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ANALYSIS

Permanence discounting for land-based carbon sequestration☆

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ABSTRACT

One major concern regarding land-based carbon sequestration involves the issue of permanence. Sequestration may not last forever and may either be released in the future or require expenditures to maintain the practices that keep it sequestered. In this paper, we investigate the differential value of offsets in the face of impermanent characteristics by forming a price discount that equalizes the effective price per ton between a "perfect offset" and one possessing some with impermanent characteristics. We find this discount to be a function of the future needs to replace offsets (in the face of lease expiration quantity or volatilization upon activities such as timber harvest) and the magnitude of any needed maintenance costs. We investigate the magnitude of the discounts under alternative agricultural tillage and forest management cases. In those studies, we find that permanence discounts in the range of 50% are not uncommon. This means that in the market place an impermanent sequestration offset may only receive payments amounting to 50% of the market carbon price. Furthermore, we find that in the face of escalating carbon prices that offsets may prove to be worthless.

1. Introduction

Land-based soil carbon sequestration has been widely suggested as a potentially cost-competitive means for reducing net greenhouse gas (GHG) emissions as well as a way to increase opportunities for farmers and foresters (Dixon et al., 1993; Sampson and Sedjo, 1997; Marland and Schlamadinger, 1999). Additionally, some studies insist that practices for sequestering carbon in soil or forests have other agricultural and environmental benefits (co-benefits) for example increasing biodiversity, decreasing soil erosion, or improving water quality (Lal et al., 1998; Antle and Diagana, 2003; Pattanayak et al., 2005). Various studies have explored the potential of land-based carbon sequestration strategies in the US such as afforestation, reforestation and other land use changes (Adams et al., 1993; McCarl and Schneider, 2001; Parks and Hardie, 1995; Plantinga et al., 1999; Stavins, 1999; Stavins and Richards 2005).

One major concern regarding sequestration that has been widely discussed in the international debate over potential GHG abatement policy (See Intergovernmental Panel on Climate Change, 2001 for discussion and references) involves the issue of permanence. Permanence encompasses several fundamental issues related to the time dynamics of sequestration options:

(i) Differential rates of accumulation over time and a long run decline to a near zero rate of net sequestration. In particular, carbon will be accumulated only until the ecosystem becomes effectively saturated in a given land management system (often called *saturation*). This has been called an "attainable maximum" or the equilibri-

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um stock of carbon under a given management practice (Ingram and Fernandes, 2001).

(ii) The possibility that carbon will not remain sequestered over the long term. Generally, sequestered carbon can be rapidly released back to the atmosphere if the carbon sequestering practice is discontinued or when certain random events occur like a forest fire (commonly called *volatility*).

(iii) Contract terms that either require generation of sequestration offset for only a limited time period (i.e., "leasing" carbon for 20 years then having no continuing obligation) or incorporate costs that are not a function of carbon uptake (maintenance costs to maintain the practice beyond the saturation point.)

These permanence issues arise somewhat uniquely under the sequestration case with most alternative strategies not being subject to such concerns. For example, methane capture and combustion in subsequent energy production permanently avoids a methane emission. In such a case, the mitigated GHG is not volatile, nor are there saturation or leasing concerns.

The question addressed in this paper is whether the permanence concerns associated with sequestration may alter the market place value of the resultant carbon offsets. In the market place when a carbon offset is sold this involves a transaction wherein one party (the buyer) pays another party (the seller) to either reduce emissions or sequester carbon by a certain amount in order to "offset" some emissions that the buyer has generated or is otherwise responsible for. An example of this might be an electric utility paying farmers to plant trees or engage in conservation tillage to offset some of the utilities emissions from fossil fuel combustion. From an offset purchaser's point of a view, a ton of carbon emission offset created through an impermanent sequestration asset may be worth a different amount than one created though other means – i.e., the offsets are not perfectly fungible without some sort of permanence adjustment to make them so.

The potential for differential values of commodities with heterogeneous characteristics is an important consideration in many markets. Commonly, grading standards have evolved to differentiate among heterogeneous products as discussed in Tomek and Robinson (2003) (e.g., gasoline grades are characterized by octane level and have differential prices while corn grades are defined in terms of moisture and broken kernel content etc. and exhibit different prices). Grading standards are generally defined based on key components that differentiate consumers' preferences. In turn, the market reflects the different prices that consumers are willing to pay for commodity units of different qualities. In the context of a carbon market, the purchaser's willingness to pay may be determined, in part, by rules established by the market's governing entity to ensure that impermanence risks are properly remedied. In other words, carbon credits may need to be discounted when the credits exhibit different degrees of adherence to the rules of the market. For instance, the Clean Development Mechanism (CDM) under the Kyoto Protocol treats GHG credits from land use, land use change, and forestry (LULUCF) as temporary, requiring periodic re-verification to be placed on a comparable basis with permanent reductions. By and large, this can cause temporary LULUCF credits to be less valuable than permanent reductions. We will explore the rational for and potential formation of such discounts here.

In this paper, we first develop a grading standard type of discount based on a theoretical comparison of an impermanent offset versus a permanent offset. Then we illustrate the empirical magnitude of that discount under a range of conditions.

2. Sequestration contract characteristics

Purchasers of GHG offsets are likely to have to demonstrate that their activities have caused GHGs to be not emitted or removed from the atmosphere in the current and all subsequent years or for some longer term future (a commitment period). Permanence considerations may complicate this for sequestration activities, if

- a lease runs out before the end of the commitment period,
- an unplanned event occurred causing release of sequestered carbon, or
- the producer discontinues the practice causing release.

If any of these actions occur, then the offset purchaser paying for carbon sequestered could be responsible for making up the shortfall or would face a noncompliance penalty (Marland, Fruit and Sedjo, 2001). In such cases, the offset purchaser would likely be required to buy the same amount of offset from other sources. Alternatively, the offset purchaser can offer incentives (a maintenance cost) to insure the sequestered carbon is maintained beyond the point that the seller might otherwise maintain it.

3. Analytical development of a permanence discount

The reason prices might differ between two alternative goods is that the purchaser's use value of the alternatives may differ, due to difference in characteristics. In economics, this is referred to as the *hedonic* characteristics of differentiated goods (Rosen, 1974). In turn the price difference between the goods would be the amount that the purchaser determines makes the use value the same for the two alternatives.

We will use an approach based on equalizing use values to derive a price discount. Suppose the offset purchaser faces two alternatives. One has impermanence characteristics including possibilities for saturation, volatility and leasing terms while the other does not and is herein called perfect[1]. Assume that the offset purchaser would be willing to pay the same effective price of offset that could be claimed.

3.1. *Perfect prospect*

We define a perfect prospect from the standpoint of permanence as one that (i) does not exhibit volatility, and (ii) has zero

[1] As pointed out by a reviewer we could have discounts because of uncertainty, as discussed in Kim et al. (2006) or Kurkalova (2005, CJAE). However we neglect this and just concentrate on permanence. Kim (2004) discusses procedures to handle multiple discounts simultaneously.

transaction costs (i.e., costs other than the direct cost of acquiring the offset that are proportional to the amount acquired). Given current and future carbon prices P_t, then the total cost for an offset at time t would be $TC_t^p = P_t\, Q_t$ where Q_t is the amount of offset at time t,[2] and the superscript, p, refers to the perfectly permanent offset prospect.

The current cost of an offset (TC_{Today}) can be developed using the (net) present value concept as $TC^p_{Today} = \sum_{t=0}^{T} P_t \cdot Q_t \cdot (1+r)^{-t}$, where T is the duration of the contract or the total length of the time period being considered, and r is the annual interest (discount) rate.

Under these circumstances, the effective price (PE) today paid for a future stream of offsets is the present value of cost divided by the offset quantity

$$PE = \frac{TC^P_{Today}}{TQ^P} = \frac{\sum\limits_{t=0}^{T} P_t \cdot Q_t \cdot (1+r)^{-t}}{\sum\limits_{t=0}^{T} Q_t} \tag{1}$$

where the denominator in Eq. (1) is the sum of quantity of offsets throughout the life of project. Note that some authors recommend that time discounting should be imposed on the summation of carbon quantities in the denominator to adequately capture the timing of carbon benefits (Richards and Stokes, 2004; Richards, 2004), while others argue that discounting should occur only if the carbon value remains constant over time (Herzog, Caldeira and Reilly, 2003). We do not impose discounting in the denominator quantities here, but as will be shown below, the denominator term will cancel out in computing the permanence discount, so this choice does not affect our results. A critical element of Eq. (1) is the carbon price path. If we assume that the carbon price is constant over time ($P_t = P_0$), then PE in Eq. (1) equals $\frac{P_0 \cdot \sum_{t=0}^{T} Q_t \cdot (1+r)^{-t}}{\sum_{t=0}^{T} Q_t}$. The constant carbon price implies constant marginal damages from increasing emissions of GHG. Justification of constant carbon price can be found in Herzog, Caldeira and Reilly (2003, p 300). Carbon price can increase, however, reflecting a view that the additional carbon holding capacity of the atmosphere is a fixed resource that is allocated over time like any finite natural resource. The notion of allocating a fixed resource over time has long been known in economics as the *Hotelling condition*, under which the price of the resource rises optimally over time at the rate of interest (r). Note that in an actual carbon market setting, this may not be the case. The carbon market is generally driven by efforts to comply with a fixed GHG target. The market sets the price at the point where a buyer's marginal willingness to pay equals a supplier's marginal cost. The buyer's willingness to pay will generally be a function of the value of the costs they can avoid by purchasing the offset rather than the value of the environment of avoided damages. Therefore the change in the market price will reflect changes in the target level and the costs of achieving it. Although credit banking may provide some of the underlying forces by which Hotelling conditions might arise (you can trade credits across years, just as you can trade resource extraction across years), these provisions may not always apply via market rules. Thus, in general, the carbon price might rise at a rate different than the interest rate. If we assume that the carbon price is increasing at the rate of g over time ($P_t = P_0\,(1+g)^t$), the PE in Eq. (1) equals $\frac{\sum_{t=0}^{T} P_0 \cdot Q_t \cdot (1+g)^t (1+r)^{-t}}{\sum_{t=0}^{T} Q_t}$. If $g = r$, it is simplified to be P_0.

[2] The amount offset, Q_t, should be clarified here. For non-sequestration options, it is quantity of avoided emissions and always positive. For sequestration options, this is a single-year increment to the carbon stock which is most likely positive but it might be negative (emissions). We assume that we can obtain only positive sequestration after adopting a carbon sequestration project.

3.2. *Impermanent prospect*

Now suppose we consider a generalized imperfect prospect that exhibits impermanence related characteristics. Suppose these manifest themselves in some mixture of the following situations.

- The contract for a sequestration project is for a fixed time, which is less than the total purchasers' commitment time for emissions. At the end of the sequestration contract, the purchaser has to buy new offsets to cover those previously held through the sequestration contract (now best thought of as an expired carbon lease). This is defined as a *buyback* of credits in year t of the quantity B_t.
- There may be costs incurred that are not related to the amount of carbon sequestered that we will call a *maintenance cost*, M_t. These costs are part of the contract to compensate for efforts to maintain sequestered carbon perhaps past the time when effective saturation in the land use practice is attained (i.e. a payment to maintain reduced tillage after the period when carbon has ceased accumulating). Without these continued payments, farmers might otherwise have no incentive to continue with the practice. Note that the maintenance costs are fixed amounts under the contract because they do not vary directly with the amount of carbon sequestered. Rather, they are compensation for the landowner's opportunity costs of maintaining these practices even beyond the point that they are sequestering carbon.
- The quantity of carbon sequestered varies over time.

Under such circumstances the total cost at time t under the impermanent prospect would be $TC_t^s = P_t\, Q_t + P_t\, B_t + M_t$, where the superscript, s, indicates the impermanent sequestration prospect. We assume for simplicity that the perfect prospect sequesters the same amount of carbon in each year as does the imperfect prospect, so that Q_t here is the same Q_t as in Eq. (1). In turn, today's effective cost per ton (PE_s) of an offset (TC_{Today}) can be developed again using the (net) present value concepts as follows:

$$PE^s = \frac{TC^s_{Today}}{TQ^s} = \frac{\sum\limits_{t=0}^{T} (P_t \cdot Q_t + P_t \cdot B_t + M_t)(1+r)^{-t}}{\sum\limits_{t=0}^{T} Q_t}. \tag{2}$$

3.3. *Permanence discount*

Given the above two formulae for the current effective cost per ton under the perfect and impermanent prospects, we now define a permanence discount that equates the current cost per ton. Suppose a purchaser equates the current cost per ton from each prospect by introducing a permanence discount (PDisc) that reduces the effective carbon price paid for the impermanent sequestered carbon relative to the price paid for a perfect offset. A rewrite of the above Eq. (2) introducing this is

$$PE^s = \frac{TC^s_{Today}}{Q^s_{Today}} = \frac{\sum_{t=0}^{T} (P_t \cdot (1-\text{PDisc}) \cdot Q_t + P_t \cdot B_t + M_t)(1+r)^{-t}}{\sum_{t=0}^{T} Q_t} \quad (3)$$

where, PDisc is applied to the price paid per ton but not to the buyback as we assume that replacement has to be paid at the prevailing "perfect" market price.

3.3.1. *Discount under constant carbon prices*

Now we can derive the permanence discount by equating Eqs. (1) and (3). Initially we will also assume that carbon price is constant over time.

$$\frac{P_0 \cdot \sum_{t=0}^{T} Q_t \cdot (1+r)^{-t}}{\sum_{t=0}^{T} Q_t} = \frac{\sum_{t=0}^{T} (P_0 \cdot (1-\text{PDisc}) \cdot Q_t + P_0 \cdot B_t + M_t)(1+r)^{-t}}{\sum_{t=0}^{T} Q_t}. \quad (4)$$

Dividing through by P_0 and then solving for PDisc, we get:

$$\text{PDisc} = \frac{\sum_{t=0}^{T} (B_t + M_t/P_0)(1+r)^{-t}}{\sum_{t=0}^{T} Q_t \cdot (1+r)^{-t}}. \quad (5)$$

Eq. (5) shows that the permanence discount is a function of the buyback term and the extent of the maintenance cost relative to the carbon price, divided by the present value of the quantity of offsets. Consideration of the terms in this formula leads to the following conclusions:

(i) A permanence discount will only exist when a buyback, and or a maintenance cost requirement are present.
(ii) The rate of accumulation by itself causes no discount although it does determine the size of the discount.
(iii) If a carbon sequestration project (such as no-till agriculture) is profitable, such that land owners would continue this management system after the carbon reaches saturation without any payment or incentive then no discount is needed.

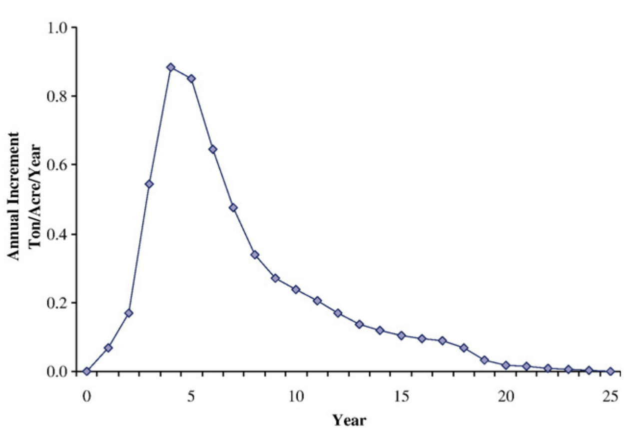

Fig. 1 – Carbon sequestration rates from conventional tillage to zero tillage.

3.3.2. *Increasing carbon price over time*

The carbon price path is important because the value of PDisc can be significantly affected by the carbon price path. As discussed in the above section an increasing carbon price might be the case when we consider the additional carbon holding capacity of the atmosphere as the fixed resource (*Hotelling condition*) (Herzog, Caldeira and Reilly, 2003). Therefore, here we assume that the carbon price increases at the rate of g. By equating Eqs. (1) and (3);

$$\frac{\sum_{t=0}^{T} P_0 \cdot Q_t \cdot (1+g)^t (1+r)^{-t}}{\sum_{t=0}^{T} Q_t} = \frac{\sum_{t=0}^{T} \left[P_0 \cdot (1+g)^t \cdot (1-\text{PDisc}) \cdot Q_t + P_0 \cdot (1+g)^t \cdot B_t + M_t\right](1+r)^{-t}}{\sum_{t=0}^{T} Q_t} \quad (6)$$

Dividing through by P_0 and then solving for PDisc, we get:

$$\text{PDisc} = \frac{\sum_{t=0}^{T} \left[B_t \cdot (1+g)^t + M_t/P_0\right](1+r)^{-t}}{\sum_{t=0}^{T} Q_t \cdot (1+g)^t (1+r)^{-t}} \quad (7)$$

Eq. (7) is slightly different from Eq. (5) but yields the same conclusions.

4. How big is the discount: case applications

The following cases provide stylized illustration of the magnitude of our permanence discounts under some hypothetical alternatives using data for potential forest and agricultural projects.

4.1. *Agricultural soil carbon sequestration project cases*

Suppose a project involves conversion from conventional tillage to zero tillage ("no till"). The data for a hypothetical project in this class will be based on the average soil carbon accumulation pattern given in West et al. (2004), which is based on an average across more than 250 field observations of changes in soil carbon. In those data, the carbon accumulation occurs over a 25-year period, with maximum sequestration rates occurring between 5 and 10 years. Carbon accumulation then stops in year 25. This is graphically shown in Fig. 1. Project duration is 100 years. We choose 100 years under the common assumption that carbon storage of 100 years or more is permanent storage. A rationale for the 100 year period is the argument that the problem of comparing carbon storage of different lifetime is conceptually equivalent to comparing GHG if different lifetime. This comparison has already been addressed in the construction of Global Warming Potential, where the GWP measures adopted by the Intergovernmental Panel on Climate Change (IPCC) are based on a 100 year horizon. We assume that the initial carbon price, P_0, is

$30/t, and the annual interest rate is 4%. In addition we assume that carbon price is rising at the interest rate, that is, $g=r$.

4.1.1. *Case 1—perfect sequestration*

Suppose the no till system is more profitable than conventional till at the end of the 25 years of accumulation so the farmer does not revert once the carbon payments cease. In such a case, the practice continues on indefinitely without the need for either maintenance or buyback considerations. The permanence discount is zero under both constant and increasing carbon price assumption and this implies that soil carbon sequestration is equivalent to a perfectly permanent offset.

4.1.2. *Case 2—maintenance costs needed*

Suppose that after the carbon accumulation ceases and the contract specifies a maintenance cost starting in year 25 that is needed to maintain use of the tillage practice ($5 per acre in this case) which is in the neighborhood of Kurkalova et al. (2003) conclusion that we would need $3 per acre above and beyond the profitability difference between the two systems.

Under a constant carbon price, the permanence discount is 36.3%. In other words, the price paid for sequestered soil carbon that equates the effective cost per ton is 63.7% of that paid for a perfect emission offset. So a purchaser would pay the creator of such an impermanent offset only about 2/3 of the amount that they would pay for a perfect permanent offset. Under an increasing carbon price (again, at this interest rate), the permanence discount is found to be 27.8%; thus the buyer would pay 72.2% of the price paid for a perfect prospect. In essence, under rising carbon prices, the fixed per acre maintenance cost is a better bargain than under constant carbon prices, since the value of maintained carbon is higher.

4.1.3. *Case 3–buyback needed*

Suppose that lease terms are established. In year 25 the lease expires and in year 26, the purchaser must replace 100% of the offsets attained over the entire project at the market price. No maintenance cost is paid. In this case, the permanence discount is 49.1% under the constant carbon price. This implies the amount paid for the non-permanent sequestration generated offset quantity would be roughly half the amount paid for the perfectly permanent offset.

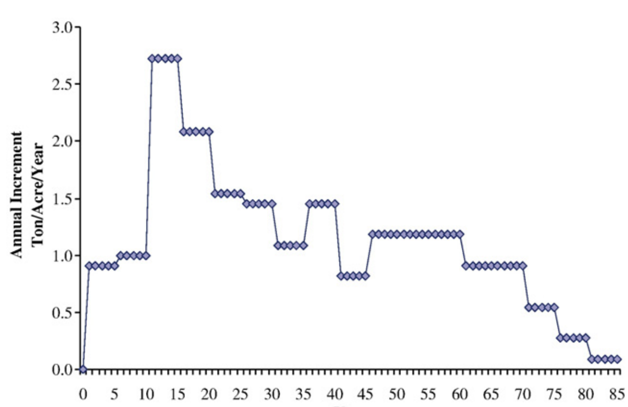

Fig. 2 – Carbon sequestration rates from afforestation.

Under the increasing carbon price, the permanence discount will be 100% because the buyer needs to buy back all of the carbon sequestered through the 25 year contract. Sequestration has only temporarily delayed the need to provide these permanent offsets. The value of temporary storage is the deferral of the buyback until some future period. This allows the money that would have been spent to purchase permanent reductions at the outset earn interest (r) in another use. However, because the price of replacing carbon has risen at the rate of r, the net benefit to the buyer of deferring the payments is zero. In other words, temporary soil carbon sequestration has no use value to the buyer in this case. This point was also introduced by Herzog et al. (2003).

4.2. *Afforestation*

Now consider a forest-based offset. Such a case adds additional considerations because there is a need to include the possibility of a forest harvest, the future fate of carbon in harvested products, and whether reforestation occurs after harvest. The time to carbon saturation for a forest stand and post harvest carbon profiles are based on data from Birdsey (1996). This is summarized in Fig. 2. Again, we assume that the initial carbon price, P_0, is $30/t, and the annual interest rate is 4%. For afforestation, we consider four cases. More explanations for each case can be found in Kim (2004).

4.2.1. *Case 1—no harvest—forest preserve*

Suppose the forest is never harvested and is kept forever so that there is no possibility for volatility. However, maintenance cost is required to maintain forests after the carbon quantities cease to accumulate (exhibiting saturation) beginning at year 85. Under a constant carbon price, the permanence discount for this case is found to be 0.2%. Thus carbon in such a preserve would be paid a price equal to 99.8% of that paid for a perfect offset. Under an increasing carbon price, the permanence discount is found to be 0.07% or that carbon would be paid for 99.93% of that for a perfect offset. In essence, forest preservation provides an essentially permanent equivalence offset[3].

4.2.2. *Case 2—harvest year 85—carbon buyback required*

Suppose the forest is harvested in year 85 but is not reforested. In this case, a buyback is needed in year 85 of all the project carbon at the prevailing market price. We assume that the material harvested in year 85 is all sawtimber. We assume approximately 23% of the forest carbon from a sawtimber harvest is emitted immediately to the atmosphere at the time of harvest, with additional emissions from decay and disposition of carbon in wood products after that point (based on data in Birdsey 1996). We assume that buybacks (or carbon debits) would be purchased every year that carbon is emitted at and after harvest.

Under these circumstances, the permanence discount is 5.4%. However, if some of the emitted carbon is used to generate

[3] We have assumed away natural catastrophic loss from fire, insects, disease etc. of which could cause the preserved forest to re-emit carbon.

energy that is a substitute for fossil fuels, this can be treated as a GHG credit. With such energy credits, the permanence discount decreases to 3.8% under a constant carbon price, demonstrating that sequestration for 85 years, followed by harvest is nearly equivalent to a permanent reduction. However, when the carbon price rises at the rate of discount, this leads to a discount of nearly two-thirds (67.7%) (with energy credits, the permanence discount decreases to 49.6%). The reason for the high discount, of course, is that future buybacks for released carbon are very expensive[4].

4.2.3. *Case 3—harvest year 20 without reforestation—carbon buyback required*

Suppose shorter rotation forestry (harvest at 20 years) is employed to reflect a forest primarily managed for pulpwood. Subsequently reforestation is not done so the offset purchaser must buyback carbon that is emitted in year 21 and thereafter. Based on Birdsey (1996), about 32% of stored carbon would be released to the atmosphere right after harvest and emissions would continue over time after harvest. Like Case 1, foresters need to purchase the equivalent of buyback (debits) every year an emission occurs up until year 100. In this case, under a constant carbon price the permanence discount is 51.9% (37.2% with energy credits) while under an increasing carbon price, the permanence discount would be 93.4% (72.7% with energy credits). Again, carbon prices rising at the discount rate renders temporary storage of little value to the buyer.

4.2.4. *Case 4—Harvest year 20 with reforestation—some carbon buyback required*

This case depicts short rotation forestry with harvest followed by reforestation. In this case, we need to buy back the carbon lost at harvest time; but in this case, accumulation begins again as the replanted forest grows. Again 32% of stored carbon would be released to the atmosphere right after harvest, but buyback required for the carbon lost at harvest time is substantially diminished because carbon starts re-accumulating along with reforestation. In this case, the constant price permanence discount is 22.7% (8.5% with energy credits) and the increasing carbon price one is 31.7% (11.9% with energy credits).

5. Concluding comments

Land-based carbon sequestration can have different characteristics from other greenhouse gas offsets in terms of its time dynamics — saturation, volatility, maintenance costs and limited term leases. We investigate the differential value of offsets in the face of such characteristics by forming a price discount that equalizes the effective price per ton between a "perfect offset" and one possessing impermanent characteristics. The resultant discount depends on the need to acquire future carbon when the contract expires or the practice is stopped and carbon is re-released. A maintenance cost may need to be paid beyond the time of effective increases in sequestration in order to maintain practices and carbon. However, if buying back expired or re-released credits is not required and/or maintenance costs are not needed to preserve stored carbon, then no permanence discount exists for sequestered carbon.

Empirically, the permanence discount was found to be potentially large with amounts between 0 and 50% computed depending under constant real carbon prices. In the case of a buyback requirement (or lease contract), the permanence discount rises to 100% in the case of the agricultural soil carbon sequestration, and 80% in the case of the afforestation when prices increase at the Hotelling rate equal to the interest rate. In other words, impermanent sequestration has little value in these cases.

Taken together, the findings in this paper suggest that permanence considerations could substantially affect the terms of trade for (potentially) temporary carbon sequestration and permanent emission reductions. Terrestrially sequestered carbon can rather easily be re-emitted to the atmosphere through changes in practices, harvests, and natural disturbances. Therefore, their inclusion in an emission trading or offset system has been met with some concern that sequestered carbon is not as secure or valuable as a permanently foregone emission. Or put another way, if a ton of carbon sequestered allows another ton to be emitted via an offset trade, there is broad concern that net emissions could rise if the stored carbon is re-emitted in the future. As a consequence, some sort of provision is necessary to ensure that these imbalances do not occur. This paper discusses one such provision – the notion that the buyer of the sequestration credit must replace these credits in the future if either a re-emission of the sequestered carbon occurs or when the contract ends. This can, in some cases, substantially undermine the value of the sequestration credit.

Factors that diminish the value of sequestered carbon are: (1) short period of time until the carbon stops accumulating or is re-released, (2) rising prices, causing the buyback liability for carbon to rise, and (3) the amount that must be paid to landowners after the carbon has stopped accumulating to keep the carbon maintained until the end of the contract period. In some cases, these factors render temporary storage via sequestration of little to no value. However, the most important of the factors above is the notion of carbon prices rising perpetually at the discount rate. By itself, this greatly diminishes the value of sequestered carbon if that carbon must 1 day be bought back.

While there is a theoretical foundation to the notion of carbon prices rising at the discount rate, there are also theoretical and practical reasons to expect this might not occur perpetually into the future. For instance, given the parameters used in our case studies ($30/t C and 4%), the carbon price would rise to over $1500 per ton in 100 years. It seems more than likely that a backstop technology would intervene well before the price of carbon reaches this point, thereby structurally adjusting the price path. If so, then temporary storage may indeed be a wise interim strategy to get carbon reductions that are relatively cheap and able to be implemented in the short run while the backstop technologies evolve. This has been referred to elsewhere, for instance Richards and Stokes (2004) and Richards and Andersson (2001), as carbon sequestration's bridge to the future.

[4] It is noteworthy that if the carbon price rose 4% for 85 years it would be incredibly high- $841/ton- and probably would induce a backstop technology before it gets that high.

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