avoiding deforestation).

A national-level REDD mechanism, on the other hand, would address the leakage issue (at least within country) by generating credits based on the performance of the entire country, rather than on a project-by-project bases. A country's performance would be measured relative to a national established baseline for deforestation rates; the methodology for determining national baselines that seems to be generating the most discussion is one based on a multi-year average of historical deforestation rates.[10]

There are several ways in which a national-level REDD mechanism could be structured to accommodate impermanence, depending on whether and what type of national accounting systems exist for GHG emissions in the credit source country. Two scenarios seem to be garnering the most attention, one in which the source country has no GHG emissions accounting responsibility, and the other in which the source country is held to annual accounting and reporting of emissions requirements.

In the latter case, national GHG performance is measured over multiple sectors; the REDD mechanism creates a responsibility for maintaining improved national performance (by the amount of credited carbon), but the forestry sector is just one sector that can be used to achieve the reductions "promised" through the sale of carbon credits. Increased deforestation due to an annual fluctuation in soybean prices, for instance, can be compensated for through carbon reductions in other sectors. In this case, the forest project can be seen as an interim sequestration tool; selling REDD credits creates the responsibility for ongoing national reductions that would be reflected in a change in the national annual GHG accounting and requirements. As long as the liability for the REDD reductions (which began in the forest but may not remain there) is unbroken and monitored through the annual accounting mechanism, the permanence of the reduction can be maintained, albeit across sectors rather than specifically in the forestry sector. Theoretically, permanent liability through national accounting obviates any further need to adjust for the type of permanence risk we are discussing here.

In the former case, the REDD mechanism creates a responsibility for maintaining credited reductions (i.e. sequestrations) that is specific to the forestry sector, and adherence to those required reductions will be measured over time by what the forest does. Forest losses, due to either natural or anthropogenic causes, threaten the "permanence" of such a reduction.[11] Such a system is much like a national offset project, where the project refers to the performance of the entire forestry sector rather than single land-use project within it. As in the biological offsets projects described above, the permanence issue could be addressed through the negotiation of forest-based sequestration contracts of fixed length with trading ratios determined by that contract length and a set of social cost of carbon numbers. Awarding value to fixed-length contracts, while at the same time recognizing them as fixed-length and therefore of variable value depending on the length of the storage period, may help find middle ground between

[10] There are objections to establishing a baseline this way, largely based on the fact that deforestation patterns do not tend to stay constant over a country's history, even in a "business as usual" situation. Observed "forest transitions" at the national level suggest that a dynamic baseline should reflect decreasing deforestation rates over time and with development. The myriad difficulties associated with selecting a baseline are not the topic of this paper, however.
[11] Unlike a project-based mechanism, a specific project's sequestration can be impermanent as long as the forestry sector itself compensates through losses of sequestration in one area with increased sequestration in another.

source country concerns about national sovereignty over natural resources and environmental concern about the integrity of the credits sold.

VII: Conclusions and Policy Implications

The recently released federal interagency task force estimates of social cost of carbon suggest that it is possible to achieve permanent climate benefits from carbon storage projects that do not necessarily ensure permanent reductions or sequestration. While these estimates are, of course, sensitive to the methodologies used to calculate them, as well as to a number of assumptions about projected emissions paths, damage functions over time, economic growth paths, etc., it is instructive to understand the implications of non-zero temporary carbon storage values across a number of policy arenas.

A couple of broad generalizations emerge from an examination of the social cost of carbon numbers themselves. Of critical significance in most policy arenas is the fact that temporary storage value is highly sensitive to the length of storage and to the discount rate and structure used to aggregate and compare the monetized costs and benefits associated with climate change over time. Though such generalizations are intuitive, illustrating this sensitivity using available numbers highlights the importance of incorporating such considerations into policy design (in the case of sensitivity to project duration) and transparent policy decision-making (in the case of discount rate selection) when dealing with issues related to temporary carbon storage.

The question of how the value of temporary storage compares to that of permanent reductions is a fundamental issue across a number of current, and contentious, policy debates. Relevant policy arenas range from carbon markets concerned with fungibility of credits for temporary storage to life cycle analysis of the GHG content of a product whose emissions benefits or costs play out over time. In this paper we present approaches to using the new social cost of carbon estimates to address such questions in the context of biological offsets and the life-cycle analysis of the GHG content of biofuels. We hope this paper, and the methodologies presented, will advance the dialogue in these areas by clarifying the concepts involved and moving discussion beyond theoretical debate to the potential policy applications of actual estimates. The science of carbon cost estimation continues to evolve, however, and if such estimates are to be useful in policy applications, a critical issue will be designing practical mechanisms for addressing their inherent uncertainty in policy design. Moreover, as our understanding of the impacts of climate change evolve, mechanisms will be needed to ensure that advances in scientific understanding are incorporated into policy design and implementation in a timely and ongoing manner.

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